

# Future Use Cases for Mobile Telecoms in the UK

# National Infrastructure Commission



Issued to: National Infrastructure Commission Issue date: October 2016 Version: 1.00

Real Wireless Ltd PO Box 2218 Pulborough West Sussex RH20 4XB United Kingdom

t +44 207 117 8514 f +44 808 280 0142 e info@realwireless.biz www.realwireless.biz



# ..............

# **Version Control**

Item	Description
Source	Real Wireless
Client	National Infrastructure Commission
Report title	Future Use Cases for Mobile Telecoms in the UK
Sub title	National Infrastructure Commission
Issue date	October 2016
Document status	Final Version

Version	Date	Comment
1.0	31/10/2016	Report issued to NIC





# **About Real Wireless**

Real Wireless is a leading independent wireless consultancy, based in the U.K. and working internationally for enterprises, vendors, operators and regulators – indeed any organization which is serious about getting the best from wireless to the benefit of their business.

We seek to demystify wireless and help our customers get the best from it, by understanding their business needs and using our deep knowledge of wireless to create an effective wireless strategy, implementation plan and management process.

We are experts in radio propagation, international spectrum regulation, wireless infrastructures, and much more besides. We have experience working at senior levels in vendors, operators, regulators and academia.

We have specific experience in LTE, UMTS, HSPA, Wi-Fi, WiMAX, DAB, DTT, GSM, TETRA – and many more.

For details contact us at: info@realwireless.biz

my Tap into our news and views at: realwireless.biz/blog

Stay in touch via our tweets at twitter.com/real\_wireless

Copyright ©2016 Real Wireless Limited. All rights reserved. Registered in England & Wales No. 6016945

# **Executive summary**

This report has been prepared for the National Infrastructure Commission (NIC) to establish representative use cases for future mobile telecommunications in the UK. The NIC asked for:

- A set of likely services and use cases likely to be delivered by future wireless communications networks such as 5G along with social and private benefits
- Description of the infrastructure requirements and associated costs

To answer these questions, we selected a set of fifteen key use cases from a candidate list of almost fifty based on their potential for impact. For the set of selected use cases we identified the societal and industrial benefits along with the requirements for the communications infrastructure. These requirements established the basis for a cost analysis that derived a per use case indicative cost of the wireless infrastructure with an approximate event horizon of 2025.

In our search for <u>likely</u> services and use cases we identified a set that represents incremental change, as well as those that represent potentially more radical transformation from traditional mobile telecommunications uses of today. To achieve this, the demand and supply side analysis considers industries that are adjacent to the traditional mobile telecoms sector where cogent dynamics indicate potential for substantial value creation. We have not provided an exhaustive list of all mobile telecoms services and use cases that may be available by 2025. We have focussed on those that are likely to represent a majority of the 2025 mobile traffic demand and/or significant new value and be maturing in use by this timeframe. These use cases are worthy of the attention of the NIC for strategic planning considerations regarding the availability of suitable national infrastructure to support these services and use cases.

The costing methodology for the infrastructure that supports the use cases has been underpinned in three services platforms. The service platforms have been derived to adequately encompass the necessary technical infrastructure capabilities as required by the use cases. The service platforms are Mobile Broadband (MBB), Machine Type Communications (MTC) and Mission Critical Communications (MCC). The MBB service platform enables high mobile data rates, with an acceptable level of reliability and latency. The MTC service platform enables lower data rate services and lower costs that are typically necessary for machines. The MCC service platform enables the highest level of coverage and has the highest level of availability and resilience.

Through the use case analysis, we determined the service platform that would address most of the derived requirements, this service platform establishes the basis for use case costing and is designated the primary service platform (green tick in Table 1). In most cases, there is ambiguity in the full set of services that are required which may point to a secondary need for a further service platform; a secondary service platform (orange tick in Table 1).

		Cor ເ	nnected use case	Car s	U	Railway Ise case	S	H	ealthcar ise case	e s	Utility ເ ເ	& Suppl ise case	y Chain s	Media and Cloud use cases			
		Entertainmen t Service	Driver Assistance	Vehicle Management	Passenger Broadband	Command & Control	Telemetry Service	Assisted Living	Remote Healthcare	Preventative Health	Smart Grid	Road Haulage	Drone Delivery	4K Content Everywhere	Immersive Gaming	Mobile Office	
Mobile Broadband	MBB	<b>~</b>	(✓)	(✓)	<	(✓)	×	(✓)	×	<b>~</b>	x	x	×	×	<	~	
Machine Type Communications	мтс	(✓)	×	<b>~</b>	×	(✓)	<ul> <li>Image: A start of the start of</li></ul>	<ul> <li>Image: A second s</li></ul>	(✓)	(✓)	~	~	~	×	×	(✓)	
Mission Critical Communications	мсс	×	<b>√</b>	×	×	<ul> <li>Image: A second s</li></ul>	×	(✓)	×	×	(√)	(√)	(√)	×	(✓)	×	

Table 1: Representative UK Use Cases and Supporting Service Platforms



Infrastructure costing for the set of use cases is based on dimensioning of the primary service platform around salient geographic features of the UK. The salient geographic features are rural, urban and sub-urban areas and the road and rail transport corridors. The costing is based on green field deployment costs, including backhauling to core network point of presence; we do not cost the core network or mobile devices. Green field deployment does not include consideration of existing mobile infrastructure and re-use of equipment, thus providing an upper bound costing, if re-use is not viable. Costing excludes costs of spectrum and we assume spectrum is available when and where it is required. However, to dimension networks consideration of spectrum is essential. Therefore, we have identified three spectrum bands for deployment of infrastructure, Low-band (in the range 700 - 900 MHz), Medium-band (in the range 1.4 - 3.5 GHz), and hi-band (26 - 60 GHz).

In the following we summarise the representative use cases.

# **Connected cars**

The **Connected Car** is identified by some as the next mobile device beyond the current generation of wearable devices. Both the mobile communications service providers and vehicle OEMs identified use cases that are linked to the longer-term trend of Connected and Autonomous Vehicles (CAV). The trade-off between intelligence in the vehicle, tending in the extreme to fully autonomous vehicles, and usage of mobile services accessed through the infrastructure to deliver safety enhancements, driver assistance and telematics based uses, presents the opportunity for a compelling eco-system.

The connected car establishes three use cases; **entertainment services**, **driver assistance** and **vehicle management**. **Entertainment services** provides over the top services such as audio and video streaming services and general internet access. Typically, an in-built Wi-Fi access point in the car supports several devices and applications simultaneously. Such use cases can place high demands on networks especially with several people in a car watching streaming video.

**Driver assistance** – sometimes call Advanced Driver Assistance Systems – ADAS – uses on board sensors and connections to other vehicles and back office systems to improve safety as well as reduce congestion. Vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) connections – collectively V2X - provides better control to road operators as well as enhancing on board sensing capabilities e.g. receiving a message from vehicles on front that they are stationary. ADAS connectivity is classed as critical requiring low latency and certainty of communication.

**Vehicle Management** – provides a variety of convenience facilities – such as booking the car in for service at the appropriate time/mileage or identifying a potential fault long before it becomes noticeable to the driver. Vehicle management also provides the OEMs with data to analyse the performance of their vehicles and the parts and sub-systems in it – leading to improved designs in the future and as well as helping to identify potential faults leading to a recall. Vehicle management is essentially an M2M requirement.

The main challenge for connected vehicles remains the provision of **high reliability ubiquitous coverage**. We cost infrastructure for the SRN; however, in subsequent use cases we cost for general UK wide coverage for 4k Everywhere which would provide adequate coverage and capacity for the remainder of the roads. For these use cases mid-band spectrum proves to have the highest utility, with mmWave proving necessary in entertainment, and vehicle management finding low-band sufficient but not in high demand areas.



#### Railway

The railway sector establishes three use cases; **passenger broadband**, **command and control** and **telemetry services**. Whilst passenger broadband is clearly consumer oriented, both command and control and telemetry services illustrate how future mobile telecommunications infrastructure can significantly enhance operational efficiency. Today train passengers can access mobile networks whilst travelling, and for some trains WiFi connectivity is offered; however, these experiences are widely perceived as inadequate. The **passenger broadband** use case establishes the benefits of enabling passengers to work, stream content and access social media. We note the aspiration of the Department for Transport to have 100Mbps to a train, but suggest a target of 1Gbps by 2025 would be necessary to meet the anticipated demand. To achieve such a target, it is likely that wireless infrastructure will need to be deployed trackside.

The **command and control** use case offers operational benefits in terms of increased safety through improved signalling, increased capacity of train services and greater resilience of train services – it also saves costs through the removal of trackside signalling equipment. To secure these benefits infrastructure needs to be highly reliable but a modest data rate is adequate thus low-band is sufficient. The **telemetry service** use case will enable more efficient use of track and trackside equipment with improved maintenance regimes, again showing potential for significant operational expense reductions. The wireless infrastructure is only required to support relatively low data rates and reliability is reduced over that of command and control. Low-band spectrum is sufficient for this MTC based use case.

## Healthcare

Healthcare establishes three use cases; **assisted living**, **remote healthcare** and **preventative health**. **Assisted living** presents the opportunity to reduce the number of hospital admissions caused by the rise in the UKs aging population. The relatively modest data rates that are supported by 4G today are adequate but the services offered by the network need to evolve to more M2M like communications and be made available to the general population. The network infrastructure required may be met by a low number of sites, in the low band.

**Remote Healthcare** promises to make a significant impact by reducing the need for in surgery patient appointments and more efficient delivery of care for conditions like Type2 diabetes. The higher demand requirements require MBB thus increasing costs to a national coverage low-band MBB service platform. **Preventative Health** puts a degree of autonomy and well-being in the hands of the population, through the increasing use of wearable devices and smart application software issues such as obesity may be tackled. No exceptional demands are placed on networks to offer these services.

The Healthcare use cases clearly demonstrate societal benefits, but we find no appetite in the health sector to shoulder the cost of deployment of infrastructure. However, we do see evidence of early adopter professionals in the sector who are willing and able to engage in application based clinical trials. This establishes a credible case for early adoption of future communications services on national infrastructure if they were offered at an appropriate cost. A significant proportion of Healthcare use case services will be consumed indoors, this places demands on outdoor to indoor coverage that we have not costed, or on indoor wireless systems which may connect to fixed broadband which is again out of scope for costing.



## **Smart Utility**

The **Smart Utility** use case consists of **Smart Metering** and **Smart Grid** applications - designed to seamlessly integrate to produce a reduction in consumption, lower costs for consumers and through aligning generation with consumption in near real time leads to an overall reduction in the requirement for new generation capacity. In addition, both **Smart Metering** and **Smart Grid** implementation will lead to reductions in carbon emissions

**Smart Metering** is an M2M requirement where utility meters are ultimately connected to central servers and meter readings can be automatically uploaded regularly throughout the day. In the UK, some 50m meters will upload consumption details every hour via wireless networks. Benefits include more accurate bills, lower meter reading costs and reduced consumption due to consumer awareness of their energy consumption. In the future, smart metering may provide some level of control over demand to even out demand peaks. Smart metering is being deployed in the UK over a 5-year programme.

**Smart Grid** exercises automated control over generation, main grid and distribution network functions – optimising this overall 'system of systems' against defined criteria and responding to demand peaks and problems rapidly with the most efficient solution. Smart grid requirements and technologies are at an early stage of development and standardisation – however it is clear that exercising any control over what is classed as critical national infrastructure needs to be secure and highly reliable. For this reason, Smart Grid is classed as a critical service requiring low latency at times and certainty of communication.

The capacity demands for these use cases are well within bounds of support in the low-band on an MTC service platform.

## **Supply Chain**

**Road haulage** covers the transport of goods by both light goods vehicles (LGV) typified by vans delivering internet shopping and heavy goods vehicles (HGV) typified by the large trailer trucks delivering goods to distribution centres. Competitive pressures and environmental factors are pushing fleet operators to improve efficiency, reduce costs and reduce carbon emissions. Fleet management systems and logistics management systems require a permanent connection to vehicles and drivers to provide real time location and average speed that support journey prediction and optimal routing/re-routing software tools. V2X capabilities will also be required to support traffic management by road operators and safety benefits. The forecast demand for this use case is attainable from a low-band MTC service platform.

**Drone Delivery** is now in the early stages of design and testing, this use case if realised will certainly lead to faster deliveries of small parcels close to distribution points. Whether there are cost savings, at scale, is not yet clear and probably depends on the legal framework that such services operate within. Drones will mostly fly autonomously with on-board sensors to detect obstacles and other drones. Delivery range will be limited due to battery capacity, limiting delivery to urban and sub-urban areas. There is significant variance in the views on the level of connectivity and drone density; we costed based on urban and sub-urban coverage midband MTC with a reasonably high V2I requirement. A significantly lower cost using low-band MTC could be viable if drones were more clearly constrained in their density and connectivity requirements.



# **Media and Cloud**

**4K Content Everywhere** continues the already significant growth in consumption of video through mobile devices. The trend in growth is driven by digital natives who interact on social media platforms that have more and more picture and video content. These demands on networks will continue for the foreseeable future and increase opportunities for entertainment on the move, digital advertising, and pay-TV business models. The use case requires high capacity MBB, and is in fact likely to drive investment in MBB.

**Immersive Gaming** builds upon the recognised strength of the UK for innovation in gaming. There is evidence that having national infrastructure that is known to be capable of supporting gaming could reduce barriers to "mobile first" games using the latest in virtual and augmented reality. There are significant developments in indoor VR based on a 360-degree experience that may set consumer expectations in terms of outdoor services; however, the extent to which this will be the case is not established. Furthermore, multi-player gaming platforms also create potentially significant demands on infrastructure, including a requirement for lower end-to-end latency of services.

**Mobile Office** recognises the demand for increased worker and business efficiency and the increasing demands on mobile. Collaborative working platforms using conferencing, cloud based productivity apps and storage and enterprise oriented social networking present a relatively low peak rate demand; however, in urban areas the cumulative device density pushes infrastructure capacity demands.

#### Use case combining

Having considered each use case in turn we find that the priority in terms of national infrastructure for mobile telecoms is the provision of infrastructure that supports mobile broadband services (MBB). The consumer demand for video is forecast to be greater than 80% of content over wireless networks and clearly establishes widespread need for this capability; thus, bringing 4k content everywhere to the fore in both the railway and connected car categories both benefit from the presence of 4K Everywhere MBB capable infrastructure; however, there is an incremental cost to provide an adequate level of service in their associated corridors of use.

The principal objective of the report was to provide infrastructure costs on a per use case basis. However, high level qualitative combining analysis was carried out to highlight opportunities for synergies between use cases and their associated infrastructure. Combining the dimensioned infrastructure of 4k content everywhere, connected car – entertainment, and railway – passenger broadband would yield synergies in deployment costs that would significantly decrease the cost of infrastructure when compared to a simple summation of costs but would still be substantially more than the standalone cost of 4k content everywhere.

Combining of use cases when they utilise the same service platform type is a realistic approach that may yield synergies and cost benefits. A national MBB capable infrastructure that provides media and cloud use cases would be adequate to provide the majority of healthcare use cases at no incremental cost of infrastructure. Similarly, a national MTC supporting infrastructure for utility and supply chain would likely be adequate for vehicle management as road haulage is included in supply chain use cases.

Combining of use cases across service platform types should be carried out with caution. If one were to establish a MBB service platform infrastructure, the cost of upgrading to an MCC capability would primarily be based on multi-connectivity for diversity and reliability of connections, this is likely to require significant replanning of the existing MBB infrastructure. Starting from a MBB infrastructure supporting 4k Everywhere an overlay of MTC smart grid may be viable as these are both national level coverage systems. However, factors such as spectrum planning, and prioritisation of the heterogeneous traffic in the network would need to be taken in to account.



Future Use Cases for Mobile Telecoms in the UK

Further considerations in terms of multi-service and multi-tenant dynamics would also be in scope of such a combining analysis.

## **Rational Infrastructure deployment**

Our cost modelling applied a rational approach to infrastructure deployment that considers forecasted available spectrum in three bands. By assuming this spectrum availability, adequate coverage and capacity can be achieved into the 2025 timeframe. Our higher end demand forecasts illustrate the need for deployment of systems that have potential to deliver significantly more capacity, and the benefits of having an infrastructure that can handle multiple services to obtain synergy gains. The mobile telecoms industry has already identified spectrum bands with potential to deliver more capacity, so called mmWave systems. We have costed infrastructure including mmWave, and based these estimates on nascent technology and trials activities to show the potentially significant capacity increase and cost efficiency of mmWave solutions. It is prudent to consider approaches to dimensioning of backhaul in readiness for the arrival of commercially viable mmWave mobile systems; however, when compared to low-band and mid-band systems mmWave system performance and system readiness is far more speculative. We found no evidence to support investment in mmWave as a general coverage technology.



.....

# Contents

1.	Introduction
1.1	Background2
1.2	Scope and objective 2
1.3	Structure of the report2
1.4	UK context3
2.	Approach and methodology7
2.1	Methodology overview7
2.2	Service platform definitions8
2.2.1	Fixed wireless access exclusion11
3.	Analysis of representative UK use cases
3.1	Automotive - connected cars use cases14
3.1.1	Overview14
3.1.2	Current connected cars use cases20
3.1.3	Future connected cars use cases22
3.1.4	Network service requirements25
3.1.5	Potential benefits to the UK26
3.1.6	International perspective27
3.1.7	Use case summary27
3.1.8	Case studies
3.2	Public transport – railway use cases 32
3.2.1	Overview
3.2.2	Current railway use cases35
3.2.3	Future railway use cases35
3.2.4	Network service requirements38
3.2.5	Potential benefits to the UK38
3.2.6	International perspective
3.2.7	Use case summary40
3.2.8	Case studies41
3.3	Healthcare - remote and preventative care use cases
3.3.1	Overview43
3.3.2	Current healthcare use cases45
3.3.3	Future healthcare use cases46
3.3.4	Network Service Requirements49
3.3.5	Potential benefits to the UK50
3.3.6	International perspective51
3.3.7	Use case summary52



3.3.8	Case studies	54
3.4	Utilities – smart utility use cases	59
3.4.1	Overview	59
3.4.2	Current utility use cases	61
3.4.3	Future utility use cases	63
3.4.4	Network service requirements	63
3.4.5	Potential benefits to the UK	64
3.4.6	International perspective	65
3.4.7	Use case summary	65
3.4.8	Case studies	65
3.5	Supply chain - road haulage and drone delivery use cases	67
3.5.1	Overview	67
3.5.2	Current logistics use case	68
3.5.3	Future logistics use cases	70
3.5.4	Network service requirements	71
3.5.5	Potential benefits to the UK	72
3.5.6	International perspective	72
3.5.7	Use case summary	74
250	Case study	74
5.5.0	case study	/4
3.5.8 3.6	Cloud services - media and business use cases	
3.6.1	Cloud services - media and business use cases	74 
<b>3.6</b> .1 <b>3.6</b> .2	Cloud services - media and business use cases Overview Current media and business cloud use cases	74 75 78
<b>3.6.1</b> 3.6.2 3.6.3	Cloud services - media and business use cases Overview Current media and business cloud use cases Future media and business cloud use case	
<b>3.6.1</b> 3.6.2 3.6.3 3.6.4	Cloud services - media and business use cases Overview Current media and business cloud use cases Future media and business cloud use case Network service requirements	
<b>3.6.1</b> 3.6.2 3.6.3 3.6.4 3.6.5	Cloud services - media and business use cases Overview Current media and business cloud use cases Future media and business cloud use case Network service requirements Potential benefits to the UK	
<b>3.6</b> .1 3.6.2 3.6.3 3.6.4 3.6.5 3.6.6	Cloud services - media and business use cases Overview Current media and business cloud use cases Future media and business cloud use case Network service requirements Potential benefits to the UK International perspective	
<b>3.6</b> <b>3.6</b> <b>3.6.2</b> <b>3.6.3</b> <b>3.6.4</b> <b>3.6.5</b> <b>3.6.6</b> <b>3.6.6</b> <b>3.6.7</b>	Cloud services - media and business use cases Overview Current media and business cloud use cases Future media and business cloud use case Network service requirements Potential benefits to the UK International perspective Use case summary	
3.6.1 3.6.2 3.6.3 3.6.4 3.6.5 3.6.6 3.6.7 3.6.8	Cloud services - media and business use cases Overview Current media and business cloud use cases Future media and business cloud use case Network service requirements Potential benefits to the UK International perspective Use case summary Case studies	
3.6.3 3.6.2 3.6.3 3.6.4 3.6.5 3.6.6 3.6.7 3.6.8 <b>4</b> .	Cloud services - media and business use cases Overview Current media and business cloud use cases Future media and business cloud use case Network service requirements Potential benefits to the UK International perspective Use case summary Case studies Infrastructure costs analysis	74 75 75 78 80 83 83 83 85 86 89 89 89 <b>91</b>
3.6.3 3.6.2 3.6.3 3.6.4 3.6.5 3.6.6 3.6.7 3.6.8 4. 4.1	Cloud services - media and business use cases Overview Current media and business cloud use cases Future media and business cloud use case Network service requirements Potential benefits to the UK International perspective Use case summary Case studies Infrastructure costs analysis Introduction	
3.6.3 3.6.2 3.6.3 3.6.4 3.6.5 3.6.6 3.6.7 3.6.8 4. 4.1 4.2	Cloud services - media and business use cases Overview Current media and business cloud use cases Future media and business cloud use case Future media and business cloud use case Network service requirements Potential benefits to the UK International perspective Use case summary Case studies Infrastructure costs analysis Introduction Costing methodology	74 75 75 78 80 83 83 83 85 86 89 89 89 <b>91</b> 91
<ul> <li>3.6.3</li> <li>3.6.2</li> <li>3.6.3</li> <li>3.6.4</li> <li>3.6.5</li> <li>3.6.6</li> <li>3.6.7</li> <li>3.6.8</li> <li>4.</li> <li>4.1</li> <li>4.2</li> <li>4.3</li> </ul>	Cloud services - media and business use cases Overview Current media and business cloud use cases Future media and business cloud use case Network service requirements Potential benefits to the UK International perspective Use case summary Case studies Infrastructure costs analysis Introduction Costing methodology Cost analysis by use case	74 75 75 78 80 83 83 83 83 85 86 89 89 89 91 91 91 91 91 91
<ul> <li>3.6.3</li> <li>3.6.2</li> <li>3.6.3</li> <li>3.6.4</li> <li>3.6.5</li> <li>3.6.6</li> <li>3.6.7</li> <li>3.6.8</li> <li>4.</li> <li>4.1</li> <li>4.2</li> <li>4.3</li> <li>4.3.1</li> </ul>	Cloud services - media and business use cases	74 75 75 78 80 83 83 85 86 89 89 89 91 91 91 91 91 94
<ul> <li>3.6.3</li> <li>3.6.2</li> <li>3.6.3</li> <li>3.6.4</li> <li>3.6.5</li> <li>3.6.6</li> <li>3.6.7</li> <li>3.6.8</li> <li>4.1</li> <li>4.2</li> <li>4.3</li> <li>4.3.1</li> <li>4.3.2</li> </ul>	Cloud services - media and business use cases	74 75 75 78 80 83 83 83 85 86 89 89 
<ul> <li>3.6.3</li> <li>3.6.2</li> <li>3.6.3</li> <li>3.6.4</li> <li>3.6.5</li> <li>3.6.6</li> <li>3.6.7</li> <li>3.6.8</li> <li>4.</li> <li>4.1</li> <li>4.2</li> <li>4.3.1</li> <li>4.3.2</li> <li>4.3.3</li> </ul>	Cloud services - media and business use cases	74 75 75 78 80 83 83 83 83 85 86 89 89 91 91 91 91 91 91 91 91 91 91 91 91 92 99
<ul> <li>3.6.3</li> <li>3.6.2</li> <li>3.6.3</li> <li>3.6.4</li> <li>3.6.5</li> <li>3.6.6</li> <li>3.6.7</li> <li>3.6.8</li> <li>4.</li> <li>4.1</li> <li>4.2</li> <li>4.3.1</li> <li>4.3.2</li> <li>4.3.3</li> <li>4.3.4</li> </ul>	Cloud services - media and business use cases Overview Current media and business cloud use cases Future media and business cloud use case Network service requirements Potential benefits to the UK International perspective Use case summary Case studies Infrastructure costs analysis Introduction Costing methodology Cost analysis by use case Connected car use cases Railway use cases Healthcare use cases Utility & supply chain use cases	74 
<ul> <li>3.6.3</li> <li>3.6.4</li> <li>3.6.5</li> <li>3.6.6</li> <li>3.6.7</li> <li>3.6.8</li> <li>4.1</li> <li>4.2</li> <li>4.3</li> <li>4.3.1</li> <li>4.3.2</li> <li>4.3.3</li> <li>4.3.4</li> <li>4.3.5</li> </ul>	Cloud services - media and business use cases Overview Current media and business cloud use cases Future media and business cloud use cases Network service requirements Potential benefits to the UK International perspective Use case summary Case studies Infrastructure costs analysis Infrastructure costs analysis Introduction Costing methodology Cost analysis by use case Connected car use cases Railway use cases Healthcare use cases Utility & supply chain use cases Media and cloud use cases	74 



4.5	Summary	106
5.	Conclusions	107
6.	Annex	113
6.1	Summary of all use cases	113
6.1.1	List of all use cases	113
6.1.2	Use case description and rating	114
6.2	Capacity and cell range assumptions	129
6.2.1	Spectrum ranges	
6.2.2	Cell ranges	130

# Tables

Table 1: Representative UK Use Cases and Supporting Service Platformsi
Table 2: Performance category definitions9
Table 3: The three types of service platforms10
Table 4: Representative UK use cases and supporting service platforms
Table 5: Road lengths by classification (in thousands of miles)17
Table 6: Demand numbers for different use cases
Table 7: Medium acquire, design and build cost for different cellular site types
Table 8: Entertainment use case – MBB sites and estimated cost requirement95
Table 9: ADAS use case – MCC sites and estimated cost requirement96
Table 10: Vehicle management use case – MTC sites and estimated cost requirement96
Table 11: Passenger broadband use case – MBB requirements and estimated costs97
Table 12: Command and control use case – MCC site requirements and estimated cost 98
Table 13: Telemetry service use case – MTC site requirements and estimated costs99
Table 14: Smart grid use case – MTC sites and estimated cost requirement101
Table 15: Road haulage use case – MTC sites and estimated cost requirement101
Table 16: Drone delivery use case – MTC sites and estimated cost requirement102
Table 17: 4K content use case – MBB sites and estimated cost requirement102
Table 18: Immersive gaming use case – MBB sites and estimated cost requirement103
Table 19: Mobile office use case – MBB sites and estimated cost requirement103
Table 20 use cases and service platforms104
Table 21: Cost of infrastructure (£millions)106
Table 22: List of all use cases with priority rating
Table 23: Mobile downlink spectrum and cell capacity versus frequency band
Table 24: Some assumptions for cell range calculation131

# Figures

Figure 1: The stages of this study	7
Figure 2: Forecast UK production and penetration of connected vehicles [12]	15
Figure 3: The 6 stages (level) of vehicle automation and expected timeline	16



Figure 4: Maps showing the strategic road network (SRN)
Figure 5: Percent road length by type and traffic carried for Great Britain [17]19
Figure 6: The range of connected car services and their growth patterns [20]22
Figure 7: Overview of some advantages of V2X []24
Figure 8: Connected car with infotainment26
Figure 9: Rail passengers' top 10 priorities for improvements in Great Britain [36]33
Figure 10: One of the top 10 complaints on rail travel is wireless connectivity [37]34
Figure 11: Typical parties involved in providing mobile broadband to rail passengers37
Figure 12: DfT mobile broadband for train facts and target figures [37]42
Figure 13: UK digital health markets 201444
Figure 14: Size and growth rate by health sub-sector46
Figure 15: CareTRx <sup>™</sup> inhaler system54
Figure 16: TIHM test bed architecture (Source: University of Surrey)55
Figure 17: Example devices from 9 companies participating in TIHM55
Figure 18: Possible 80% cut in greenhouse gas emissions in the EU (100%=1990)60
Figure 19: Current projection of smart and advanced meter installation per year61
Figure 20: Overall GB smart metering architecture []62
Figure 21: Telefonica's choice of 3 communications hubs
Figure 22: Supply and demand gap for Thames Water
Figure 23: Growth in LCVs compared to HGVs67
Figure 24: Growth trends in vehicle categories on UK roads
Figure 25: Amazon's delivery drone71
Figure 26: Peleton technology's on board systems to support truck platooning73
Figure 27: DPD drone trial73
Figure 28: Year-Over-Year Growth of Digital Ad Formats (UK) [91]76
Figure 29: 4K display revenues year-over-year growth rate to 2020 [120]81
Figure 30: Distribution of type of device used for gaming82
Figure 31: Livestreaming 360° panoramic 4K 3D video from a panoramic camera84
Figure 32: Forecast of 4K display smartphone shipments [137]87
Figure 33: AR and VR revenue share forecast 2020 [138]87
Figure 34: Revenue Share in the gaming market [138]88
Figure 35: Network cost model methodology92



# 1. Introduction

# 1.1 Background

The terms of reference of the National Infrastructure Commission (NIC) defines the scope within which the analysis for this report has been carried; an understanding of these terms of reference is therefore beneficial. The NIC is a body independent of government with the objective of enabling long term strategic decision making to build effective and efficient infrastructure for the UK. The commission looks at the UK's future needs for nationally significant infrastructure, with the intent of helping to maintain the UK's competitiveness amongst the G20 nations, and assists in providing greater certainty for investors by taking a long-term approach to major investment decisions that the UK faces. The NIC expectation is that the fifth generation of telecommunications systems, or 5G, will enable an advance in digital communications that will benefit UK business and society. The NIC will consider what the UK needs to do to become a world leader in the deployment of future communications networks such as (but not limited to) 5G, and what the UK can do to take early advantage of the potential applications of future communications services. This report, along with other reports commissioned by the NIC at the same time, provides recommendations on future communications infrastructure challenges.

# **1.2** Scope and objective

The objective of this study was to develop a set of feasible UK focused services and use cases which we would expect to be delivered by future wireless communications networks such as 5G in the next 5 – 10 years. This should be informed by a view as to which services and use cases will deliver most social and economic benefits to the UK, including the public and private sectors. The analysis should show where these benefits are accrued, what type of coverage is required and the implications in terms of infrastructure. International comparators have been assessed and the key requirements and implications of the use cases are highlighted.

Further, the scope includes a view on the infrastructure requirements necessary to meet the defined use cases, including cost and resilience considerations.

This highlights the most relevant "Future Use Cases for Mobile Telecoms" in the UK. The viewpoint of the industry and users has been the focus as opposed to the viewpoint of the MNOs and system vendors as this is not a technology driven study.

# **1.3** Structure of the report

In the remainder of chapter1 we provide a short overview of the forces of change (or context) within which the mobile telecoms sector operates today.

- Chapter2 introduces the methodology that has been applied to research the use cases, determine the set of representative use cases and we introduce the concept of service platforms.
- Chapter3 provides an in-depth description of the set of use cases and the requirements they will impose on the relevant service platforms along with pertinent case studies.



- Chapter4 provides an overview of the costing methodology and estimated costs for each of use case. A high level combining analysis and guidance is provided.
- Chapter5 provides high level conclusions and summarises the use cases and associated costs, we also make recommendations for follow on work.

# 1.4 UK context

Ever since the launch of the first mobile voice services in 1985 the United Kingdom has retained its position as one of the leading markets for adoption of mobile devices and the usage they enable, whether this be making and receiving voice calls on the earliest car phone to watching streaming videos on Facebook. Each device category and usage places demands on the network infrastructure and the Mobile Network Operators (MNOs) that supply the services to highly dynamic consumer and business markets. Services must meet the consumer need for on-the-move (mobile) connectivity in both their private and professional lives.

Underpinning this user demand is the deployment and operations of communications infrastructure. Communications infrastructure enables the mobile devices to connect to networks and access the required services. There are substantial regulatory and planning constraints that limit the choices for location of the essential communications infrastructure. These constraints, along with the time required and the costs relating to the practicalities of the identification, acquisition, deployment and operations of suitable sites are some of the reasons that gaps exist in today's network coverage and capacity.

The mobile network infrastructure of the UK has matured over a number of years to support four principal MNOs. Today these businesses dominate the direction of evolution of the infrastructure and device eco-system. The MNOs are also part of the communications service provider value chains along with many Mobile Virtual Network Operators (MVNOs) and other digital service providers. The challenge to the MNO has been to balance the investment in network infrastructure based on competitive service and coverage needs with revenues. The original phone and messaging services requiring outdoor and wide geographic area coverage have been overtaken by todays mobile broadband based services that now dominate the growth in data traffic and require outdoor and indoor coverage in cities, transport hubs, retail parks and stadia.

#### Capacity and capital crunch

The **capacity crunch** is characterised by scarcity of spectrum and infrastructure in geographic areas where demand for mobile services is high. The growth of the Over-The-Top (OTT) business model, which is labelled as such because the revenues for the digital service provider are not paid to/shared with the service platform provider, has precipitated the challenge. The service platform provider cannot easily forecast the nature of demand because of the innovations in the OTT service provider domain. Whilst the media rich content of social media platforms like Facebook creates data transport demands on the network infrastructure, the Service Provider platform remains reactive to the growth in demand on their networks. A supply of spectrum and densification of networks can assist in alleviating these challenges.

The **capital crunch** is characterised by limited opportunity to increase revenue whilst demand for data supply grows, leading to challenges to finance investment in the capital-



intensive parts of the business such as network infrastructure. The mature UK mobile data market has established a relatively low Average Revenue Per User (ARPU) compared to some overseas markets, and has resulted in limited flexibility for the MNO to monetise anything other than fixed data plans. Effective approaches to capture the value of the services above and beyond data transport are proving to be elusive. In an era of low interest rates, MNOs can access finance for capital investment in infrastructure; however, they are still hampered by their relatively poor return on investment compared to other sectors.

The latest Ofcom UK market report [1] shows the telecoms sector grew by 0.5% in 2015, this is a reversal of a five-year trend in revenue decline; however, the average household spend on mobile voice and data increased by just under 1% from 2014 to 2015. Ofcom consumer research shows that 36% of respondents consider the smartphone to be the most important device for internet access and there continues to be a decline in usage of the traditional mobile messaging service (SMS), as users substitute SMS by internet messaging applications such as WhatsApp. In the internet service domain, the balance of power lies with global internet scale service companies such as Google, Amazon, Facebook and Apple. However, future mobile communications services that benefit from location, security, privacy and proximity to infrastructure could tip the balance towards value created by national infrastructure; providing an opportunity to alleviate the capital crunch challenge.

## Increasing capacity requirements (mobile broadband)

The demand for mobile broadband capacity continues to grow, and despite the rise in use of Wi-Fi to supplement cellular networks, the challenge of avoiding a capacity crunch remains.

Precise calculations of capacity vary, but the trend is common. For instance, Cisco's most recent Mobile Data Traffic Forecast said that the average mobile-connected end user generated 964 MB of data traffic per month in 2015, up 52% from 636 MB in 2014 [2]. By comparison, Ofcom said the figures were 870MB and 530MB respectively [3].

The Cisco calculations indicate that UK traffic reached 86.2 petabytes per month in 2015 and the average connection speed was 5.8 Mbps. UK mobile data traffic is predicted to grow sevenfold between 2015 and 2020, with video traffic growing nine-fold [2].

The challenge is to support the projected growth in consumer and business usage, while maintaining or improving quality of service, availability and low latency.

## Broadband for rural, remote & not-spot areas

In December 2015, Ofcom's Connected Nations report indicated that 83% of premises are now in reach of a superfast (30 Mbps or more) fixed line broadband, up from 75% in 2014 [3]. The target to reach 95% by 2017/18 becomes more challenging when rural and remote areas are addressed, yet areas defined as rural account for 22% of premises. As well as remote villages and islands, there may be other not-spots which are hard to reach with fixed lines.

Despite government support for build-out, the business case for operators of rural broadband services can be difficult to achieve. Yet without fixed broadband, many challenges face underserved communities, from limited ability to run local businesses, to exclusion from online citizenship (e.g. tax returns, government petitions). Lack of



broadband, or limited speeds, deter investment in an area and may increase population defection. By contrast, the net annual GVA (gross value added) impacts for the UK, attributable to high speed broadband availability, could rise to about £17 billion by 2024, compared to 2008, with about £4.6 billion accruing to 'rural' areas [4].

Some cellular options have been trialled or deployed to bring fixed broadband to remote areas over wireless connections and it is notable that, in the USA, fixed wireless access is likely to be the first Use Case for 5G.

#### Indoor environments

About 80% of mobile traffic is consumed indoors [5], yet achieving a high level of coverage and quality of service within buildings is challenging, especially where a location is densely populated, or the building itself is hostile to mobile signals. Ofcom has set a target in the most recently auctioned O2 spectrum licence that 98% of premises should be able to receive a 4G signal indoors by 2017.

Consumers and workers are increasingly dependent on good indoor coverage. They are becoming more reliant on mobile connections for work and leisure – because of trends like mobile-first enterprises or smartphone-based shopping and content consumption. Therefore, a workplace or other location, such as a retail mall, must be able to support good indoor mobile connectivity to operate efficiently and attract visitors.

With the spread of wireless machine-to-machine (M2M) services such as smart metering, deep indoor coverage becomes critical.

Several methods of improving indoor services in the domestic, business and venue environments are available, generally falling into two approaches:

- the use of Wi-Fi to provide broadband access along with evolving technologies such as Voice over Wi-Fi to provide voice call capabilities directly from the phone's dialler app. This means that users will typically be unaware that calls that they make or receive are using Wi-Fi for the last 10m or so
- the use of small cells, femto cells and distributed antenna systems (DAS) to provide improved internal network coverage. This can be supplemented by enhanced external network deployments to improve the inside coverage from the outside

These trends in indoor environments are evidence of a changing landscape in the connectivity platforms upon which new indoor services emerge. Indoor services are an important stimulant of consumer expectations for outdoor mobile experiences and thus an important source of evidence for potential outdoor mobile use cases.

## Transport corridors - road and rail coverage and capacity

The UK has 19,000 miles of railways, including 250 miles of tunnels, travelling through every kind of terrain. High variance in terrain creates challenges for provision of good quality mobile connectivity, especially when trains are travelling at high speeds. Rail operators install and maintain dedicated wireless networks, such as GSM-R and ERTMS, but these do not support broadband.



Railway usage is rising, to 1.65 billion journeys in 2014-2015 (up 69.5% from 2002-2003) [6], and so capacity requirements are rising too, especially as users increasingly expect to work or consume content as they travel.

UK car traffic hit a new record in 2015, at 247.7 billion vehicle miles, while lorry traffic saw its biggest increase since the 1980s, at 3.7% year-on-year [7]. Despite investment in new roads and in improvements to existing roads and to city planning, there is increased risk of traffic congestion, with impacts on business productivity, safety and environment. Wireless connectivity may be a way to help address the challenge of increased road traffic and limited capacity. The UK is already recognising the potential and stimulating innovation in this area. In the March 2016 budget, there was a proposal to establish a £15 million 'connected corridor' from London to Dover to enable vehicles to communicate wirelessly with infrastructure, as well as plans for trials of driverless lorries. Like the rail network the approach to provision of coverage and adequate capacity is the subject of ongoing review, we identify use cases that re-enforce the nascent motivation to deliver improved mobile connectivity and infrastructure.

# Security and privacy

One of the most significant challenges for any government or industry is protecting the security and privacy of its citizens and their transactions. The rising use of digital infrastructure rightly brings these considerations to the fore. Examples of security issues that are being addressed by the mobile sector are:

- Privacy and misuse of personal data, especially with the rise of social media, context-aware applications, mobile healthcare, mobile payments and other behaviours which involve submitting personal data.
- The objective of the mobile industry is that mobile infrastructure is increasingly based on open source technologies and open IP platforms, rather than closely controlled, proprietary networks. There can be a greater vulnerability to hacking and violation. While in-built security and encryption in cellular networks has so far been highly trusted, modern mobile usage does introduce new challenges.
- The Internet of Things raises further security concerns based around the need to establish and protect the digital identity of millions of 'things'.

The mobile industry is acutely aware of security as an important property of their service platforms; there is ample evidence of a solid track record in realising robust security at a network infrastructure level. Whilst our analysis stops short of identification of security requirements for infrastructure costing, it is explicit in our analysis that we are deriving our costs based on mainstream mobile networking technologies and approaches, this brings with it an implicit assumption in terms of security capability.



# 2. Approach and methodology

The goal of our methodology was to determine a short-list of use cases and associated costs. To achieve this objective, we defined four key stages of analysis as depicted in Figure 1. The timescales of the project required that all stages were complete within two months.



# Figure 1: The stages of this study

In this section, we briefly set out the principal elements of each stage in the methodology overview. Given the importance of the service platforms in establishing common elements for derivation of costs in subsequent sections the service platform definitions are also provided.

# 2.1 Methodology overview

# Use case identification

Data gathered for this report has come through an extensive survey of public studies, utilisation of previous real wireless studies, reviewing the NIC call for evidence responses, and primary data gathering by application of structured and semi-structured interviews of representative stakeholders. Through qualitative data analysis and focus group discussion we could deduct a comprehensive long-list of forty-eight use cases as an initial view in our use case identification process. A brief description of each of these long-list use cases and rationale for its initial priority rating can be found in the Annex. For some of the use cases further qualitative data was gathered by way of case studies.

The research set out with the objective of determining the priority use cases for the UK based on the criteria as established by NIC. A combination of weighted numerical scoring and focus group analysis tested the prioritisation approach against the key evaluation factors:

- Scale and socio-economic importance
- Size of benefits delivered and to whom they accrue
- Impact and need of national infrastructure

This approach established a shorter list of use cases; however, making quantitative or qualitative prioritisation choices between uses in the health sector and uses in the transport sector ultimately challenged the prioritisation methodology. We therefore make no prioritisation indications amongst the final set of use cases, that emerged from the short-list process.

# Service platform definition



We found that each long-list use case established a requirement in terms of key parameters of performance for telecoms services, these parameters of performance were grouped into performance category definitions guiding our service platform definition. We carried out the rationalisation of the service platforms in two steps; firstly based on the long-list use cases, as a short-list of fifteen use cases was fixed we rationalised the service platform definition to adequately encompass the great majority of the service platform requirements that subsequently define the infrastructure cost elements.

#### **Principal Infrastructure identification**

To identify the **principal infrastructure**, we considered use case performance aspects as well as requirements in terms of accessibility of the service through properties of coverage and the typical profile of the stakeholders in the use case to derive capacity demand. These considerations were also informed by the scope of the NIC in terms of their UK infrastructure spheres of influence. Through this NIC perspective we are constrained to provision of mobile services to predominantly outdoor environments. We are limited to terrestrial systems but exclude indoor wireless coverage and indoor wireless systems and high power high tower systems typical of terrestrial broadcast.

For each use case a costing of significant components of infrastructure derives a representative cost that can be used as a comparator between the use cases. The costing approach focusses on significant capital cost elements based on the relevant service platform derived to suit the specific use case requirements (e.g. capacity and locations). Not only the telecoms equipment, but also the costs of provisioning supporting infrastructure such as power, backhaul, cell sites and towers are included.

We exclude the cost of provisioning both core networking and edge-cloud. Through interviews with mobile operators we could ascertain that whilst edge cloud oriented approaches to achieve lower latency services are of significant interest. The approach that is being taken to deploy such capabilities in networks is to incur a small additional capital expense on general purpose processing capability at the site when site upgrades are carried out as part of standard site refresh and maintenance cycles. When compared to the cost of establishing sites and the cost of radio equipment, the cost of general-purpose computing platforms for support of edge cloud is not a significant cost component.

# 2.2 Service platform definitions

Our research identified significant outcomes of Industry fora regarding desirable performance requirements for future mobile telecoms systems, such as within 5GPPP [8,9] and NGMN in their 5G White Paper [10]. We recognise the primary motivation of the NGMN and 5G-PPP activities at the time was to focus large scale research and standardisation activities. Nevertheless, their technical outcomes provide a useful framework within which to identify our performance categories and ultimately to develop our service platform definitions. We established a comprehensive performance categories definition (see Table 2) that meets the needs of all the long-list use cases.



•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	0	•	0	•	0			•		(

Table 2: Performance	category	definitions
----------------------	----------	-------------

ategory	Typical Descriptor	Device Density	Mobility	User Data Rate	Latency	Availability	Environment	
Ċ		per sq km	km/h	DL = Most constraining	-	Incl. coverage & reliability	Rural, Urban, ID, OD, Vehicle,	
A	Broadband Everywhere	Low to Medium 10-10000 per km <sup>2</sup>	Very Low to Medium Static - 50 km/h	<b>Medium</b> 50-100 Mbit/s	<b>Medium</b> 10-50ms	<b>High</b> >99% (National Coverage)	<b>All</b> Rural<->Urban ID & OD	
В	High Speed Urban	<b>High</b> Up to 1,000,000 per km <sup>2</sup>	Low to Medium 0-50 km/h	High to Very High 100 Mbit/s – >=1 Gbps	Low to Medium 1-50ms	<b>Medium</b> 95-99% (Localised Coverage)	<b>Urban Indoor</b> (can be localised)	
С	Machine Type Communication (M2M / IoT)	Machine Type         High to Very High         Very to V           Communication (M2M / IoT)         10,000 - >1m per km <sup>2</sup> H			Very High to High >50ms	High >99% (National Coverage)	<b>All</b> Rural<->Urban ID & OD	
D	Connected Vehicles	Connected Vehicles Medium 1000-10000 per km <sup>2</sup>		<b>Medium</b> 50-100 Mbps	<b>Medium</b> 10-50ms	High >99% (National Coverage)	<b>All</b> Rural<->Urban (trspt links) In- Vehicle	
E	Remote Pilot	Medium         I           Remote         1000-10000         50           Pilot         2         k		Low <50 Mbps	Very Low <=1ms	Very High 99.9- 99.999% (National Coverage)	All Rural<->Urban OD & In Vehicle	
F	Factory Automation	ttory Up to Very Low mation 1,000,000 per Static		Low <50 Mbps	Very Low <=1ms	<b>Very High</b> 99.9- 99.999% (Localised)	Localised (e.g. specific factories)	
G	Broadcast	High Up to 1,000,000 per km <sup>2</sup>	Low to High 0-360 km/h	Medium DL Only - 10-300 Mbps	High 50ms- 1sec	High >99% (National Coverage)	All Rural<->Urban ID, OD, In- Vehicle	
н	Mission Critical Communication	High Up to 1,000,000 per km <sup>2</sup>	Low to High 0-360 km/h	Low <50 Mbps	<b>Medium</b> 10-50ms	Very High 99.9- 99.999% (National Coverage)	All Rural<->Urban OD, In Vehicle & Air	

A definition of the performance attribute is given as:

- **Device density:** The volume of users or devices per km<sup>2</sup>
- **Mobility:** Whether the use case requires mobility or is static and the expected range of speeds
- User data rate: The typical data speed that the use case would need to operate effectively typically this is in the downlink direction
- **Typical cell edge data rate:** This is the minimum data speed that is needed at the edge of the cell (i.e. the most onerous location in terms of network infrastructure capabilities). This is used in the analysis to determine the range of the cell and hence the number of base sites required
- Latency: This is the level of delay that the use case can tolerate. End to end latency measures the time taken to send data packets from the user device to the application server and back to the user device. Typically for example email



services are delay tolerant and therefore can have a high latency, whereas interactive gaming, or remotely controlled vehicles could not tolerate much delay and therefore increases the need for lower latency systems

- Service Availability (reliability): This is a measure of tolerance of loss of connectivity or service. This encompasses aspects of coverage, areas where there is no coverage are deemed to suffer from low availability of service.
- Infrastructure Availability (installed): This is related to physical network infrastructure availability that could be used to deliver service, as compared to service availability (as described in the bullet point above)

Through the process of reduction of use cases from long-list to short-list the required set of performance categories is reduced. The categories merge from eight to three as indicated by the font colour used in Table 2 and Table 3.

- Category A and B (green) were merged and designated "Mobile Broadband"
- Category C (blue) remained and was designated "Machine Type Communications"
- Category D (**black**) doesn't stand as a distinct service platforms and was merged into others (see chapter on Connected Cars and Railway)
- Categories E, F & G (grey) were excluded from analysis as they proved to be niche performance requirements that did not command significant enough demand in the final short-list use cases.
- Category H (red) remained and was designated "Mission Critical Communications"

The remaining performance categories form the definition of our service platforms that adequately encompass the primary requirements of the short-list use cases i.e. the final set. The values selected are typically a blend of those proposed in respected references but tailored for the UK (for example in reference [10] which is a global paper, includes mobility from 0-500km/h, whereas we have reduced the upper speed to 360 km/h to align with UK's HS2). Their naming and performance criteria are summarised in Table 3 below:

ID	Service Platform	Device Density	Mobility (km/h)	User Data Rate	Typ. Cell Edge Rate	Latency	Availability (Reliability)
MBB	Mobile Broadband	Up to 10k / km²	Static - 360 km/h	50 - 100 Mbps	50 Mbps DL, 25 Mbps UL	10-50ms	99%
мтс	Machine Type Communications	Up to 1m / km <sup>2</sup>	Static – 360 km/h	Up to 100 kbps	100 kbps DL and UL	>50ms	99%
мсс	Mission Critical Communications	Up to 10k / km²	Static - 360 km/h	Up to 10 Mbps	10 Mbps DL and UL	1- 50ms	99.9% – 99.999%

# Table 3: The three types of service platforms

The three types of service platform are explained in more detail below:

# • Mobile broadband (MBB):

This service platform supports the enhanced mobile broadband capabilities that are expected for future communication systems. Improved user data speed is a key attribute with the target that mobile networks should be able to achieve the level of speed that fibre broadband currently offers today. However, these speeds should be universally available, not just very close to the base station but also at the edge of the cell (which is more onerous) and have high reliability with



at least 99% availability. Supporting low levels of delay (or latency) is also important to ensure good response times. Applications are becoming more and more interactive and some, such as interactive on-line gaming, need low levels of delay to operate successfully, whereas others such as video streaming are less critical but still need to be responsive. The MBB service platform is envisaged to support users over a range of mobility levels, from static at one extreme (e.g. for users at home or work) through to those travelling at high speeds (e.g. in a vehicle or a train) who still need access to mobile broadband services. The density of devices and users, can vary from low levels in rural areas through to many thousands per square kilometre in urban areas.

# • Machine type communications (MTC):

MTC is defined to support the multitude of Machine to Machine (M2M) and Internet of Things (IoT) use cases that are expected in future. Typically, the required data speed for these applications is low with often just a few bytes of data being sent. Delay and latency is also usually not critical. Machine Type Communications is expected to be a massive growth area with the potential that in future many everyday objects will be 'connected'. This means device densities can be huge with factories seen as the most demanding application but with limited requirements for wireless connectivity outside of the facility. Availability, reliability and mobility requirements are similar or even more relaxed that those for MBB for similar reasons.

# • Mission critical communications (MCC):

MCC defines a service platform type where reliability and availability is of the highest importance. Examples can be applications where it is vitally important that the communication or message gets through, such as with Emergency Service communications, security applications or remote piloting of vehicles. In these cases, the availability/reliability needs to be much better that 99% and on occasions up to 99.999%. This means there are significantly more onerous coverage and resiliency requirements. Whilst data speeds do not need to be as high as with MBB, the applications can be more onerous than basic messaging (e.g. video surveillance) and hence speeds greater than MTC are needed. Some applications can also have very low latency requirements (e.g. remote pilot of vehicles) which can imply latency performance better that MBB. These types of services may exist across the full range of mobility scenarios, so levels similar to MBB and MTC are needed.

# 2.2.1 Fixed wireless access exclusion

Within the nascent 5G a "fixed mobile convergence" use case that is gaining significant interest especially in the US market; is Fixed Wireless Access (FWA). This use of infrastructure is not intended for the provision of mobile device connectivity but is rather for fixed customer premise equipment connectivity as an economic solution to 'last mile' connectivity – an area that FWA has traditionally tried to address. We believe that the UK's copper and fibre infrastructure coupled with the government's push to deploy superfast broadband initially via BDUK and in the future via the planned 'universal service obligation' will leave future FWA services as a niche market in the UK. In addition, the continuous improvements in DSL technology such as G.fast, promising up to 330Mbps, albeit at limited distances and currently being trialled by Openreach will further limit the market potential for FWA in the UK. The economics of FWA have proven to be challenging with deployment





costs generally outweighing revenues. For these various reasons, we exclude FWA from the use case analysis.



# 3. Analysis of representative UK use cases

The set of use cases analysed in this section were those which emerged through the analysis processes as representative of a foreseeable future. They cover representative groups with which to test assumptions (infrastructure needs and costs) and address requirements that are apparent in vertical industries. The rationale for selecting these use cases were:

- Scale and socio-economic importance
- Size of benefits delivered
- Impact on national infrastructure

The representative set of use cases, fifteen use cases in total, and their associated service platforms are given in Table 4. For each use case we have a designated primary and secondary service platform. Each use case has a dominant characteristic in terms of required telecoms services and thus supporting infrastructure. The primary service platform will be dominant in meeting the traffic demand and thus deliver the greatest value and will drive scope and scale of infrastructure. The primary service platform establishes the basis for the costing in the subsequent chapter. However, ambiguities in requirements or niche requirements, are evident and noted as the secondary service platform.

These use cases can be seen as the driving applications for the provision of the service platform required to technically deliver the use case.

			Connected Car use cases			Railway use cases			Healthcare use cases			Utility & Supply Chain use cases			Media and Cloud use cases		
		Entertainmen t Service	Driver Assistance	Vehicle Management	Passenger Broadband	Command & Control	Telemetry Service	Assisted Living	Remote Healthcare	Preventative Health	Smart Grid	Road Haulage	Drone Delivery	4K Content Everywhere	Immersive Gaming	Mobile Office	
Mobile Broadband	MBB	×	(✓)	(1)	1	(1)	×	(1)	×	×	×	×	×	×	×	×	
Machine Type Communications	мтс	(✓)	×	×	×	(~)	×	<b>~</b>	(✓)	(✓)	×	<b>~</b>	×	×	×	(✓)	
Mission Critical Communications	мсс	×	×	×	×	<b>~</b>	×	(√)	×	×	(✓)	(√)	(√)	×	(✓)	×	
Indoor Wireless Systems	IWS	×	×	×	×	×	×	✓	✓	✓	✓	×	×	✓	✓	✓	

#### Table 4: Representative UK use cases and supporting service platforms

#### Legend:

- Primary Service platform: used mainly or exclusively for this use case
- ( $\checkmark$ ) Secondary Service platform: used to a lesser extent for this use case
- Service platform is not used or required for this use case

Please note that "Indoor Wireless Systems" are quoted as a different platform as it addresses about 80% of all mobile traffic which is generated indoors [5]. However, given indoor solutions and coverage does not have a wider external national infrastructure impact, it was not considered in our use cases and infrastructure analysis.

It should be noted that the IoT use cases analysed in this study represent the key use cases in terms of volumes and benefits. The IoT landscape is forecast to be very large – over 15 billion connected devices by 2021 is one of many forecasts [11] – use cases range from farmers monitoring connected animals to smart cities deploying connected waste bins and



environmental sensors. It is beyond the scope of this study to examine the many IoT use cases and how these are to be supported in terms of wireless technologies and platforms.

# 3.1 Automotive - connected cars use cases

The **Connected Car** is divided into three substantive use cases **entertainment services**, **driver assistance** and **vehicle management**. Both the mobile communications service providers and vehicle OEMs recognise the longer-term trend of **Connected and Autonomous Vehicles** (CAV). The main challenge for connected vehicles remains the provision of a high degree of coverage of adequate reliability.

**Entertainment services** encompasses media and general internet services. This use case will place high demands on networks; however, both the automotive and mobile communications industries recognise the opportunities and thus can be expected to invest in capabilities.

**Driver assistance** encompasses safety as well as congestion reduction. Critical communications characteristics of low latency and certainty of communication are evident. Whilst there are societal benefits, clarity around the case for business investment for delivery of these benefits is not immediately apparent.

**Vehicle Management** encompasses beneficial services for vehicles owners and OEMs relating to vehicle servicing, fault management, and provision of vehicle and sub-system management data enabling improved future products and services. Essentially an MTC requirement for infrastructure, with clear business benefit for OEMs. There is a likelihood that business models will emerge to realise this use case.

# 3.1.1 Overview

## Scale

The connected car is perhaps one of the largest and most significant use cases of all that we have examined – not only does it provide significant benefits to consumers, road operators and the automotive industry today but it provides significant potential for further benefits to stakeholders going forward. For this reason, our coverage of this use case is more in depth than other use cases. The Society of Motor Manufacturers and Traders reports in its statistics: The automotive industry is a vital part of the UK economy accounting for more than £71.6 billion turnover and £18.9 billion value added. With some 169,000 people employed directly in manufacturing and in excess of 814,000 across the wider automotive industry, it accounts for 11.8% of total UK export of goods and invests £2.25 billion each year in automotive R&D. More than 30 manufacturers build in excess of 70 models of vehicle in the UK supported by around 2,500 component providers and some of the world's most skilled engineers.

A KPMG study [12] concluded that "we believe the UK will become a centre of excellence for connected and autonomous driving" citing:

• Premier brands like Jaguar Land Rover (JLR) carry out R&D in the UK and market their cars heavily here, driving adoption



- The UK government has committed a £200 million fund to develop connected and autonomous car technology
- One of Europe's premier connected car testing facilities is at MIRA
- The UK has strong positions in telecoms and insurance

Figure 2 shows separately the levels of UK vehicle production that will be connected and autonomous out to 2030. By 2026 100% of UK produced vehicles will include connectivity. The timelines to autonomous vehicles are somewhat slower and must take in the level of autonomous capability – see Figure 3 for an explanation of these levels. KPMG forecast that by 2028 100% of UK produced vehicles will have either level 3, 4 or 5 capabilities.





Year	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Connected Car Penetration	50%	55%	59%	64%	68%	73%	77%	82%	86%	91%	95%	100%	100%	100%	100%	100%
L3 Production Penetration	0%	0%	4%	7%	8%	12%	16%	25%	48%	75%	81%	83%	87%	88%	84%	75%
L4/5 Production Penetration	0%	0%	0%	0%		0%	0%	0%		0%	4%	7%	8%	12%	16%	25%

#### Figure 2: Forecast UK production and penetration of connected vehicles [12]

The market growth and opportunity for connected vehicles is significant. In 2014 only 5% of all new cars sold worldwide contained embedded connectivity, and 15% of these contained mobile-device tethered connectivity. In 2019 those figures are expected to have increased to 57% and 60% respectively, and by 2024, 89% of new cars sold are projected to include both embedded and mobile device tethered connectivity, which translates into 48% of the installed base of passenger vehicles [13].

Connected vehicles are generally seen as a pre-requisite for autonomous vehicles. Whilst we see benefits of connectivity in autonomous vehicles e.g. driver entertainment, generally the autonomous capabilities rely on sensors and on board compute capabilities to provide the required situational awareness, vehicle control and decision making capabilities. Autonomous vehicles will be connected simply as part of the market take up of connectivity and the fact that early autonomous capabilities will, as is the industry norm, trickle down from premium (and therefore connected) vehicles to family vehicles. However autonomous functions may not require connectivity at least for 100% of the time. Therefore, the end to end journey capability of a level 5 fully autonomous vehicle will be possible even if some parts of the journey are in areas where there is no or poor quality connectivity.

The automotive industry has generally accepted the 6 levels of vehicular automation first put forward by the US Society of Automotive Engineers in their document J3016 published



in January 2014. Below we show these levels and likely timelines taken from the same KPMG study referenced above.



Figure 3: The 6 stages (level) of vehicle automation and expected timeline

In the UK, there were 35.6 million vehicles on the UK roads in April 2016 [14], and UK adults spend, on average, 10 hours a week driving and cover 7,413 miles per year [15]. When



Future Use Cases for Mobile Telecoms in the UK Issue date: October 2016 Version: 1.0 .....

passenger hours are also taken into consideration, the car clearly rivals the home and office as an environment where people will consume content, information and services.

The continued success of the UK's automotive sector is crucial to employment and exports. The increasing deployment of technology within vehicles not only supports a research and development eco system but also provides routes for manufacturers to increase margins whilst demonstrating innovation.

#### Challenges – coverage, capacity and latency

#### **Coverage and capacity**

Almost 4,600 miles (2%) of British roads have no 2G coverage from any network provider. Only 48% of UK roads have full 3G network coverage, whereas 6% have no coverage at all. In terms of 4G, 18% of roads have full 4G coverage and 56% have no coverage at all [16].

The DfT's 'Road Lengths in Great Britain 2015' [17] combined with the DfT Transport NI's 'Northern Ireland transport statistics 2015-2016 road network' [18] highlights the breakdown by road classification in thousands of miles shown in Table 5.

(all numbers in miles)	GB	NI	UK
Motorways	2.3	0.07	2.4
'A' roads	29.1	1.4	30.5
'B' roads	18.8	1.8	20.6
'C' roads	52.4	2.9	55.3
'U' roads	143.3	9.7	153
Total	245.9	15.9	261.8

## Table 5: Road lengths by classification (in thousands of miles)

The report also states that the Strategic Road Network (SRN) for England which is composed of all motorways and some 'A' roads is 4,436 miles (7081Km) long (less than 2% of total road length) yet carries 33% of traffic. The SRN is shown in Figure 4.





# Figure 4: Maps showing the strategic road network (SRN)

(Source: Strategic Road Network Statistics – January 2015 published by the DfT)

Applying the same pro rate percentages of motorways and A roads to Wales, Scotland and Northern Ireland gives a 'UK SRN' figure of 5539 miles, which is 8914 km. Figure 5 shows the average distribution of traffic by road type – again highlighting the concentration of traffic on motorways and rural 'A' roads. Another DfT source [19] shows the average number of vehicles per hour across GB roads as being – 80,200 on motorways, 13,300 on A roads and 1,400 on minor roads. The business motorway sections can reach over 200,000 vehicles per day.



#### Percentage of road traffic and road length by road type in Great Britain, in 2015



#### Figure 5: Percent road length by type and traffic carried for Great Britain [17]

Entertainment and driver assistance services are already delivered over 3G or LTE, often accompanied by in-car Wi-Fi, but there is clearly a **need to increase coverage and capacity** to support the current and future connected vehicle opportunity and its performance requirements. Mike Bell, connected car director JLR: *"The UK's mobile phone network has been built around population centres and making voice calls, rather than the routes between these urban areas and data communication. The pervasiveness of connectivity on our roads is a barrier in terms of enabling us to deliver high bandwidth into the vehicle. That's something we need to address as a country. There are a significant number of roads with not even 3G speeds on them."* 

The **infrastructure gap is expected to widen** as in-car services rise in variety, complexity, data security, availability and capacity demand. The main driver for capacity is high resolution media/content streaming (at e.g. 4K or 8k resolution).

Clearly the statistics above suggest that the motorways and SRN in England should have high capacity coverage along its entire length to support the volume of vehicles and their connectivity requirements. This would be targeted 'linear' coverage along the SRN transport corridor – similar in many respects to providing coverage along rail tracks. Furthermore, the 'U' roads include the streets where people live so it might be expected that operators would want to provide coverage on these roads, in order to offer outdoor coverage to their customers as a minimum. However, the challenge is understanding which use cases deliver societal benefits such as safety or environmental related and which are narrower perhaps less important.

#### Latency

To date, most ITS and V2X systems e.g. road tolling, operate in unlicensed or lightly licensed bands, using e.g. 802.11p which supports Dedicated Short-Range Communications (DSRC) in the 5.9 GHz band. Wi-Fi-based DSRC has established the foundation for latency-critical V2X communications.

In addition to DSRC, there is the emerging LTE-V specification which could allow usage of an LTE network where coverage was sufficient. Cellular V2X is expected to bring improvements over 802.11p/DSRC for active safety use cases and is part of the 3GPP release 14



specifications, which is scheduled to be completed by the end of the year. Testing is already taking place on the A9 Motorway Test Bed, at Ingolstadt, in Bavaria.

The UK DfT expects a dramatic increase in connected cars over the next 5-10 years and their priority is to work out how to provide that connectivity for V2X. They will have to produce a road building plan for 2020-2025 within 1-2 years and are concerned that they will have to choose a technology before it is clear what choosing 5G could entail.

A DfT representative commented: "*Neither DSRC nor LTE are addressing all our needs today*. The commercial networks don't provide the latency, reliability, prioritisation and security that are essential for critical applications such as safety and congestion management. There is a real issue over how a public network can prioritise bandwidth sharing at a busy London Junction over playing Pokémon Go."

Entertainment and driver assistance services have different requirements in terms of capacity, latency and criticality – it isn't clear yet whether one network will support these different use cases or whether separate networks would be more appropriate. The challenge for road operators and city authorities is particularly around V2X services which are now starting to appear in premium cars (at least as V2V capabilities although possibly without cross brand inter-operability at the moment) – what infrastructure should they plan to deploy – DSRC, LTE-V or wait for 5G. This is a very specific issue which requires deep analysis of the current state and strategies of the OEMs, the Tier 1 suppliers (who would supply the on-board V2X sub-systems), V2X vendors, cellular vendors, road operators, city authorities, standards bodies and other parts of the eco system.

Roaming may also be an issue, especially in business models where the OEMs are paying the mobile operators for data usage, rather than the consumer. UK-based Cubic Telecom is integrating an LTE-based M2M solution specifically to support connected car services for operators across Europe, and is partnering with EE in the UK. The solution uses local in country networks but utilises a single SIM approach (IMSI SIM) to allow the SIM to operate in different countries without paying expensive roaming charges. Cubic manages this process for OEMs using the Cubic service in their vehicles.

Barry Napier, CEO of Cubic Telecom explained this infrastructure approach: "*EE will be the backbone of cubic in the UK – this will help it get global companies into the UK. We enable partners on the EE network without them having to invest themselves for M2M automotive and PC OEM. The biggest challenge is that everyone underestimates the complexities of connectivity. Each region is different, but people expect to put a SIM into a device and for it to work."* 

# 3.1.2 Current connected cars use cases

Connected cars are an attractive series of use cases because it is already in operation on existing infrastructure, providing good indicators of likely future direction and uptake. For example, Ericsson's 'Connected Vehicle Cloud' service today provides cloud based services for end users including in car entertainment apps and remote vehicle security and monitoring – all new Volvo cars can have this service as an option.

Connected cars provide three types of services – entertainment, driver assistance – typically called Advanced Driver Assistance Services (ADAS) and vehicle management. Connected cars can extend the mobile broadband business model from the smartphone to the car, expanding the addressable market for MNOs and mobile content providers,



creating a new value chain embracing car makers and their partners, whilst delivering productivity and leisure benefits to consumers, road operators and other stake holders. Some manufacturers still use the term 'infotainment' – originally used to link broadcast radio and sat nav (**info**rmation and enter**tainment**) mainly because the human interface for both was focussed around one central dashboard screen. However, we believe now that with the rapid growth in the breadth of ADAS services and the demands made for high capacity streaming entertainment services it is more appropriate to examine the requirements for these services separately. These use cases – for today's connected cars - are as described below:

#### **Entertainment services**

Connectivity adds over the top (OTT) internet services to broadcast radio and where fitted broadcast TV capabilities as well as general internet and app access for driver and passengers through provision of an in car Wi-Fi access point or a small cell with either being backhauled over a cellular connection. This provides the capability for several devices to be used simultaneously thus increasing the capacity requirements. Some vehicles now offer the ability to run smart phone apps on the car platform and are available on the dashboard screen – e.g. Android Auto and iOS CarPlay - somewhat blurring the role of the car connection and the smartphone connection. However, entertainment services such as catch up TV or movies can dramatically increase capacity requirements and the cost for even just SRN coverage might be prohibitive. Alternative solutions could involve in car media storage on a hard drive, downloading to the device before the journey and delivery by urban Wi-Fi when in range and then on board cache.

Cars typically have a separate SIM card slot available to the owner to support such services or the connection can be made via a tethered smartphone

#### Advanced driver assistance systems

ADAS covers a variety of services – fromV2X, satellite navigation with up to date traffic and congestion information, parking applications guiding drivers to vacant parking spaces and security apps including car location, remote lock/unlock and alerts if the car is moved. On board systems also provide self-parking with the driver controlling the accelerator and brake, radar controlled cruise control with emergency braking, lane departure warning, drowsiness detection to name but a few. All of these capabilities use on-board sensors and on board compute capabilities – none require connectivity.

Currently V2X services have limited deployments although several OEMs (Mercedes, BMW, Volvo, Toyota) have announced forthcoming capabilities coming in 2017.

#### Vehicle management

Covers services operated by the OEM and/or their franchise dealers – these gather data on vehicle performance, environmental data, component wear/failure and support service management and booking, software updates and recall management. Typically, such information is sent over a separate connection not available to the driver. The information is not time critical and other than software updates will be low data volumes.

Examples of connected car services already available in the UK include BMW iDrive, Audi MMI, Jaguar InControl and Nissan Connect. Other platforms are provided by software players e.g. Apple CarPlay, Google Android Auto, either directly to the consumer, or white-labelled by the car maker.



An assessment of the various connected car services, done by SDB for the GSMA (see Figure 6), indicates that the services across these 3 use cases are largely consumer driven and have fast growth rates [20].



Source: SBD, 2012

## Figure 6: The range of connected car services and their growth patterns [20]

# **3.1.3** Future connected cars use cases

Perhaps the two most significant changes in connected cars over a 10-year horizon are likely to be:

- Service take up as shown in Section 3.1.1 the take up of connected cars will be some 95% of new vehicles by 2025 up from 55% today
- Deployment of increasing levels of automated vehicle control

Below we examine how these trends are likely to impact the three connected car use cases.

## **Entertainment services**

A very wide array of options is included in current generation of entertainment systems, from in-car audio and seatback video to weather alerts, location-aware recommendations and smartphone pairing. Current in-car entertainment services are delivered via a modem integrated into the vehicle, or a tethered smartphone. These may also support a Wi-Fi hotspot or Small Cell (even Vehicular CrowdCells [21]) within the car.

Outside of cities, coverage and capacity challenges will limit the availability of some services – particularly streaming video. The economics of provisioning high capacity streaming for even an average-case demand are challenging, let alone worst-case scenarios say when a road is closed and motorists are stuck for many hours.



Entertainment services is likely to evolve in the same way as other broadband consumer services to include services which harness:

- precise contextual awareness and delivery of personalised suggestions and promotions
- interactive entertainment
- high quality on line video gaming
- communications with other vehicles for social media or group gaming
- cross device and cross platform connectivity so you can continue to listen to a
  piece of music as you move from home to car
- more OTT services delivered to higher quality screens 4K and 8K
- greater use of cloud services particularly as download speeds increase

All of these services will add to the capacity required. However as mentioned previously entertainment services bring few societal benefits and operate in a well-established market – we believe it unlikely that government intervention in any form will be a priority.

As vehicle manufacturers continue to move towards fully autonomous vehicles they will progress along the 6 level SAE model. Currently we are at level 2 – where 2 functions such as automatic lane keeping and radar controlled cruise control can be operated together – although the driver still has to provide 100% attention to driving. Such systems are already deployed and are evolving rapidly as well as trickling down to lower costs cars.

Timescales to fully autonomous vary with OEMs describing a different stepping stones to reach Level 5. Most talk of the late 2020's or 2030 and beyond. The path to autonomous vehicles has limited dependence on the communications aspects – much more of sensor technology – cameras, radar, lidar, plus the software to integrate it all together and statute setting out a legal framework agreed by all parts of the eco system.

Clearly once drivers do not have to take any part in the driving of their vehicle it is likely they will want to utilise some form of entertainment service and/or access to the internet to keep occupied whilst being driven. This again will increase the capacity requirements particularly in rush hour when the majority of cars are driver only.

#### Advanced driver assistance systems (ADAS)

These services are concerned with safety and navigation, and so are more critical and more reliant on real time communications. Many functions of such systems do not require connectivity such as collision avoidance, road sign reading and blind spot warning.

ADAS includes Vehicle to Infrastructure and Vehicle to Vehicle services (collectively V2X) an area car manufacturers have shown interest in, as it could allow differentiation of their vehicles. City and local authorities are also interested as such capabilities aim to reduce congestion, speed up parking and reduce environmental impact through the intelligent monitoring and direction of vehicles.

However, V2X is at an early stage of deployment for example some 2017 US Audis will, in some US cities, display how many seconds before a red light turns green as the car approaches the traffic lights – this being the first step in Audi's V2X deployment. This is a cloud service using an LTE connection, although Audi's Justin Goduto commented "DSRC is more robust than LTE so we'll use that along with cellular".



ADAS systems using V2X technology can provide the following benefits:



# Figure 7: Overview of some advantages of V2X [22]

With many sensor based capabilities already widely offered on many vehicles the provision of V2X is the next logical step in extending the safety, convenience and environmental benefits from 'line of sight' of a vehicle sensor or the driver to some distance away say where a queue is forming Adding additional ADAS features can perhaps be seen as the stepping stones to fully autonomous driving – so beyond today's radar controlled cruise control and automatic lane keeping the next step could be for the vehicle to automatically overtake a vehicle that it comes up behind.

How connectivity requirements for ADAS will evolve is unclear at this point – many ADAS capabilities rely on on-board computing and multi sensor capabilities to make decisions. We see this increasing as additional sensors are added - radar, lidar and enhanced cameras. However, whether uploaded images or streaming video to the cloud will have applications is unknown and currently not a defined use case. It is possible to imagine that road operators and city and local authorities could benefit from automated 'crowd sourced' images or video in certain circumstances as an extension to what is done on social media today. There would of course be many privacy issues. Should such services prove of value then the capabilities required to support such services would move from the V2X low data rates but low latency and safety critical into a mobile broadband requirement.

The start of mass deployment of fully autonomous vehicles in the late 2020's and beyond will bring additional safety requirements to the connected car.

Future use cases will bring vehicle platooning – whereby a group of vehicles travel as a convoy with perhaps only driver of the lead vehicle retaining manual control of his vehicle. Please see Section 3.5.3 for a description of vehicle platooning on a road haulage use case.

## Vehicle management services

We expect manufacturers to use the data gathering capabilities to undertake more extensive analytics to inform new vehicle design and development including new component development in their supply chain. Additionally, data for service management of the vehicle including the use of analytics to forecast impeding component failure and driver performance data for insurance purposes could all be streamed from the vehicle in increasing amounts. As a result, we would expect more data to be uploaded from vehicles in future scenarios of vehicle management services although the data remains non-critical.


## **3.1.4** Network service requirements

### **Entertainment services**

This use case requires MBB services to support the large download capacity used for streaming videos and general internet browsing, apps and e mail – potentially simultaneously on several devices in the worst-case. The demand is likely to vary by time of day, day of the week and with seasonal variations. Total demand for MBB from entertainment services will vary significantly with the road class because of the different traffic densities across the time of day, day of week and seasonal variations.

We estimate that on the SRN demand per linear km across both carriageways could vary in the range 1.6-4.9 Gbps representing the dense but free flowing traffic scenario to a stationary traffic scenario. Other roads as explained in 3.1.1 has much less traffic on average – non-SRN 'A' roads carrying some 17% of the SRN traffic.

However, it must be considered that cars will have different usage patterns from other devices. A study for Teoco by Machina Research concluded that some cell sites could experience a 97 % spike in data traffic over the next decade with urban rush hour traffic being the dominant factor [23]. By 2020, connected cars will account for less than 4 % of total mobile data traffic, says Machina, but resource management will be stretched by the spiky nature of car usage.

### Advanced driver assistance systems (ADAS)

Connectivity for ADAS going forward is expected to be driven by V2X services some of which could be critical in terms of latency and certainty of transmission/reception. Capacity requirements per vehicle could be low as the volume of V2X data will be limited, however should use cases for vehicles to upload video or images then such demand would be served as part of the MBB requirement. Capacity to support V2X we have assumed to be 100 Kbps. Future cellular networks are expected to support V2X requirements – planned LTE releases 13/14 will include the V2X requirement and this capability is expected to be in 5G from the start. The challenge therefore for road and city operators is which system to choose to ensure a degree of future proofing and alignment with the what the OEMs fit to their cars.

### Vehicle management services

We have assumed a requirement per vehicle of 100 Kbps provided over an M2M platform for vehicle management services (VMS). Whilst today VMS can be served with such low capacity M2M services it is possible that in the future the amount of data being gathered by OEM, road operators and insurers might rise significantly. If this was the case, then VMS would need to be supported over the MBB connection.







Figure 8: Connected car with infotainment (Source: BMW)

Typical demand per vehicle across all services has been calculated to be in the range from 0.7 Mbps for single occupancy, streaming audio with ADAS and vehicle management services - up to 25.7 Mbps for driver plus 3 passengers, two of whom are streaming video and one accessing the internet, email and social media.

# 3.1.5 Potential benefits to the UK

Connected and autonomous vehicles (CAVs) are of critical importance to the UK automotive industry. With an enabling wireless technology, it has the potential to encourage the deployment and uptake of CAVs, leading to opportunities to capture economic value of £51 billion per year by 2030 and harness new investment into the UK automotive industry as reported by KPMG [24]. Such benefits arise because CAVs improve efficiency in operation of the road infrastructure, and may bring considerable social benefits through reducing journey times, reducing accidents, improving productivity and reducing the impact of transport on the environment.

The need for V2I is high because it can significantly reduce accidents and can ease the strain on struggling road infrastructure. Furthermore, better traffic management will increase productivity, reduce stress, traffic jams and pollution. KPMG further estimate that 2,500 UK lives will be saved, and 25,000 serious accidents prevented, by connected car technology over the period 2014-2030. Another future potential benefit, equivalent to the deployment of in cab signalling for trains (ERTMS/ETCS) would be savings to road operators, such as Highways England, by the removal of all roadside signs and equipment because all relevant information would go straight to the vehicle from roadside infrastructure, sensors in roads, and other vehicles. Clearly the train situation is a tightly controlled environment – the roads are somewhat different and any such benefits could only begin to accrue once all vehicles on the road could receive in vehicle 'sign' information, for this reason it is clear that a credible business case could not be delivered supporting such a strategy over the 10-year time horizon of this study. It is possible that on a more controlled environment such as a motorway some parts of the roadside infrastructure could be eliminated eventually with



quite large savings – this would obviously would need to be part of a programme to change the current design standards for such roads.

Whilst V2V delivers some benefits such as the 'brake now' instruction sent to the vehicle behind in the event of an emergency stop, V2I provides road operators with a much broader capability to understand traffic flows and react to them by informing drivers of situations when they have time to take avoiding action. The challenge for the whole eco system is how best to deliver these benefits and developing a solid business case to show that the cost of deploying and operating V2I services is less than the value of the benefits.

On the user side, similar to mobile broadband for railway passengers, connected cars could drive some productivity benefits for business and consumer welfare. The ability to consume content and information in the car has some benefits in terms of consumer satisfaction, productivity and pleasure. More transformational social effects, such as supporting travel for disabled or elderly people, are more associated with autonomous vehicles.

# 3.1.6 International perspective

We reviewed various markets and found significant activity in the OEMs in Asia, US and EU all adding LTE MBB connectivity for entertainment services and sometimes a separate connection for vehicle management services plus sensors and on board compute capabilities for ADAS. However little progress appears to have been made on the deployment of infrastructure based services such as V2I with a general lack of agreement on standards – opinions varying between the use of LTE-V and DSRC exemplified by the US Audi V2I deployment mentioned in 3.1.3. The German OEM eco-system appears to be creating a centre of gravity for investment and progress and making the greatest headway in that the German government has already set out its strategy for connected and autonomous vehicles. The strategy includes a commitment to ensure that all German motorways are equipped with connectivity rates of at least 50 Mbps by 2018 based on 700 MHz licence conditions, while higher bandwidths including 5G is planned to be rolled out in the longer term [25]. We could not find any evidence of similar plans for the UK SRN.

Use cases	Direct (Industry/User) Benefits	Indirect Benefits (e.g. industry infrastructure)	Network Infrastructure Requirements
Entertainment Service	<ul> <li>New one off and recurring revenues</li> <li>Enhanced services for driver and passengers</li> </ul>	<ul> <li>Children entertained leads to less driver distraction and improved safety</li> </ul>	<ul> <li>MBB service, 0.5 – 25.5 Mbps per car</li> <li>On SRN requires 1.6 Gbps in the best-case and 15.3 Gbps in the worst-case per km</li> </ul>
Driver Assistance	<ul> <li>Reduction in deaths and injuries</li> <li>Congestion reduction, improved average speeds</li> </ul>	<ul> <li>Road operators have improved real time control of traffic</li> </ul>	<ul> <li>Primarily MCC application</li> <li>Mix of vehicle to vehicle and vehicle to infrastructure, 10 - 100 kbps for V2I per car</li> </ul>
Vehicle Management	<ul> <li>Maintenance schedule aligned vehicle diagnostics</li> </ul>	<ul> <li>Reduction in component failures</li> </ul>	<ul> <li>MTC service – mostly gathering performance data from vehicle</li> <li>10 - 100 kbps per car</li> </ul>

## 3.1.7 Use case summary



## 3.1.8 Case studies

### Case study 1 – Jaguar Land Rover's connected car services and platforms

Jaguar Land Rover (JLR) is developing a wide range of connected car services for the near to medium term, and is one of the leading firms carrying out development and trials in the UK. Its emerging services will be launched to UK users at an early stage of commercialisation. They are highly indicative of the type of services which will evolve in future, and the type of network which will be required to support them.

### **Current InControl product**

JLR currently offers the InControl platform [26], integrating many apps and service, whose services are summarised in the picture below.



Jaguar Land Rover's head of product marketing for connected cars, Leon Hurst, says there are relatively few differences between a connected car and a wearable. "Firstly, they call upon a number of similar components and services, such as sensors, on-board computers and telecoms providers. Secondly, their reason for existing is to improve the user's life by bringing together the services that they need when they need them."

An example of this in action is navigation. While the driver will usually start their journey in the car, it often continues once they have parked up. This means that for true door-todoor navigation, the user will use their watch or phone as well as their car. The user won't want to input their destination again once they've exited the vehicle. This means that the car and the watch must be synchronised to work together to create the ultimate experience.

Jaguar Land Rover showed how this works in practice, using the new Jaguar F-PACE at the Wearable Technology Show at ExCeL London in March 2016. For example, Jaguar Land Rover's InControl Route Planner can share the driver's ETA with a friend or a colleague when on the move as well as find available parking before it reaches its destination.

The F-PACE also features a lot of innovative new wearable technology. Its InControl Remote smart watch app lets the driver turn on the car's engine and heat or cool the interior using an Apple Watch or with Android Wear. This means that when you step into the car, it is already at the perfect temperature – ideal for markets with extreme weather conditions. The app also lets you plan your route before your journey and track your car.

A feature that is exclusive to Jaguar F-PACE is Activity Key. Expecting that a number of Jaguar F-PACE owners are likely to lead an active lifestyle, Jaguar Land Rover has developed a rugged, rubber wristband. Waterproof up to 20 metres, it can temporarily



act as the vehicle's key. This leaves owners safe in the knowledge that the key won't get lost or damaged when they are rock-climbing or white water rafting, for example, or even simply not having to leave the key on the front tyre or in your pockets when going for run.

### **Future roadmap**

JLR's future roadmap is illustrated in the picture below.





The future capabilities that JLR is now researching in the UK will demand far higher bandwidth, reliability and lower latency. They are heavily focused on AI-enabled analytics to predict drivers' needs and risks on a real time basis e.g. an infotainment which predicts, and turns on, the content a driver or passenger will want to consume at a given time or situation. A first step to this will be voice or gesture activation of content (already available in the BMW 7 Series).

Other developments include the Mind Sense system, which uses technology borrowed from Nasa - tiny sensors embedded in the steering wheel can scan a driver's brainwaves and detect when they are distracted or drowsy.

In commercial terms, JLR's Bell says there are three main drivers behind the connected car strategy [27]:

- Competitive positioning especially in the premium market
- Upcoming legislative requirements in the European Union, Russia and Brazil for e-call and vehicle tracking. JLR wanted to generate enough revenue from in-car systems to offset the cost of fitting them to meet legal requirements.
- Enhance the relationship with customers through enhanced feature sets.



## Case study 2 – Jaguar Land Rover's efforts in the CAV domain

Jaguar Land Rover has demonstrated various enablers of future autonomous vehicle and is a leader in all-terrain driving, which enables non-consumer applications for industrial or military use as per the picture below [28]. This technology is being developed to help drivers as well as autonomous vehicles.



Tony Harper, Head of Research, said: "We don't want to limit future highly automated and fully autonomous technologies to tarmac. Whether it's a road under construction with cones and a contraflow, a snow-covered road in the mountains or a muddy forest track, this advanced capability would be available to both the driver and the autonomous car, with the driver able to let the car take control if they were unsure how best to tackle an obstacle or hazard ahead."

This would be enabled by advanced always-active sensors feeding to an artificial intelligence engine for decision making. The car uses surface identification and 3D path sensing, combining camera, ultrasonic, radar and LIDAR sensors to give the car a 360-degree view of the world around it. Ultrasonic sensors can identify surface conditions by scanning up to five metres ahead of the car and obstacles such as low-hanging branches are also identified in advance. If there are hazards, the car will warn the driver with a message in the infotainment touchscreen.

JLR was also the first in the world to demonstrate off-road V2V communications between two Range Rover Sports over DSRC (Dedicated Short Range Communications) technology to create an Off-Road Connected Convoy. This communications system shares information including vehicle location, wheel-slip, changes to suspension height and wheel articulation, as well as All-Terrain Progress Control (ATPC) and Terrain Response settings instantly between the two vehicles.

Such work will feed into JLR's broader connected and autonomous (CAV) project, centered on its 41-mile 'living laboratory' test corridor on roads around Coventry and Solihull, which will be used to evaluate new systems in real-world driving conditions.



The £5.5m 'UK-CITE' (UK Connected Intelligent Transport Environment) project will create the first test route capable of testing both vehicle-to-vehicle and vehicle-to-infrastructure systems on public roads in the UK. New roadside communications equipment will be installed along the route during the three-year project to enable the testing of a fleet of up to 100 connected and highly automated cars.

Dr Wolfgang Epple, Director of Research and Technology at JLR, said: "Similar research corridors already exist in other parts of Europe so this test route is exactly the sort of innovation infrastructure the UK needs to compete globally. The connected and autonomous vehicle features we will be testing will improve road safety, enhance the driving experience, reduce the potential for traffic jams and improve traffic flow. These technologies will also help us meet the increasing customer demand for connected services whilst on the move."

The test corridor will include five different types of junction. Warning messages will be sent directly to the dashboard rather than flashed overhead, with a focus on more advanced warnings. For instance, JLRs' Emergency Vehicle Warning system would identify that a connected ambulance, fire engine or police car was approaching through V2V and warn other drivers before the sirens would be heard.

JLR is also part of the MOVE\_UK consortium to test autonomous cars in real world conditions, based in Greenwich, London. Other partners are Bosch, Direct Line Group, The Floow and the Royal Borough of Greenwich.



# **3.2** Public transport – railway use cases

The railway sector is divided into three substantive use cases; **passenger broadband**, **command and control** and **telemetry services**. Whilst passenger broadband is clearly consumer oriented, both command and control and telemetry services illustrate how future mobile telecommunications infrastructure can significantly enhance operational efficiency.

**Passenger broadband** encompasses enabling passengers to work, stream content and access social media. The Department for Transport aspiration of 100Mbps to a train should be surpassed by a target of 1Gbps by 2025 to meet anticipated demand. The requirements can be met by MBB infrastructure and the societal and business productivity benefits are apparent; however, this has been so for some time based on existing demand but existing WiFi provision is widely perceived as inadequate. Clarity around the case for business investment for provision of infrastructure is not immediately apparent.

**Command and control** encompasses increased safety through improved signalling, increased capacity of train services, greater resilience of train services, and cost saving through removal of trackside signalling equipment. To secure these benefits infrastructure needs to be highly reliable but a modest data rate is adequate. The business case within the sector is evident; however, existing operational practices and expectation around service lifetime of equipment can create a perception that the dynamics of the market could benefit from more focus to deliver the benefits.

**Telemetry service** encompasses enables more efficient use of track and trackside equipment with improved maintenance regimes, showing potential for significant operational expense reductions. The infrastructure requirements show MTC is adequate, the likelihood of the rail industry establishing a business case to deliver the benefits is high.

# 3.2.1 Overview

## Scale

The National Rail network in Great Britain is the 17th largest railway network in the world and is also one of the safest rail networks in Europe [29]. With 4,000 trains, 15,760 km of rail route and 2,552 passenger stations [30], the rail network is amongst the densest of global rail networks [31]. In 2014, there were 1.65 billion journeys on the National Rail network, making the British network the fifth most used in the world [30]. The passenger number has doubled since the rail privatisation in 1994/95 and is set to double again in the next 25 years [32]. The busiest area is London with over 1 million daily arrivals on a typical weekday and the busiest station is Waterloo with 100 million passenger entries and exits per year [33].

The Northern Ireland Railways network is not part of the National Rail network which is limited to Great Britain. It does not use Standard Gauge; instead uses Irish Gauge in common with the rest of the island of Ireland. The Northern Ireland Railways network is 330 km long, has 22 stations (and halts) and operates 43 trains [34].



The railway sector employs 212,000 people and its tax contribution, of £3.9 billion in 2013, offsets government funding for the industry almost precisely. The sector calculates that it delivers £13 billion a year in benefits to passengers and freight users, and £10 billion of additional GDP through its supply chain and impact on stimulating other economic activity [35].

### Challenges

According to a study conducted for the government by Transport Focus [36], the top priorities for passengers, in terms of improving railway services, are as follows:



### Figure 9: Rail passengers' top 10 priorities for improvements in Great Britain [36]

Depending on the time and location of the survey, on-board Wi-Fi might rank higher, but it is consistently in the top 10 passenger priorities related to rail. Many of these improvement priorities could be addressed by more real time information about the train, and the ability to control trains intelligently in order to minimise delays and congestion, while keeping passengers informed and entertained.

**Passenger connectivity:** Passenger demands for connectivity and information are often not being met, as seen in a presentation from the Department for Transport [37].





#### Figure 10: One of the top 10 complaints on rail travel is wireless connectivity [37]

According to Nina Gaubert from DfT, Client Side Network Rail: "The goal is to provide seamless and operator agnostic wireless connectivity from the point passengers enter the station of departure, until they leave the destination station. There are significant challenges to this, e.g. achieving in-carriage coverage in tunnels, cuttings and remote areas."

**Rail capacity:** Railway lines are divided up into signalling sections, or 'blocks'. These blocks are dimensioned to support the oldest rolling stock, e.g. each block anticipates that the train is of 1970s technology, not modern trains with better breaking capability. The signalling system keeps the railway safe by only allowing a train into a block section after the preceding train has vacated it. This maintains a safe distance between trains, but makes inefficient use of the railway infrastructure as trains must move in lock-step as they wait for blocks to be vacated and a small delay to one train can cause massive knock-on effect. Modern signalling could address this issue.

**Command and control:** There are challenges in delivering a network which can track and control high speed trains.

While GSM-R is only just becoming ubiquitous, it is likely to become obsolete within the next decade or so and a replacement service is not yet clear. In particular, the GSM-R radios use to communicate to the trackside, are said to be obsolete by 2025. According to an industry source: "From a signaling point of view, GSM-R is far from ideal. GSM-R is based on a 2G technology and suffers from legacies issues. Further improvements are necessary to make the system more adequate for railway applications (Voice and Data). There is also the E-GSM challenge where some of the mobile network operators (MNOs) 3G technologies, operating at 900 MHz, cause interference issues and performance degradation to the GSM-R system. This issue is of high concern as there is no legislation that allows managing this interface between MNOs and railways. Unfortunately, we are reactive instead of proactive and these issues are often only managed once interference has occurred and had affected train services. We need a reliable and secure, native IP based solution, delivering higher capacities, especially in busy areas to support signalling, telemetry data and voice services. We are looking for a network architecture which is simple and therefore not expensive to maintain."

Rail signalling and management systems run on any IP network, but GSM-R as it stands today, is not sufficient because its air interface does not provide the critical train focused capacity and reliability needed to support modern and future rail signalling and management. With the implementation of future command and control technologies delivered over wireless infrastructure, if signalling connectivity to a train is lost, the train will stop.

The trade-offs between the risk of migrating a huge and critical system, and the benefits of more modern technology, have to be closely assessed. LTE is being discussed, but in some views a dedicated 'LTE-R' network would require new spectrum – one suggestion is that spectrum adjacent to GSM-R (872-876 MHz paired with 917-921 MHz), might be allocated in future, or alternatively some of the frequencies in the hotly contested 700 MHz broadcast band, when that is freed up around 2018-2020; or options in 400 MHz. However, at least 10 MHz of spectrum would be needed.



Sharing with commercial traffic (and networks) would only be possible if key conditions on reliability, availability, cost, technical capabilities are addressed in addition to Europeanlevel acceptance of putting a public safety network in commercial hands. However, while data (and operational voice, as a fall back) is increasingly critical, general voice will become less critical and could be run on the public networks in future. Regardless of spectrum/network choices, there is likely to be development of the radio technology as the European Train Control System (ETCS), a key part of the European Rail Traffic Management System (ERTMS), becomes increasingly central to railway safety and efficiency by replacing track side signalling with cab signalling promising many safety and cost benefits. On the wish list is an ETCS-optimised, ultra-robust wireless system delivering 10- 20 kbps at speeds up to 500 kilometres per hour [**35**].

# 3.2.2 Current railway use cases

The rail operators introduced GSM-R in the 1990s but the implementation was very slow. GSM-R did become universal and GPRS is being added to increase its functionality. The network was designed to provide operational voice communications and data for the ETCS (European Train Control System), as well as other rail-related uses. It utilises dedicated 900 MHz spectrum, outside of the usual GSM mandated frequencies. The rollout of European Rail Traffic Management System (ERTMS) has increased the strain on the GSM-R network and extra capacity is required to support railway operations.

Adding new signaling is currently very slow and disruptive, as each signaling project is highly specific to the local landscape. They are expensive, complex and lengthy undertakings. Just to maintain existing signals in the UK, £3bn are spent every five years [32].

As GSM-R it is expected to reach the end of life within the next decade, the International Railway Union (UIC) calls for a replacement for GSM-R. Therefore, the UIC is outlining plans for a Future Railway Mobile Communication System and the plan is to have a successor technology in place for trials by 2020 and for deployment by 2022 [38].

According to Digital Railway, there are currently a number of digital-enabled initiatives under way but this bears the risk of 15 different standards and approaches that need to be aligned to achieve a coherent "end-state" for the future digital railway.

# 3.2.3 Future railway use cases

## Overview

Future rail use cases address a fully connected train which is similar to a connected car as it is about passenger broadband, command and control and telemetry. The focus is on a better travel experience for the passenger and a smoother operation for the rail operators. Some of the benefits include; passenger safety, increased capacity and reliability, reduced congestion (delays) and disruptions, reduced power consumption and environmental impact, better scheduling, proactive maintenance etc.

The key goals of a new wireless infrastructure and a suitable rail command and control solution are [32]:

1. To provide significant additional capacity and better performance on increasingly overcrowded parts of the network.



- 2. To increase the flexibility and connectivity of the railway so that the right train service is available at the right time, with flexibility to make short-notice changes that better match supply with demand. Modern freight services should be as agile and dynamic as the modern supply chains of which they are a part
- To improve end-to-end customer experience of the railway system from simplifying the purchase and authentication of tickets for end-to-end journeys to providing real-time flexibility for how and when they travel.
- 4. To reduce the operating cost of the railway whilst further improving safety, and make optimal use of existing assets rather than building new ones.

Network Rail and RSSB run an investment initiative - the Future Railway programme - to progress innovative technology based solutions addressing some of the challenges faced by the GB railway industry [39]. These investments support the goals of the 30-year Rail Technical Strategy and include some of the following projects:

- Running trains closer together to increase capacity
- Resilience and continued service in case of failure
- Future-proofing against cyber threats
- Addressing real-world capacity challenges
- New infrastructure monitoring technologies
- Network Rail signalling innovation group
- Autonomous rail inspection and maintenance machines
- Improving customer experience on the railway
- Innovative ticket detection solutions
- Smart tickets for easy efficient journeys (smart phone based)

### **Passenger broadband services**

Passenger broadband is currently a challenge and will remain a challenge as trains become more thermal efficient (reflective), data consumption grows and passenger expectations increase.

The UK government launched a programme provide seamless and operator agnostic wireless connectivity from the point a passenger enters the station, on the train journey and until he leaves the station at the destination.

A number of trains are already equipped with on-board Wi-Fi or in-train repeaters. But the enforced requirement by the DfT to get free Wi-Fi on 90% of all UK train routes with a backhaul requirement of up to 100 Mbps per train has only just started. It will take 10-12 years till full UK wide implementation. The reason being is that it takes 10-12 years till all new franchises are signed.







Figure 11: Typical parties involved in providing mobile broadband to rail passengers

However, for a future use user behaviour and data requirements, 100 Mbps might not be sufficient for high capacity services for a "moving village" (the train) with up to 850 passengers in 2025. To enable the benefits of mobile broadband for passengers, capacities in the Gbps range would be required as discussed at the recent "The Gigabit Train" event [40].

## **Command and control services**

This future use case starts with digitising the railway command and control system, for instance with the ERTMS (European Rail Traffic Management System) but future evolutions are envisaged as enabled by advanced wireless communications. These include driverless trains beyond light metro systems; intelligent signals; more effective train-to-infrastructure communications [149]. To take advantage of these potential benefits, the service platform needs to support network reliability (100% uptime), data security (cyber-attack secure) and higher capacities (current GPRS based GSM-R is not sufficient).

### **Telemetry services**

Telemetry services are not as mission critical and command and control services, but enable Big Data on rolling stock and rail track infrastructure. This will open the door for "condition based maintenance" (or preventative maintenance) based on a view of the mobile and fixed infrastructures status.

Vibration sensors in the wheels can signal issues with the wheel itself or the ball bearings. Instead of replacing ball bearings and maintaining wheels at set intervals, the maintenance can be extended as potential issues will raise alarms. Therefore, there is less maintenance and less stock holding required as well as less downtime due to informed preventative "condition based" maintenance. This principle applies to many other components alongside the rail infrastructure and within the rolling stock, leading to a smoother ride, less disruptions and reduced delays for passengers. The rail & train operators benefit from less downtime, therefore better scheduling and less (but informed & targeted) maintenance efforts and costs.



## 3.2.4 Network service requirements

**Passenger broadband services:** The broadband requirement fits into the MBB service platform with the added challenge that a high user density vehicle travels through urban and remote areas at high speed. Reliability is not as urgent as for command and control, but it impacts the passengers QoE. Based on the DfT figures for the new franchisees, the backhaul per train is 100 Mbps with an average peak hour passenger number of 560 [37]. We estimate however the need to be rather in the region of 1 Gbps by 2025. Within this bandwidth, the rail operators would include non-vital rail related applications such CCTV, passenger information, schedule updates etc.

**Command and control:** This is a typical MCC service platform application. The operational data has to be sent to the train in a secure way; encrypted, reliable and available (99.999% in terms of network uptime). This is critical as with modern command and control systems, the train will stop if the connection is lost, as is cyber security. Lost packages can be re-transmitted and the latency requirements is in the range of 10ms. The capacities for signalling and telemetry are low, 10 - 100 kbps bandwidth per train for vital applications [41]. In a case with a cell covering multiple trains, we estimate that 1 Mbps is sufficient for vital communications.

Voice is another requirement for potential future ATO (automatic train operation), allowing the signaller in the traffic management centre to control the train and communicate to passengers when needed. 100 kbps (65 kbps plus overhead) has to be provided for that.

However, if the connection is lost with modern command and control systems, the train will stop; therefore, availability is crucial and mission critical, as is cyber security.

**Telemetry:** Telemetry data can be supported by the MTC service platform. It is low in capacity requirement and less critical in terms of availability. Telemetry data will open many opportunities to support big data analytics, to further improve activities such as predictive maintenance and intelligent scheduling. Telemetry bandwidth is very low per device, but based on the number of devices on a train, the average bandwidth (for maintenance purpose) is estimated up to be 300 kbps (a few 100 kbps [41]).

# 3.2.5 Potential benefits to the UK

## Benefits to the rail industry

The rail capacity will be improved dramatically with modern command and control, delivered over a reliable network. The train capacity can be increased by up to 40% and delivered at about 30% lower cost than the construction of new lines. The increased number of reliable train paths, will enable more people to travel and more goods to be transported. It will lead also to 35% reduction in primary delay caused by signalling asset failures and also result in faster recovery from faults when they occur. The railway will also be safer as 80% fewer Signals Passed At Danger (SPADS) are predicted and less trackside work will be required.

There will be a substantial flexibility benefit with the introduction of agile timetabling to optimise supply to meet demand, including freight and passenger mix. The journey times will be reduced through better connectivity and there will be fewer line closures by exploiting bi-directional network capability. Another benefit is optimised train management during disruption.



An open data approach to rail information enables real-time journey planning information, helpful information during disruption, intelligent guidance from one transport mode to another, electronic ticketing with open interfaces for ticket/token validation and greater scope for service differentiation.

Telemetry data enables the rail operator to know more about the trains and trackside infrastructure and enables "condition based maintenance" which also reduces failures, disruptions and cost.

The train operator can therefore benefit from higher capacity, increased reliability, reduced cost and increased revenues by attracting more passengers to use rail. There was no quantifiable figure for increased revenues or reduced costs, but the forecast is that the passenger number will double in the next 25 years [32].

A good example enabled by modern signalling, enabled by future command and control solutions is that trains can travel closer to each other and speed variations can be reduced. This will be resulting in less acceleration and breaking and therefore power savings. Mike Haigh, Programme Director for London Midland, stated: "If we know how much electricity we are using, we can start to manage that usage and do things differently. As well as energy consumption data, the technology we are fitting to our trains can also transmit data on the condition of train systems which will ultimately help us to improve reliability and our maintenance processes. If trains can tell us 'how they are feeling' we can resolve issues before they become a problem and give passengers a more reliable service."

### **Benefits to passengers**

There will be more trains, addressing the capacity challenge and growing passenger numbers on the routes that are impacted. The connections will be better due to improved flexibility in the rail timetable and also the ability to responding to changing patterns, therefore managing traffic in real time. The ride will be smoother, the punctuality improved and less disruptions.

The convenience will be improved as customers have connectivity on the train (can work, stream and access social media), access rail information and ticketing services that work across all modes of transport and get real time updates, e.g. about changes in scheduling.

There is anecdotal evidence of passenger modal shift particularly for long journeys where Wi-Fi is offered. The in-train wireless systems will be paid for mainly by the TOC, but DfT is supporting trials.

### **Benefits to the MNOs**

Many mobile operators may see little increase in direct revenue from improving railway coverage, hence this could be an important area for government intervention. However, some MNOs see it as an opportunity to get access to sites on land owned by Network Rail (or the permit to build sites).

## 3.2.6 International perspective

For the MNOs, there is no clear business case for rail coverage and passenger connectivity. The MNOs average revenue per user (ARPU) will not increase to any great degree as a result of providing passenger connectivity as most subscribers are on fixed voice and data plans. Also, the MNOs' sites along the railway tracks would have to be overprovisioned in



terms of capacity to meet the "moving villages" of capacity demand. This would indicate that the initiative to improve mobile coverage along the rail routes should come from the rail industry rather than the mobile industry. This approach has been taken up in the United States by Amtrak. The quality of service of Amtrak's on-board passenger Wi-Fi was so poor that it became increasingly frustrating for passengers. Overhauling on-board Wi-Fi became essential to Amtrak's brand reputation. As a result, Amtrak has started to lay down its own (MNO independent) trackside infrastructure across its national network. According to the company's website, 90% of Amtrak's customers now have access to free on-board Wi-Fi [42].

Use cases	Direct (Industry/User)	Indirect Benefits (e.g.	Network Infrastructure
	Benefits	industry infrastructure)	Requirements
Passenger Broadband	<ul> <li>Convenience and</li> </ul>		<ul> <li>MBB application for all</li> </ul>
	attractiveness of	<ul> <li>Might require to build</li> </ul>	UK rail routes
	connected rail travel	more sites than are	• DfT is planning 100
	<ul> <li>Enabling passengers to</li> </ul>	available which can be	Mbps per train
	work stream and	used for MCC and MTC	• We suggest $1.2 - 2.7$
	access social media		Chas for 2025 por train
			Gbps for 2025 per train
Command & Control	<ul> <li>Increased safety, 80%</li> </ul>		
	fewer "Signals Passed	<ul> <li>Will delay the need to</li> </ul>	<ul> <li>MCC application for all</li> </ul>
	At Danger"	build out rail network	UK rail routes
	<ul> <li>40% more train</li> </ul>	<ul> <li>Reduced power</li> </ul>	<ul> <li>Vital services, needs</li> </ul>
	capacity at 30% lower	consumption, hence	high availability
	cost	delay in power grid	(99.999%)
	<ul> <li>35% reduction in</li> </ul>	upgrade	<ul> <li>200 kbps per train</li> </ul>
	signalling caused delays		
Telemetry Service	Condition based		
	maintenance and less	<ul> <li>Less stocking of spares</li> </ul>	<ul> <li>MTC application for all</li> </ul>
	failures	Removal of physical	UK rail routes
	<ul> <li>Reduction of signalling</li> </ul>	signalling infrastructure	<ul> <li>Best effort traffic, when</li> </ul>
	maintenance spend	Better use of facilities	service available
	(currently f3bn spent	as less maintenance	• 300 kbps per train
	every five years)		
	every live years)		

# 3.2.7 Use case summary



## 3.2.8 Case studies

### Case Study 1 – Discussion with a rail operator

The rail operator manages rail infrastructure (track, stations, tunnels and signalling) on a line where trains reach speeds of up to 300 kilometres per hour (186 mph). In terms of wireless connectivity, they see two main advantages and priorities:

- 1. Services to passengers
- 2. Signalling and telemetry

According to a representative from the rail operator, passenger connectivity has become a "basic need of our customers" and is essential in order for them to be seen as a highclass service and "to be market leader and to provide outstanding value for money".

This is not just about competing with other train operators, but with other transport modes (car, bus & planes) and connectivity is essential to keep travellers using rail instead of other transport. Their approach is to take away any negative decision criteria and therefore removing the barriers for travellers to choosing a train as their preferred mode of transport.

To support this goal, rail operators would also like to see cellular, Wi-Fi and operational wireless connectivity improved on their track but also in tunnels and stations to improve their operations but also for the benefit of passengers. This would give passenger the benefit of being able to find each other at the station, ordering taxis before arriving at the destination and keeping passengers updated on private (e.g. social media), work (e.g. email) and travel related matters. Deployment of distributed antenna systems (DAS) at major stations has been as one of several options that they are analysing in their costbenefit analysis. But at this stage it isn't clear who should pay for these connectivity improvements.

Current limitations on train tracks are stated to be the train to train distances which are about 4.5 km based on current block sections for this train operator. Based on telemetry and advanced signalling technologies, safety would improve but it would also increase the number of trains supported on the same track, therefore improving capacity. Improved scheduling and punctuality are also benefits of the above technology introduction. Travel speed adaption by knowledge of other trains and upcoming signals is also of advantage, leading to a smoother journey (with less acceleration and braking) and results in substantial energy savings.

# Case Study 2 – DfT franchises enable Mobile Broadband for all UK trains

According to DfT; the in-train Wi-Fi programme will cover data (broadband) and voice (over Wi-Fi). DfT is assuming passengers have (or will have) devices that support Wi-Fi calling. MNO in-carriage coverage, as opposed to Wi-Fi coverage, is not a requirement as it does not give universal internet access to all subscribers and passengers, given that not all operators will have continuous coverage everywhere.

To give passengers connectivity from the point the enter the station, railway stations have to covered too. Wi-Fi coverage in stations is usually the responsibility of the TOC. However, if multiple TOCs are using the same station (e.g. Waterloo, Victoria, Clapham),



# then it becomes the responsibility of Network Rail. By now, 90% of all UK stations are already covered.



## Figure 12: DfT mobile broadband for train facts and target figures [37]

In terms of on-board Wi-Fi, it will take 10-12 years until full UK-wide implementation because it will be that long before all routes have been re-competed (those signed in the past 18 months did not have Wi-Fi included as an obligation). A franchise duration is in average 10 years and the first franchise with a Wi-Fi requirement is expected be signed in November 2016. The franchise obligation is to start deploying Wi-Fi within three years and has 5 years for full delivery. Promising a shorter time to Wi-Fi deployment increases the chance of an applicant winning the franchise.

The KPI is 100 Mbps backhaul per train (on busy routes with 560 passengers in average peak hour) for 95% of the route (for 85% of passenger's journeys). Wi-Fi has to support basic internet services such as social media, emails, Wi-Fi calling and web-browsing but not HD streaming. The suggested approaches are licensed (MNO) or unlicensed (Wi-Fi) technologies and networks for backhaul to on-board Wi-Fi access points, or a mix thereof [**37**].

### Relevant but independent UK rail Wi-Fi trial:

Cisco and partners are currently conducting a Wi-Fi and rail related project on a railway line in Scotland but unfortunately there is not much public data available. The project called SWIFT (Superfast Wi-Fi In-carriage for Future Travel) aims to deliver high quality and high-speed WiFi broadband to rail carriages. It is an 18-month project that will demonstrate high-speed in-carriage Wi-Fi with handover durations of 2ms, that improves the passenger experience, enhances commercial opportunities and improves train management.

Further, Wi-Fi is moving beyond a pure Internet access model to value-added services based on location and presence-awareness with Big Data analytics. These types of services allow customer engagement and are seen increasingly in the retail sector, but have not as yet reached the rail industry [43].



# **3.3** Healthcare - remote and preventative care use cases

Healthcare is divided into three substantive use cases; assisted living, remote healthcare and preventative health.

**Assisted living** encompasses benefits such as the opportunity to reduce the number of hospital admissions caused by the rise in the UKs aging population. The relatively modest data rates that are supported by 4G today are adequate. The infrastructure requirements point to a more M2M like capability to be made available to the general population.

**Remote Healthcare** encompasses benefits such as reducing the need for in surgery patient appointments and more efficient delivery of care for conditions like Type2 diabetes. A MBB Infrastructure requirement is established; however this is not a demanding use case.

**Preventative Health** encompasses benefits such as obesity reduction through placing a degree of autonomy and well-being knowledge in the hands of the population. A MBB Infrastructure requirement is established; however this is not a demanding use case.

The Healthcare use cases clearly demonstrate societal benefits, but we find no appetite in the health sector to shoulder the cost of deployment of infrastructure. However, we do see evidence of early adopter professionals in the sector who are willing and able to engage in application based clinical trials. Thus a credible case for early adoption of future communications services on national infrastructure can be made; however this sector is highly cost sensitive.

## 3.3.1 Overview

### Scale

Digital healthcare services can range from future envisaged services like remote and robotic surgery to more current assisted living services (monitoring vulnerable citizens remotely) and improved access to patient records. A report for the Office of Life Sciences in September 2015 valued the UK Digital Health market in 2014 at £2 billion and expecting to grow to £2.9 billion by 2018 (at a CAGR of 11%) [44]. Of the different segments making up the digital health market the largest by far is digital health systems which covers patient held and provider held digital records.





**Figure 13: UK digital health markets 2014** (Source: Deloitte for the Office of Life Sciences [44])

While telecare (provision of care and support at a distance) and telehealth (remote exchange of clinical data between a patient and their clinician) services clearly rely on good fixed line or wireless connections to homes, all digital health segments above stand to be impacted by better mobile communications in some way [44]. For example, cloud based services are set to be an integral part of future IT and 5G mobile communications networks. Availability and accessibility of such cloud based services could make digital health systems with medical records more readily available and improve the efficiency with which healthcare professionals could access records and treat patients appropriately. Similarly, health analytics could benefit from medical records and collected sensor information for patients being more readily accessible and combined via cloud services.

However, it is worth noting that before mobile networks improve accessibility to and usage of medical records these records need to be made paperless in the first place. Therefore, in the near to mid-term the most immediate requirement for Digital Health Systems in the UK is to achieve better integration of IT systems generally as outlined in the NHS Five Year Forward View [45].

The Deloitte study [44] concluded that "The UK is well positioned in many elements of digital health and has the potential to grow into a global leader in this segment." Therefore, the scale of opportunity from leadership in digital healthcare services is likely to extend beyond the UK to a portion of a global market for digital health which was worth £23 billion in 2014 and expected to double by 2018 [44].

### Challenges

The healthcare related use cases that stand to be impacted by mobile networks the most and hence that we have considered, as described in 6.1, fall into the following three categories of:

- Assisted Living
- Remote Healthcare (monitoring & consultation)
- Preventative Health

One of the key characteristics of the above use cases of health services is that they are largely consumed indoors rather than outdoors. For example, assisted living involves alarms or sensors in the homes of the elderly or those needing assistance being connected to central monitoring services. The sensors or alarms are connected to a local home network (via short range wireless) which is then connected to a fixed telephone line or mobile broadband connection to provide the onward connection from the home to the monitoring service provider and first responders. Similarly, remote healthcare involves virtual consultations with GPs or hospital consultants and monitoring of patients from a distance. In this case patients will likely be either at home or already at other medical facilities. So again the connection from the users' device will go via an indoor wireless network to a fixed or mobile broadband connection to the premise. Hence the broadband connection to the premise becomes the point where mobile networks may be needed in the unlikely case that fixed line broadband is not available.

Overall, the key requirement of mobile networks to support health services therefore becomes one of providing mobile broadband to a greater proportion of the UK population.



This in particular will apply to rural areas where access to medical centres may be difficult (particularly for those with limited mobility as frequently targeted by telecare services). Therefore, high coverage levels in rural and other areas without good fixed broadband services, and the subsequent increased costs, scarcity of low frequency spectrum and difficulty accessing sites associated with this, will be the key challenges for ensuring the UK's mobile communications networks can support digital health services.

An additional challenge arises if a highly reliable connection is needed which may be the case for patient monitoring alarms in assisted living systems. These will increase the cost of the mobile network by requiring additional sites and equipment to add redundancy and resilience to the network.

Clearly another key barrier if digital medical records are to be stored centrally and more accessible to patients and medical professionals is ensuring data security and privacy. This concern extends to remote monitoring and telehealth services also where patient information is being transferred or the is some form of remote control of medical devices [46]. The security of health networks and particularly IoT devices is an area starting to get more attention particularly in the US and, though low currently, cybersecurity spending on connected medical devices is set to triple by 2021 [47]. This challenge is not unique to wireless networks though and end to end authentication and security for accesses such databases will be needed regardless of whether access is via fixed or wireless connections.

Though fewer there are some use cases of digital healthcare services being consumed in an outdoor environment where mobile connectivity might be more crucial. Examples include "Connected Ambulances" with voice, broadband and video links back to medical centres with potentially the capability to perform "remote surgery" in some futuristic cases. Indeed, feasibility studies of using portable medical devices by paramedics at the scene of emergencies and then uploading test results to hospitals (so they can be assessed ahead of the patient arriving at the hospital and time saved) are already being supported by NHS [48]. However, we consider this to be part of the ESN network already being procured today for emergency services generally and not just for ambulance crews. Also in the case of "remote surgery" these procedures are likely to be performed between medical facilities and hence over an existing fixed line connection rather than wireless.

Some preventative health devices such as smart watches and Fitbits may be used outdoors where the end user is exercising but in most cases are tethered to a mobile phone for uploading measurements and downloading analysis and hence will be covered by overall better mobile broadband coverage for all initiatives which stand to impact so many verticals. Other wearable telehealth devices such as remote monitoring devices for chronic health disorders such as diabetes will be used indoors and so make use of indoor wireless networks as highlighted earlier.

## 3.3.2 Current healthcare use cases

The UK has been an early adopter of telecare and as such telecare solutions have already been used to provide "care at a distance" in the UK for some time. Many areas have community alarm services where sensors or alarms in the homes of the elderly or others requiring assistance are connected via the home telephone line to the community alarm services and can be responded to in the event of a fall, fire, intruder etc. A 2012 report from The Strategic Society Centre supported by Age UK found that in 2008 just over 1



million (1,095,000) people aged over 50 in England were using personal alarms or had an alerting device fitted to their home [49].

As reported by Deloitte [44], the UK is already at the forefront of using primary care electronic health records via systems provided from organisations such as EMIS. Remote video GP consultations are also already available in the UK via private healthcare providers where patients can book appointments online and receive a consultation remotely via video with a GP within 24 to 48 hours [50]. This type of service is also available from some healthcare providers in the US where the private healthcare market is much larger than in the UK [51]. Finally, the use of mobile apps for monitoring patients remotely and providing remote healthcare is expanding. This ranges from the use of smartwatches and Fitbits by consumers to monitor, log and analyse their own health and wellbeing to emerging products that can remotely monitor blood pressure, oxygen levels for asthmatics, glucose levels for diabetics etc.

# 3.3.3 Future healthcare use cases

As reported by Deloitte [44], the UK is already at the forefront of telecare and digital health systems. This is reinforced by Figure 14 which shows the UK accounting for a large percentage of the telecare market. However, digital health systems and telecare are becoming more mature markets and hence also have the lowest CAGRs of the other digital health services segments shown in Figure 14.



**Figure 14: Size and growth rate by health sub-sector** (Source: Deloitte for the Office of Life Sciences [44])

Indeed, telehealth, wearables, health analysis and applications are the areas where growth is forecast to be most rapid. We focus in this study on use cases that fit with these future high growth areas and also consider the next steps from telecare under:

- Assisted living services (future extension of telecare)
- Remote healthcare services (telehealth)



 Preventative health services (including monitoring via wearables and health analytics of collected data)

### Assisted living services

This use case is an extension of health monitoring, but managed and monitored remotely by a healthcare provider, social care provider or family member. The main scenarios are to enable someone to stay in their home, rather than a hospital or care home, for longer when living with dementia or disability; and to enable patients to return home from hospital at an earlier stage after major treatment.

Sensors around the home can provide insights on a vulnerable person's movements and habits to raise alerts to any unusual behaviour (e.g. failure to get out of bed at the usual time). Automated connected devices such as fridges which order groceries when they run low can help housebound people or those with dementia. Wearables or body sensors can allow for health monitoring outside the hospital for those who would not use a smartphone app. These applications are all very low in data rate, in the range of 1 - 10 kbps.

A UK example of an assisted living trial is at the University of West of England (UWE) – this includes CASA, an Innovate-backed project focused on elderly assisted living, and Anchor Robotics Personalised Assisted Living Studio, an in-house facility to develop, test and implement assistive robots and sensor systems in a realistic environment [151,52].

There are currently two NHS Internet of Things test bed projects underway; a diabetes digital coach and the technology integrated health management system (TIHM) for dementia patients. The TIHM system is further described under our case studies. The diabetes digital coach is being led by West of England Academic Health Science Network in partnership with Diabetes UK and a number of technology companies [53]. The programme aims to bring together mobile health management sensors and tools to allow diabetes patients to self-manage their condition better and improve more timely intervention from health professionals as needed.

### **Remote healthcare services**

This use case includes, for example, patients consulting with their GPs remotely, via a secure internet or mobile link, and subsequently being monitored on an ongoing basis by the GP. A video consultation can be anything from 1.2 Mbps to 12 Mbps (standard definition to future 4K) and sensors would typically require not more than 10 kbps. This can be achieved through smartphone apps, wearables or body-based sensors depending on the symptoms to be monitored. It would particularly apply to remotely located areas or patients with limited mobility. In future, it is envisaged that the consultation experience could be made more realistic with virtual reality, and that the diagnostics could make use of AI engines to improve accuracy.

A highly futuristic use case of remote healthcare is remote surgery via Tactile Internet which could change the way people interact with digital and virtual worlds. There is significant UK input from Kings College London's 5G Tactile Internet Lab. Mischa Dohler, the professor leading the effort, sums up the use case [54]: "Sufficiently responsive, reliable network connectivity and advanced edge-haptics will enable us to deliver physical, tactile experiences remotely. Imagine our best surgeons performing operations remotely; our best engineers maintaining cars on the other side of the planet; somebody teaching me how to



paint or me teaching somebody how to play the piano ... This will be an enabler for skillset delivery and therefore pave way for an unprecedented *Internet of Skills*" [149,151,153].

There is considerable uncertainty over what tactile Internet applications will emerge and whether they will be taken up in the short to medium terms, especially given questions over consumer acceptance. Also we note that in the UK the population has good access to medical facilities and so there is not so much of a need for these remote surgery situations as in other countries.

### **Preventative health services**

This use case describes personal health monitoring but is also allowing preventative medicine based on big data and artificial intelligence (AI). It is based on health monitoring via a connected mobile device, managed by the consumer rather than a healthcare provider. These applications are often smartphone based but in future will encompass body area networks and wearables to gain more detailed data on vital signs and symptoms. Monitoring may include heart rate, blood pressure and sugar levels (as mentioned earlier in emerging products) and may be used for ongoing health management or for fitness [149,151]. Typical sensors or fitness devices (e.g. Fitbit) would only require a low data rate of 1 - 10 kbps for basic information. If connected to a smartphone, this data would then be forwarded over the mobile broadband network or Wi-Fi when connectivity is available.

The Department of Health has identified two apps which integrate patient and clinical information to support home-based healthcare – these are Patients Know Best and HealthFabric [44].

The NHS Five Year Forward view also highlights investment in preventative health services as being a key area for the UK going forwards [55].

### Other potential uses of mobile networks that could benefit the NHS

From our discussions with health sector stakeholders we have been made aware of the following potential uses of mobile networks from a site facilities and remote working perspective which could greatly benefit the NHS:

- Business continuity Communications between staff and IT systems are classed as critical to the delivery of clinical care on hospital sites and as such need to have back-up options when primary connections or equipment go offline (due to developing faults for example). This reliance on IT systems in particular is only set to increase with growing interest in areas such as the GS1 Scan for Safety programme for logging patient journeys through hospitals [56]. Mobile networks can act as a good fall-back option for maintaining communications in such situations. As such lack of mobile coverage was a big enough issue that it was even an item on the clinical risk register of one hospital we spoke to.
- Improved efficiencies in site maintenance With a vast number of sites and buildings to maintain across the NHS more efficient monitoring of facilities at these sites and delivery of maintenance could be very beneficial to the NHS. Sensors and monitoring devices, similar to the smart metering devices discussed under the utilities use case, distributed around NHS sites and connected via wide area mobile networks could help monitor the status of assets around sites more efficiently. Also availability of indoor and outdoor mobile coverage on sites helps



to keep maintenance crews connected as they move around what can be extremely large sites.

 Remote working – The NHS is in the top 5 of the world's largest employers with more than 1.5 million employees [57]. Improved mobile coverage and capacity across the UK generally to facilitate remote working would help productivity of this vast workforce and provide the ability to collaborate with colleagues even when off site.

As the above uses of mobile networks are not directly involved in the delivery of healthcare services we do not consider them further under this use case. However, we note that the above points show how the NHS could benefit from addressing some of the issues discussed under other use cases in this report such as enabling remote working via cloud services for businesses, improved supply chain efficiencies under logistics and smarter utilities.

## 3.3.4 Network Service Requirements

As highlighted in the overview in 0, preventative health services, assisted living and remote healthcare services are all most likely to be consumed in **indoor environments**. As such the home sensors or patient monitoring devices in these applications are likely connect via a local area networks to either a fixed or wireless broadband access point at the home. Therefore, the provision of rural broadband and **ensuring all of the population have access to broadband services** becomes the key requirement to support future remote health services. In areas where it is not practical to deploy fibre to every home and mobile broadband is relied upon, ensuring good availability of fibre and power to key rural sites would greatly improve the business case for mobile network operators to extend mobile coverage into these coverage challenged areas.

As we have seen many monitoring products, as in smartwatches, smart insulin pens, smart inhalers, that are either currently available or planned for the future are frequently tethered to mobile phone for upload back to central servers from where the information is collated and analysed. However, this requirement is unlikely to put significant strain on the UK's mobile networks because:

- The data throughputs and volume of data from each monitoring device is small
- Much traffic being uploaded from mobile health monitoring applications on mobile phones is likely to be offloaded to indoor networks and aggregated before being relayed back to central servers via the broadband connection to the premise which in most cases will be fixed.

Machine type communications and supporting an Internet of Things or massive densities of patient sensors or alarms are seen by many as a key requirement for future (5G or other) mobile networks. This may be a concern if such devices are deployed outside the home, medical facilities and other indoor environments but otherwise the vast majority of this traffic stands to be carried on indoor networks with the requirement on mobile networks being to provide wireless broadband in the small proportion of premises where fixed broadband is not available.

However, if mobile networks are providing this "last mile" broadband connectivity to particularly rural premises and the only means for relaying alarms or alerts from such premises then this link does become critical and incurs extremely high reliability



requirements and hence additional network costs. In fact, the preference for reliability over high data rates in health services is demonstrated by the continued interest in pager technology in this sector which has become relatively outdated otherwise [58]. However, in the case of extreme rural areas where very few patients live it may be more cost effective to relocate these patients to nearby villages where fixed line broadband is already available so that they can continue to live independently in an assisted living or telehealth scenario.

Finally, remote surgery via tactile internet is frequently highlighted as an extreme use case for 5G mobile networks that puts such networks under significant strain to provide:

- Extremely low latency so that surgeons and doctors get immediate feedback or "feeling" from their actions. The end to end (one way) latency should not be greater than 2 ms.
- Reliability of 99.999 % for these critical applications.
- Availability nationally needs to be extremely high if such remote surgeries are to be applied to emergency services situations also. For example, if remote surgery needs to be applied on site to car crash victims on all minor roads or those injured whilst out hill walking in mountainous areas the coverage requirements of the mobile network would be extreme and likely not cost effective.

As highlighted earlier we re-emphasise that remote surgery is a highly futuristic use case and seen as one more applicable to countries where medical facilities are sparse. In the UK it's use is much more likely to be limited to sharing expertise between medical facilities in which case the patient will already be located in their own local medical centre providing a clinical environment and likely a fixed broadband connection. Therefore, these stringent requirements of remote surgery on networks are more applicable to reviews of fixed mobile broadband connectivity to medical facilities than UK wide mobile networks.

# 3.3.5 Potential benefits to the UK

Health services in the UK are under pressure from an increasing and ageing populations, as well as rising user expectations. There has also been a rise in chronic conditions. For example, Diabetics UK estimated in January 2016 that there were 4.05 million people in the UK with diabetes (an increase of 65% over the past decade) and potentially a further 549,000 million people with undiagnosed Type 2 diabetes [59]. The UK also has the highest obesity level of European countries with nearly 1 in 4 adults classed as obese in 2008 [60]. More recent results for 2014 from the Health Survey of England show obesity levels still around 25% of adults aged 16+ and that in 2014 61.7% of adults were classed as overweight or obese [61]. This all puts strain on the NHS to respond to related conditions such as diabetes and heart attacks. The NHS spends around £10 billion a year caring for people affected by Type 2 diabetes alone or nearly 10% of its 2014 commissioning budget of £98.7 billion [62]. Additionally, hospital admissions continue to rise and in particular mental illness is becoming an increasing issue with more than ¼ of hospital inpatients in 2014-2015 suffering from dementia.

All of this backdrop is creating high interest and growth in digital healthcare services which can replace or complement physical resources and provide better efficiencies and cost savings.



Of the health related use cases we consider in this study we consider they could have the following impact on the UK:

- Remote healthcare services (telehealth) Applications in this area such as remote consultations with GPs could enable a significant area of health service activity to be delivered more effectively and at lower cost. It might also bring additional benefits in reducing the number of missed appointments (which costs the NHS over £1bn [63]) and provide more convenience for patients. Hence there is a strong case to invest in mobile infrastructure to support this use case where needed on economic and social grounds
- Preventative health services (including monitoring via wearables and health analytics of collected data) – Given the increase in lifestyle related health issues in the UK, as mentioned earlier, this use case targets an important goal in UK health policy by enabling patients to take more control of their lifestyle and fitness regimes. This also builds on observed trends in consumer interest and acceptance of devices that help individuals manage their health and fitness. The addressable market is large and hence the associated benefits in terms of better health outcomes and reducing the burden on the NHS could be significant. There is an added potential for improvements in public health through enabling access to "big data" analysis of nationwide health trends also
- Assisted living services (future extension of telecare) We rate this use case highly because care of the elderly is an ever more important priority for government and citizens given the UK's ageing population. There is the potential for considerable cost savings, for both local government and individuals, the longer people can stay in their homes as opposed to in hospital or residential care and there is a large benefit to individuals themselves in terms of increasing their independence and quality of life

The importance of leveraging technology to achieve better efficiencies is well recognised by the NHS already with being able to "exploit the information revolution" being one of the key actions from the NHS Five Year Forward View aimed at addressing the £30bn funding gap anticipated for the NHS by 2020 [55]. However, as highlighted by the National Information Board [64]: "While developments in clinical technology have had a revolutionary impact on healthcare over the last 30 years, the same cannot be said for the use of technology and data to improve heath and the way health and social care services are delivered. The consumer experience of care services remains much as it was before the mobile phone and the internet became commonplace."

The scope for improvement by leveraging technology to improve delivery of patient services therefore is potentially large but this applies to making the most of not just mobile connectivity to consumers but also fixed broadband access which has become commonplace too. In this way better mobile connectivity is not essential to achieving these improved efficiencies but certainly would be beneficial. Overall healthcare applications in the UK alone may not immediately be a key driver for the improvement of mobile networks but certainly would stand to benefit from the evolution of mobile networks over time.

# 3.3.6 International perspective

The UK has been an early adopter of telecare and digital services [44]. Our single healthcare provider system based around the NHS also provides the opportunity to more readily



provide the critical mass to attract investment and innovation in digital health services than might be the case in other countries.

The issue of ageing population is not unique to the UK with Germany, Italy, Greece and Japan all being classed as "Super-aged" countries (nations with 20% or more of the population being over 65). It is estimated that by 2030 34 nations will be super-aged [65].

Singapore is an example of a nation that has started a "Telehealth" initiative to take action in addressing this ageing population issue. They have already held trials of smart home solutions including elderly monitoring systems and utilities management systems.

The elderly monitoring systems have been rolled out free to trial participants currently and includes sensors that track movement in the home and alert a family member or care giver via text message alert if movement patterns have changed indicated a problem [66]. The utilities management systems monitor energy and water usage in the home through a mobile application and sends alerts when usage is high. In one example home from the trial there was a 10 to 15% cost saving in utility bills from using the utilities management systems [67]. There are also on-going trials of using wearable devices and sensors embedded in public housing smart homes to help manage chronic diseases under the same initiative.

This is complemented by development programmes in Philips Singapore who are developing systems where patients receive personalised (computer) tablets related to their condition which they can use in association with self-monitoring devices in the home to allow doctors to monitor vital signs such as heart rate, weight and blood pressure. remotely once the patient returns home. It is hoped that this will help to free up demand for hospital beds [44].

Globally the availability of mHealth apps has continued to grow with a recent study estimating that there are currently 259,000 mHealth apps available which is an increase of 57% from 2015 [68]. The number of mHealth app publishers has also grown by 28% since the start of 2015 and is currently estimated at 58,000. However, the same study shows a declining trend in the growth rate of downloads of mHealth apps with there only being a +7% increase in downloads in 2016 compared with +35% in 2016. This is likely due to the fact that the penetration of smartphone and other high end mobile devices capable of running mHealth apps is now relatively high and so the subscriber base making these downloads is growing less than in previous years.

## 3.3.7 Use case summary

Use cases	Direct (Industry/User)	Indirect Benefits (e.g.	Network Infrastructure
	Benefits	industry infrastructure)	Requirements
Assisted Living	<ul> <li>Dramatic reduction of hospital admissions</li> <li>25% of hospital in patients are dementia sufferers and could potentially be cared for remotely</li> <li>Estimated cost of £26 billion a year to the UK (NHS and private individuals) from</li> </ul>	<ul> <li>In home wireless network with home gateway compatible with all monitoring devices and providing end to end security of data transferred</li> <li>Peace of mind for carer and family that patient is monitored and can stay longer at home</li> </ul>	<ul> <li>MTC application, typically using fixed broadband, rarely MBB</li> <li>Data rates of 10 – 100 kbps per patient (sensors 1 – 10 kbps) and low intervals</li> <li>Alarm application may require high availability</li> </ul>



	dementia which could be reduced		<ul> <li>Typically all indoors, little external network impact</li> </ul>
Remote Healthcare	<ul> <li>Fewer missed appointments which costs the NHS over £1bn per year</li> <li>More efficient care for chronic conditions such as Type 2 diabetes (NHS spends £10 billion a year, 10% of budget)</li> </ul>	<ul> <li>Ensures end to end security for exchange of patient information and interconnectivity with existing medical records systems</li> <li>More convenient and efficient for patient</li> </ul>	<ul> <li>MBB application if needed outdoors (assumed to be an indoor fixed broadband case)</li> <li>GP video conferencing, SD at 1.2 Mbps, HD at 2-3 Mbps and 4K @ 12 Mbps (by 2025)</li> </ul>
Preventative Health	<ul> <li>High potentially of reduced health needs if consumers take better control of own health</li> <li>Reduced strain on NHS from UK having highest obesity rate in Western Europe</li> <li>Less health costs and reduced insurance premium</li> </ul>	• Ensures end to end security for exchange of patient information and interconnectivity with existing medical records systems	<ul> <li>MBB application if outdoors (often using indoor Wi-Fi)</li> <li>Low availability needs, buffering, best effort</li> <li>Typically smartphone tethered wearables</li> <li>Low data rate traffic, 1 – 100 kbps per person (best effort traffic)</li> </ul>



### 3.3.8 Case studies

### Case study 1 – Gecko health innovations smart inhaler [69,70]

US based Gecko Health Innovations, acquired by Teva pharmaceuticals in September 2015, has developed their CareTRx<sup>™</sup> platform for tracking and managing chronic respiratory diseases. A sensor device connects to the patient's inhaler which tracks use and gives patients reminders of doses. Sensor information is collated by the CareTRx<sup>™</sup> Journal App which tracks and records medications, symptoms, triggers, peak flow measurements and flare ups. The patient can then view statistics and get feedback on their use of their inhaler and share with medical teams.



Figure 15: CareTRx<sup>™</sup> inhaler system (Source: Gecko Health Innovations acquired by Teva Pharmaceuticals)

# Case study 2 – TIHM (Technology Integrated Health Management) for dementia study and trials in Surrey [71,72]

TIHM (Technology Integrated Health Management) for dementia is a new research study funded by NHS England and Innovate UK with the key aims of improving the quality of life for dementia patients and their carers. The study also aims to reduce hospital admissions and in-patient volumes related to dementia by providing remote care and monitoring of patients in their own homes. This study tackles a big issue for UK health currently with more than 25% of hospital in-patients in 2014-2015 suffering from dementia [59] and an estimated cost of dementia to the UK of £26 billion per year (two thirds of which is paid by people with dementia and their families either through unpaid care or paid for private social care [73]). This study is also linked to the NHS Five Year Forward View which sets out how health services need to change in order to engage with patients, carers and citizens to promote wellbeing and prevent ill-health.

The programme, launched in January 2016, has currently developed an Internet of Things testbed at Surrey University which aims to provide an integrated system in the homes of dementia patients for the range of health monitoring products to connect to. This



carers and family as appropriate. Data Analytics Engine Data-driven and patient centered Healthcare Docobo Privac Applications Intelesant eLucid Trust 8 wsense.ly Healthcare Professionals Surrey and Borders Partnership NHS Security Surrey and Borders Partnership NHS Family and care givers IoT Test Bed Cloud Vision36 argiva

Intelesant

Vis arqiva

wsense.ly

Docobo

gateway is then connected beyond the home to a central "TIHM cloud" server which routes traffic to NHS IT systems, monitoring and alert systems, healthcare professionals,

### Figure 16: TIHM test bed architecture (Source: University of Surrey)

Possible links to

Other Test Beds

The programme includes contributions from 9 UK based teams in telehealthcare providing ranges of software and hardware solutions, from monitors and sensors to virtual assistant avatars to wearable devices, demonstrating the UK leadership and innovation in products in this area.

SURREY

Surrey and Borders Partnership NHS

Hyper



External NHS, GP IT systems

Surrey and Borders Partnership NHS

Figure 17: Example devices from 9 companies participating in TIHM (Source: TIHM website [71])

The team are aiming to roll out the systems to 10 test homes by the end of 2016 and then to expand the trial to include 700 people with dementia and 700 carers (350 control



and 350 intervention (i.e. cases where telehealth devices are used)) in January 2017 which will make it the largest trial of its kind.

The system in the patients' homes consists of environmental sensors (such as monitoring doors opening, light levels, temperature, movement around the home) and physiological sensors (such as monitoring hydration levels, weight, blood pressure, temperature, and sweat levels in patients). These sensors then all connect back to a gateway in the home. With 9 different companies involved in the project with devices using a variety of wireless platforms (such as LPWA, GPRS and Wi-Fi) and traditionally their own home gateways, one of the key challenges of this project is to ensure interoperability between home monitoring devices and to combine these under one home gateway.

The connection from the home gateway to the central "TIHM cloud" is via the home broadband connection (either fixed or wireless) or SigFox and cellular communications. End to end security and authentication will be handled by the home gateways and so would not be an extra requirement on mobile networks if they were providing the home broadband connection in areas with poor fixed line connectivity. However, modest 4G data rates will likely be required to relay patient information in a timely manner. For example, an ECG can take 15 minutes to download over a GPRS or 3G connection currently. If a mobile network was providing broadband connectivity in scenarios such as the trial system here, reliability of the network to ensure that alarm signals get delivered and prioritisation of medical traffic amongst other mobile network traffic would need to be ensured.

Surrey and Borders Partnership NHS Foundation Trust was awarded £5 million in funding from NHS England and Innovate UK to lead TIHM for dementia. They are working with the Alzheimer's Society, Royal Holloway University of London and Kent Surrey Sussex Academic Health Science Network as well as the University of Surrey and nine technology innovators on the study.

### Case study 3 – Blackburn with Darwen council telecare programme [74,75]

Blackburn with Darwen council first introduced telecare in 2008 but in 2010 examined telecare delivery models in other areas and set the objective of increasing telecare users from 60 to 1800. This programme eventually became branded the "Safe and Well" programme and has included a contract with Tunstall Healthcare for telecare equipment and services as well as a number of pilot schemes of new assisted living technologies such as:

- Use of the "Just Checking" tool which via a series of sensors monitors movement in a home and logs activity which carers can access on line. In one case this delivered £36,000 per annum savings for the council in 'wake and watch' night sitting services where council carers would normally have to stay with care recipients throughout the night.
- Use of GPS systems to help reassure families and carers of those suffering with dementia.
- Development of a bespoke set of 2 blocks of apartments for adults with physical and sensory impairments and/or learning disabilities. These include



flood, fire, smoke and bed occupancy telecare sensors and aids such as lighting, heating, curtain control and automatic door opening.

In terms of benefits the assisted living technology programme was estimated to have delivered a net cost reduction of £2.2million to the council between 2008 and 2012. Preventative / early intervention approaches in conjunction with assisted living technology showed a reduction in 2013/14 of approximately £1.2 million direct budget costs.

The council's approach has been recognised in the Local Government Chronicle awards and was the 2015 winner of the "Service delivery model" category.

# Case study 4 – Working with mobile operators to achieve mobile coverage at The Royal Marsden's Sutton site

The Royal Marsden NHS Foundation Trust has two hospital sites. These are at Chelsea in London and Sutton in Surrey. They also have a Medical Daycare Unit at Kingston Hospital and provide community services in the London Borough of Sutton.

The Royal Marsden's Sutton hospital site is located in an area that has always suffered from poor mobile network coverage from all mobile network operators.

Over time more and more staff carried smartphones and other mobile devices and it became clear that having mobile network coverage at the site could really help to make communications between staff more efficient. The lack of mobile network coverage was also an issue for patients and relatives, who were often unable to communicate via mobile telephone. Additionally, it was felt that mobile network coverage at the hospital site could provide a back-up communications network in the event of the hospital's own internal network equipment developing a fault and going offline for periods. Hospital communications networks are classed as part of the critical infrastructure in providing patient care at a hospital site and so from a business continuity perspective poor mobile network coverage was actually added to the clinic risk register at the site.

The hospital engaged with mobile network operators in 2014 to improve mobile coverage. As a result, during October and November 2016 Vodafone and O2 will be installing equipment on the hospital rooftop space in Sutton. It is anticipated that this will significantly improve mobile coverage for staff, patients, relatives and visitors and the network operators will benefit from rooftop space for their equipment and services they provide to their stakeholders. The Trust's Estates and Facilities Departments have been pro-active in progressing this initiative with the main drivers being business continuity and giving staff more methods of contacting and collaborating with colleagues both across the site and external to it. However, they also highlighted that, from a critical hospital site operation and maintenance perspective, there are knock-on benefits from improved mobile coverage such as the ability to monitor site assets (remotely and in real time) and better communications between maintenance crews across the site and external contractors.

They also highlighted the importance of good mobile coverage being available in terms of patient treatment. In particular, good mobile coverage enables patients to benefit from:



- Telecare and telehealth services, even in areas where fixed broadband connectivity is limited.
  - That the vast and dedicated workforce in the NHS can avail of remote working and have real time access to colleagues off site to help collaborate on the diagnosis and care of patients for example.



## 3.4 Utilities – smart utility use cases

The **Smart Utility** is divided into two substantive use cases **Smart Metering** and **Smart Grid**. Broadly the benefits are reduction in consumption, lower costs for consumers. Through aligning generation with consumption in near real time a reduction in new generation capacity. Potential for carbon emissions reductions are also apparent.

**Smart Metering** encompasses more accurate bills, lower meter reading costs and reduced consumption due to consumer awareness of their energy consumption, elements of control over demand to even out demand peaks. The infrastructure requirement is MTC oriented. The existing UK smart meter programmes are likely to show provide a templete for the evolution regarding business and government ecosystems for the foreseeable future.

Smart Grid encompasses automated control over generation, main grid and distribution network functions applying 'system of systems' approaches for demand peak management and fault resolution. Exercising any control over what is classed as critical national infrastructure needs to be secure and highly reliable and implied MCC requirements on Infrastructure. Smart grid requirements and technologies are at an early stage of development and standardisation, thus a definitive market demand timing is to be established.

## 3.4.1 Overview

### Scale

The scale of the UK's utility infrastructure is enormous with control and sensing capabilities spread over millions of assets nationwide. The electricity transmission system runs over 4,470 miles of overhead lines, 870 miles of underground cable and 329 substations at 400kV/275kV. The electricity distribution systems operating from 132kV down to 400V comprise approximately 288,937 miles of underground cables with 196,353 miles of overhead lines and some 700,000 transformers and sub-stations. Delivery of the 240v to consumers and business brings the total of distribution assets up to over 900,000 distributed right across the UK. The gas transmission system is similarly extensive, with 4,760 miles of high pressure pipe and 23 compressor stations and associated gas distribution networks. Annual electricity demand in 2013 was 347 terawatt-hours for electricity and 835TWh for gas [76]. Meanwhile, 12 water and waste services organisations (are responsible for treating and supplying 17 billion litres of water a day in the UK, and collecting and treating 16 billion litres of waste water and sewage.

Utilities are classed as critical national infrastructure

### Challenges

With such distributed infrastructure supplying to some 25m homes and 3m businesses all of which need metering and billing the industry is facing several challenges:

### Supply versus demand

Particularly for the electricity industry as expected demand shifts because of the anticipated growth in electric cars and electricity becoming an efficient form of heating



makes matching supply to demand very challenging - both in real time and over time horizons matched to building new generation facilities. Adding to the complexity is the use of local micro power generation, mainly from solar panels making consumers both generators and users.

The water industry faces similar supply and distribution challenges as the demand for water outstrips the supply, particularly in the summer months.

### Environmental

EC legislation requires a reduction in greenhouse gas emissions of 80% (compared to the 1990 level) by 2050 – with a milestone of 40% reduction by 2030. The power sector has been identified as having the biggest potential for cutting emissions if electricity replaces fossil fuels in transport and heating, renewable and low emission sources of generation come on stream and countries invest in smart grid technologies.



### Figure 18: Possible 80% cut in greenhouse gas emissions in the EU (100%=1990)

Further EC legislation has therefore required member states to analyse the cost benefits accruing to smart meter deployment and where this is positive to reach a deployment level of 80% of homes and businesses by 2020.

The electricity industry has responded in several ways:

- Encouraging consumers and business to understand their use patterns and look for ways of reducing demand. The Smart Meter initiative is seen as a first step in making consumers much more aware of their demand and what they are paying for the electricity they are using. The expectation is that if this information is easily available then consumers will try to save energy to reduce their bills
- Improving control capabilities at the distribution network layer through Smart Grid initiatives
- Supporting consumer generation and local storage (via battery packs) to align demand placed on the network with supply capabilities


The smart meter programme is one of the largest countrywide infrastructure project for many years with installations peaking at some 14m in 2018.



### Figure 19: Current projection of smart and advanced meter installation per year

Figure 19 gives the current projection by the larger energy suppliers of the number of smart and advanced meters to be installed per year in domestic and non-domestic properties between 2015 and 2020 (as at the end of June 2015) [77].

# 3.4.2 Current utility use cases

# Smart meters current projections of smart & advanced meters installation per year

The industry is in the early stages of rolling out smart electricity and gas meters to all homes and businesses in Great Britain and Northern Ireland – 33m electricity meters and 27m gas meters are in scope. Water meters are not part of this government led programme.





#### Figure 20: Overall GB smart metering architecture [78]

The overall architecture is shown in Fig 12 involves a Data Communications Company (DCC) contracting with two wireless communications providers to connect all homes and businesses into the DCC network so that homes and businesses electricity and gas usage data can be gathered. DCC in turn provides user consumption data in an appropriate format to the energy retailers that consumers have contracted with for energy supply. Consumers are provided with an In Home Display so that they can monitor their usage and see what they are paying for and using in near real time data. The business case supporting smart meters was based on the assumption that if consumers can easily see how much they are paying in real time it would encourage them to find ways of reducing their consumption. Whilst there are other savings and efficiencies – reducing the frequency of meter reading visits, more accurate billing – the key initial benefit is showing users how much energy they are using and how much it costs.

Connection to the electricity meter is made using one of two different wireless technologies depending on the location of the property as two service providers won contracts - Telefonica covering the Central and South regions and Arqiva covering the North. The challenge for the installation programme is to ensure that the smart meter once installed does actually connect to the wireless infrastructure – in the case of Telefonica they have 3 different communication hubs – as shown in Figure 21 - two that use an external antenna and the installer is guided as to which hub is required through a series of steps set out on portable device.



### Figure 21: Telefonica's choice of 3 communications hubs

Telefonica assume that the majority of connections will be made using either existing 2G/3G cellular infrastructure or via coverage extensions to the existing cellular infrastructure being undertaken as part of the network provision or in a small number of remote properties (circa 5%) a mesh network will be deployed and linked back into the cellular network.

The Arqiva solution deploys a proprietary long range radio solution, perhaps more suitable for the challenging terrain of the north of England and Scotland and operating around 420MHz. Where necessary Arqiva will develop new base stations sites although as a tower company they are well placed to minimise the number of new sites required.

With over 1m smart meters being installed per month in 2018 and 2019 ensuring that each meter connects to the wireless network without any problems will be a key challenge



# 3.4.3 Future utility use cases

# Smart grid

Smart metering is perhaps best viewed as one half of the journey towards automating the management of demand and generation through the addition of smart grid capabilities to smart meter capabilities. Smart meters are likely to evolve to include demand management functions – so that at peak times power could be cut for short periods to fridges, freezers, electric car chargers and air conditioning so as to reduce the peak load. Tariff incentives could also be offered so that consumers can choose when to consume power and shift demand away from the peaks – again the smart meter or an evolved app based service could enable consumers to choose in real time.

Smart Grid provides more control at the distribution network and local level allowing automated solutions to be deployed integrating supply – including local micro generation – demand and optimal network operation. Smart grid is also seen as an enabler to support low carbon eco systems and reduced emissions targets.

The smart grid essentially puts IT and communications solutions at the heart of generation, transmission and local distribution and treat these parts as a single whole system. Indeed, smart grid will be built around many IoT concepts – particularly remote sensors. The approach is based around data gathering, real time analytics and an automated response. However, the remoteness of many of the network assets makes data gathering challenging. In addition, a number of smart grid activities will be critical – particularly those actions making changes to the network configuration at the time of a major incident.

Smart grid realisation will require many of the assets in the local power distribution networks to be connected either for sensor readings or for control and sensing. Typically, such networks have been controlled by SCADA systems (Supervisory, control and data acquisition) although the scale of sensor deployments at the distribution level could be very high – circa 700,000 transformers and sub-stations. The nature of these networks is that many of these assets will be at the far end of the networks thus providing challenging coverage requirements. Although capacity requirements will be low it is likely that the requirement will be classed as mission critical communications in order for the full benefits of smart grid technologies to be accrued.

# 3.4.4 Network service requirements

The environment for the electricity industry is one of vary large numbers of assets spread nationwide. It's an environment where sensing is prevalent – including metering – but the transmission and distribution networks also require various forms of remote actuation – probably on an automated and deterministic response to a set of pre-defined situations.

- The majority of sensing requirements including metering will be served by M2M services where meter readings are reported regularly – say every hour. If one reading is missed the next reading will suffice.
- Mission critical connectivity services will be required where network control is being managed as part of a smart grid solution, we also envisage future requirements where smart meters will react to commands from the network either for demand reduction or to provide the consumer with new tariffs.
- The metering end point quantities are going to dominate over all other items such as sub-stations, transformers and other assets requiring monitoring.



Densities for metering will also be high in urban areas particularly with high rise apartments. If demand management capabilities are added to the metering capability, then the number of potential end points is likely to multiply several fold although this is likely to be within the home possibly on the Zigbee network that links the IHD and gas meter to the electricity meter which links to the wide are connection module.

- We have assumed a total smart metering network data capacity of 75Tb p.a. as a reasonable mid-point in the range set out by Ofgem [79].
- For smart grid we have assumed a capacity of 1.3 kbps across 900,000 assets based on this analysis [80] .
- Currently water meters are outside of the UK smart metering programme. Water meters present several challenges they can be installed under the road in pits which have metal covers, they can be some distance from the house say at the end of the garden. Some water companies are developing and rolling out their own smart meter solutions.
- Parts of the network will require mission critical connectivity providing low latency and guaranteed operation to provide guaranteed responses to situations and emergencies. Many will be automated but will need to provide very fast guaranteed responses to incidents.

# 3.4.5 Potential benefits to the UK

According to the DECC Smart Metering Implementation Report of November 2015 [81] - the key benefits of smart metering are:

- Smart meters will enable domestic consumers to gain control over their energy consumption,
- Lower costs for industry in supporting the new smart meter infrastructure will enable savings to be passed onto consumers as well as improving customer service
- A range of system savings Network companies are expected to be able to identify and resolve outages more quickly and efficiently
- Further consumer benefits are expected to emerge from the development of new products and services,
- DECC also places equal importance on tracking non-monetised benefits, such as an improved prepay experience, quicker and easier switching and better billing arrangements.

The U.S Department of Energy identifies the following smart grid benefits [82] – all of which would be realised in a UK Smart Grid deployment

- More efficient transmission of electricity
- Quicker restoration of electricity after power disturbances
- Reduced operations and management costs for utilities, and ultimately lower power costs for consumers
- Reduced peak demand, which will also help lower electricity rates
- Increased integration of large-scale renewable energy systems
- Better integration of customer-owner power generation systems, including renewable energy systems
- Improved security



#### 3.4.6 International perspective

Smart meters and smart grids are of global interest as nations seek to combat the same environmental and demand challenges. Most smart meter deployments follow government mandates. Business Intelligence reports that global smart meter installation will grow from 450m in 2015 to 930m by 2020 [83]

Two methods of connectivity are used internationally – wireless such as in the UK and power line communications - deployed for example in Italy. Arguments can be put forward as to which approach is better from various perspectives but generally the powerline system is seen as challenging because of the noisy electrical environment and complex wiring and transformer arrangements.

3.4.7 Use case summary

Use cases	Direct (Industry/User)	Indirect Benefits (e.g.	Network Infrastructure
	Benefits	industry infrastructure)	Requirements
Smart Utility	<ul> <li>Aligns generation to demand in real time</li> <li>Faster fault repair and recovery</li> <li>More accurate and lower consumer's bills</li> </ul>	<ul> <li>Less central generation capacity required</li> </ul>	<ul> <li>Smart metering is MTC, 2 kbps / km<sup>2</sup> max, 1 kB/day household</li> <li>Smart grid is MTC &amp; MCC (focus on MTC), 1 kbps / km<sup>2</sup> rural, 100 kbps / km<sup>2</sup> urban</li> </ul>

#### 3.4.8 **Case studies**

# Case study - Thames Water - smart meter deployment

Thames Water (TW) following signing a contract with Argiva in March 2015 are deploying smart water meters to the 3.3m properties - this is the first UK deployment of smart water meters and the meters connect by wireless. TW has already found that metered customers use 11% less water than unmetered customers and smart meters were seen as the next step in demand and network management bringing benefits of real time analytics to pinpoint leaks for instance. TW has more than 20,000 miles of water mains and the smart meter platform will highlight continual usage which often indicates a leak. TW research concluded that if nothing was done by 2020 there would be a shortfall of 133m litres of water per day as can be seen in Figure 22.





#### ..... Future Use Cases for Mobile Telecoms in the UK Issue date: October 2016

Version: 1.0

# **Figure 22: Supply and demand gap for Thames Water** (Source: Thames Water – Water Resources Management Plan 2014)

The installation programme is expected to take until 2030 with 441,000 smart meters expected to be installed by 2020. As at June 2016 some 60,000 meters have been installed in London. London is being deployed first for several reasons:

- London is classed as 'seriously water stressed' with demand in some areas exceeding supply in very dry periods
- London gets less rain than many other large cities
- Londoners use in excess of 10% more water than other parts of the UK
- London's water mains are some of the oldest in the country with 44% more than 100 years old

The meters can provide water usage data every 15 minutes.

TW are using a network deployed by Arqiva based on Sensus smart meter technology – trials were undertaken in Reading to assess how well this proprietary technology worked in the water meter environment as water meters are typically fitted underground in the road, pavement, drive, garden or inside the property.

Dr Piers Clark, commercial director at Thames Water, said: "As water becomes an increasingly precious resource, smart water metering will play a critical role in helping the water industry to better manage consumption and leakage. Based on the current trial with SmartReach in Reading, we believe that long-range radio offers a simple, quick, non-obtrusive and efficient means of building a Smart Water Meter network. The system promises far more available data on water flows that will help Thames Water to manage consumer demand and pinpoint leakages. Extending the scope of the trial to London will provide further valuable data."

Customers can monitor their water usage online.



# 3.5 Supply chain - road haulage and drone delivery use cases

Supply Chain is divided into two substantive use cases Road Haulage and Drone Delivery.

**Road Haulage** encompasses benefits for fleet operators to improve efficiency, reduce costs and reduce carbon emissions, thus societal benefits are also apparent for this fast-growing sector. The infrastructure requirements are MTC. With the high degree of benefit that is apparent and the synergies with automotive vehicle management a case can be made for commercial realisation with appropriate alignment of value chains and business models.

**Drone Delivery encompasses benefits in terms of** faster deliveries of small parcels close to the operator's distribution points, providing competitive advantage dynamics to retailer and delivery value chains. Whether there are cost savings, at scale, is not yet clear with dependencies on the regulatory frameworks. Infrastructure requirements are MTC, ranges imply urban and sub-urban coverage, but with potentially enhanced capacity requirements dependent on the required protocols.

# 3.5.1 Overview

### Scale

Road haulage and logistics covers the distribution, storage and transportation of goods between various points of the eco system – typically from manufacturer to distribution centre, from distribution centre to retailer and from manufacturer or retailer to consumer.

The UK haulage and logistics industry employs some 2.2m people in 190,000 companies. 80% of UK freight is moved by road, there are 497,000 commercial vehicles over 3.5 tonnes (HGV) on the roads and some 3.3m commercial vehicles under 3.5 tonnes (LCV).

Light goods vehicles is the fastest growing sector boosted by online shopping as seen in Figure 23 taken from an RAC Foundation report [84].



### **Figure 23: Growth in LCVs compared to HGVs** (Source: RAC Foundation – Van travel trends in Great Britain)



## Car, Van and Lorry traffic have all increased over the last year.

Compared to the previous year, in the year ending June 2016:



Car and taxi traffic reached a new high of 249.2 billion vehicle miles, slightly (0.4%) above the previous peak of 248.2 billion vehicle miles for the year ending September 2007. Car traffic has grown steadily for the last 18 months by an average of 1.3% per year.



LGV traffic increased by 3.7% to a record high of 47.8 billion vehicle miles. Since 2013, LGV traffic has increased on average by 4.8% per year, and is the fastest growing traffic type.



HGV traffic increased by 3.8% to 17.0 billion vehicle miles. Since 2013, HGV traffic has grown on average by 3% per year making it the second fastest growing traffic type. However, HGV traffic remains below the peak of 18.2 billion vehicle miles observed in the year ending June 2008.

0 70.1%

### Long term trends

Over the last 20 years, traffic has increased at varying rates across vehicle types: All Motor () 17.9% Vehicles

12.6%



Figure 24: Growth trends in vehicle categories on UK roads (Source: DfT – Provisional Road Traffic Estimates)

Figure 24 above taken from the June 2016 DfT report on road traffic shows a similar growth [85].

# **Challenges**

Key trends and challenges in the industry include:

- The growth in online shopping 2015 was over 12% higher than 2014 [86]
- This is changing the structure of transport fleets with the rise of the van van miles driven has increased by 72% since 1995 and is forecast to rise by 78% over the period 2010 to 2040 [86]
- The demand for real time information and delivery predictions has put IT at the centre of the logistics industry – with retailers offering same day delivery highly automated system are required to ensure such promises are met
- No reduction in empty running the distance travelled when a vehicle is not carrying any goods – typically when returning to base after completing all deliveries. This essentially represents lost revenue
- Financial pressures combined with environmental requirements mean that the industry has to become more efficient. Improved real time routing and scheduling systems are required to ensure vehicles try to avoid jams and hold ups. Drivers are required to improve fuel consumption by changing the way that they drive – delivering not only cost savings but reducing carbon emissions.

#### 3.5.2 **Current logistics use case**

In order to provide the real-time information required by customers and fleet manager's haulage vehicles need a continuous connection to the fleet management system (FMS) which manages the vehicles and drivers and the logistics management system (LMS) which manages the movements of the goods being carried. The FMS and LMS functions may be integrated into one application.



With such a connection, several capabilities can currently be provided:

- Goods tracking at all points in the delivery chain from manufacturer to customer. Bar code scanning is starting to be replaced by internal wireless solutions such as RFID in some areas
- Real time vehicle positioning, average speed and estimated ETA based on current location, delivery schedule and road conditions
- Real time routing rather than simply using a Sat Nav the FMS takes account of remaining deliveries and collections to choose a new optimum route if say a road is closed or traffic congestion is likely to make some deliveries late
- V2X capabilities in logistics should serve to improve safety of the delivery driver and other drivers and reduce congestion by providing congestion information allowing the FMS to re-route the vehicle. Such re-routing could also reduce carbon emissions
- Vehicle platooning an advanced form of ADAS, platooning is likely to enter service in large trucks as a way to reduce fuel consumption on motorways and other major routes. Platoon vehicles travel very close to each other thereby benefit from slipstreaming. The smaller distances between vehicles could also reduce congestion although very small distances present additional requirements. "On the test track we've driven with a distance of about 10 metres between the vehicles, and we were able to achieve a 12% fuel saving for the trailing vehicle," says Magnus Adolfson, Scania's Manager for Intelligent Transport Systems. "If you want to get as close as a couple of metres, then you need several automatic systems that also take control of the steering from the driver during the time that the vehicle is in the truck platoon. That's also something we're focusing our research on."

Early deployment of vehicle platoons will require that the truck driver remains alert and able to take control should the need arise.

- Reducing empty running this percentage has been on the rise and is now around 29% of vehicle miles covered – this means assets are underutilised and carbon emissions are increased for no economic gain. Various solutions are being tried – including on-line exchanges which match spare capacity to load needing delivering. With real time vehicle location FMS systems can more accurately find matches
- Remote vehicle diagnostics and maintenance scheduling monitoring various sub systems in the vehicles allows faults to be detected early on and the vehicle booked in for service. Not only could this reduce vehicle downtime and potentially costlier repairs downstream it also provides enhanced driver safety
- Load monitoring various sensors are fitted to real time monitor and report on the condition of the load. Typically, this could be temperature and humidity but many other factors could be relevant – such as acceleration, deceleration and oxygen levels.
- Safety and security covering driver safety, who is in a lone worker environment and security of the vehicle and load. This can be achieved by tracking the load separately from tracking the vehicle. Real time in cab and around the vehicle remote video monitoring could also be provided either via continuous streaming or only when movement is detected



# **3.5.3** Future logistics use cases

We believe the current automation of road haulage processes will continue adding new capabilities and efficiencies to the use case outlined above. Smartphone apps are likely to enhance the capabilities of logistics systems as fleet management becomes an increasingly automated process whilst also reducing the cost to fleet operators. It is also likely that some of the key technology companies involved in retail like Amazon will drive the level of automation that will eventually permeate the industry.

## Vehicle platooning

In particular, we see that vehicle platooning is gaining credibility as the next step in road haulage, particularly HGV where the benefits and gains appear greatest. The European approach to platooning uses on board sensors and control systems and therefore places no further load on the network infrastructure beyond connection to the FMS and LMS – which is not specifically used for platooning. However, there are still uncertainties about how vehicles join and leave platoons and what communications requirements there may be – this is likely to be vehicle to vehicle possible supported by V2I services. The 'Lessons Learned' booklet referred to in section 3.5.6 provides more information about this.

It also appears likely that various business models will emerge around platooning – so the benefits say of fuel saving might come at a cost. Again, we see that the FMS should be able to deal with this, guide trucks to nearby platoons and deal with the commercial arrangements of how say fuel savings are to be shared.

## **Drone delivery**

One potentially disruptive influence in the road haulage sector could come from the use of drones for making deliveries. The drone industry continues to gain momentum with many new use cases and implementations being developed rapidly. Adoption across enterprise is slower than the consumer space with the rules and regulations relating to flying drones holding back investment by enterprise.

Delivery by drone remains perhaps the holy grail of drone use cases. Amazon, seen as a leader in this area, has moved its trials from the US to the UK, Canada and the Netherlands because of the FAA requirements that a drone remains in sight of the pilot. Delivery by drone advances the current delivery same day to delivery within 30 minutes or less and is seen as a way of developing competitive advantage for retailers.

Delivery by drone requires a number of leading edge capabilities to come together:

- Reliability and durability of the drone to ensure the drones do not fall and injure people
- Precise navigation possibly in dense urban environments where imagery may be needed as well as maps to detect wires and street furniture
- Airspace management specifically including co-existence with other drones and the ability to communicate with other drones
- Critical decision making capabilities to deal with several challenges such as poor weather and collision avoidance
- Continuous situational awareness probably based on 360-degree imagery, the use of other sensors and critically the availability of on board 'sense and avoid' technology. Sense and avoid technology is designed to ensure that drones avoid obstacles such as wires, trees, buildings and other drones



Whilst we would expect first delivery drone deployments to be carefully monitored or even controlled by humans, the real savings and scale are only going to be achieved when the system is fully autonomous. Amazon is giving little information out about its delivery drone plans called 'Prime Air' but the latest incarnation is shown in Figure 25 [87]. Facts released by Amazon state that the drone has a range of 15 miles on a charge, will fly at an altitude between 200-400 ft. and can carry a load up to 5 lbs.

Amazon is working in the UK with the CAA who are keen to develop appropriate policy for drones. "We want to enable the innovation that arises from the development of drone technology by safely integrating drones into the overall aviation system," said Tim Johnson, CAA policy director. "These tests by Amazon will help inform our policy and future approach."

Google is also working on a delivery drone project – known as Project Wing which was recently given permission by the US authorities to commence testing at an approved FAA test site.



### Figure 25: Amazon's delivery drone

# 3.5.4 Network service requirements

- The uses cases described above in the main will use low capacity connections typified by M2M services for connection to the FMS and LMS, although it is possible that the road haulage vehicle could be classed as a connected vehicle using a MBB connection although the capacity requirements would be low. This could change if video from the vehicle was being streamed back to an operations centre although such use cases do not appear to have emerged
- Coverage requirements for road haulage will extend to all roads but with decreasing priority as we move down from key motorways and trunk roads. Clearly the real-time position tracking and requirement to provide arrival predictions will be compromised if the vehicle is unable to report its location
- Vehicle platooning will require V2V or possibly V2I communications with requirements for low latency to support the reduced distance between trucks. Platooning is likely to be limited to motorways and major trunk roads where the length of platoons can be accommodated safely and without inconveniencing other drivers
- We have assumed M2M requirements of 100 Kbps for the M2M requirements and 100 Kbps for the V2X requirements



- Delivery drones when they arrive will require V2V communications and possibly V2X. Amazon states that the drone will require a reliable internet connection for amongst other reasons to receive air traffic information. It is likely that positional information will be constantly sent back to central servers and possibly video or images under certain circumstances – for instance to confirm to the customer that the item had been delivered. Drone delivery services will, due to the range constraints of the drone operate around cities and towns rather than in rural areas.
- We have assumed drones will require 50 Kbps M2M connectivity and assumed a maximum of 100 drones in a kilometre cube clearly we recognise that this is a developing area where such figures are still fluid.

# 3.5.5 Potential benefits to the UK

We believe that the benefits for road haulage logistics will be as follows:

- Reduced operational costs for haulage companies particularly with sophisticated apps and real time information from delivery recipients into the FMS to reduce the number of times delivery companies have to make second or third visits to attempt delivery
- Reduced carbon emissions through more efficient routing and real time rerouting
- Reduced fuel consumption and carbon emissions for trucks when they operate in platoons
- With more accurate delivery times and narrower windows, the delivery recipients can make more effective use of their time and in the case of businesses including large retailers schedule resources and other deliveries more accurately
- Opportunities for real time haulage platforms and real time collaboration to reduce the amount of empty running

# 3.5.6 International perspective

Truck platooning is of high interest across Europe with a European Truck Platooning Challenge held in 2016 where six brands of trucks started from their factory location and travelled to the Port of Rotterdam forming platoons where appropriate. Afterwards a 'Lessons Learned' booklet was produced [88]

There is similar interest in the US with a number of academic and commercial projects underway. Peleton Technology's system [89] shown in Figure 26 uses a central operations centre to give permission to specific trucks to platoon upon request and the operations centre can break platoons should circumstances dictate. Such a central command and control approach is very different to the vehicle based control favoured in Europe.

Platooning is generally seen as a stepping stone to autonomous vehicles with an expectation that it could be deployed in a few years if the required legislation is put in place.





**Figure 26: Peleton technology's on board systems to support truck platooning** (Source: Peleton Technology)

With regard to delivery drones clearly at the moment much of the investment is coming from US companies such as Amazon and Google. The legislation around flight space management and whether such drones can co-exist with regular commercial, military and private aircraft will be the key driver to push acceptance of such concepts along. DPD Group of France also have a drone delivery project underway as shown in Figure 27 where the drone drops the item into a basket [90].



Figure 27: DPD drone trial



Use cases	Direct (Industry/User) Benefits	Indirect Benefits (e.g. industry infrastructure)	Network Infrastructure Requirements
Road Haulage	<ul> <li>Reduction in carbon emissions</li> <li>Shortened delivery times</li> </ul>	<ul><li>Improved competitiveness</li><li>Reduced congestion</li></ul>	<ul> <li>MTC application</li> <li>100 kbps per vehicle</li> <li>20% of vehicles related to logistics (LGV/HGV)</li> </ul>
Drone Delivery	<ul> <li>Reduced road congestion</li> <li>Shortened delivery times</li> </ul>	<ul> <li>Reduced carbon emissions</li> </ul>	<ul> <li>Mix of MCC and MTC</li> <li>Focus on MTC with 100 drones per km<sup>3</sup></li> <li>1 – 10 kbps each</li> </ul>

# 3.5.8 Case study

# Case study: Isotrak fleet management solutions

Isotrak is a UK company supplying fleet management solutions globally. In the UK Isotrak partners with Vodafone to provide fleet management services across 99% of the UK. The system can provide fleet managers with the ability to access real time intelligence on vehicle locations and route analysis and vehicle progress. Geo-fences can be set up allowing delivery recipients to be kept informed when a delivery is close. Perishable goods can be monitored for temperature as well as rear door openings.

System data also ensures compliance with relevant driver hours' laws and vehicle maintenance schedules

Users can access the system on any device, meaning that monitoring performance can be carried out at any time.

The system can also manage the work flow processes associated with logistics such as delivery signatures.

Case studies highlighted by Isotrack include:

# A milk processing and delivery company operating throughout the UK

Key challenges were route optimisation in rural areas, driver fuel economy and driving style. With Isotrak's system integrated into the vehicles CAN-Bus, Isotrak reports a saving by the customer in fuel economy of 5% equating to some \$2.25m annual savings. Other efficiency improvements brought the annual savings to over \$3m.

:::1	PROFITABILITY	4/	\$2m saving per year through improved fleet MPG
۰.	SERVICE DELIVERY	4/	Achieved a \$664k per year saving through Plan vs actual route management
	PRODUCTIVITY	<b>\</b>	\$507k per year benefit from reduced vehicle hours spent at restricted places
	SUSTAINABILITY	<b>\</b>	Reduced CO2 footprint
	RISK MANAGEMENT	4/	Visibility of legislative compliance

# Fresh direct – fresh food supplier

A fast growth company with an expanded fleet of 166 vehicles. With this growth has come some a lack of knowledge as to where vehicles were and rising fuel costs.



Through deployment of Isotrak's fleet management system with tracking and telematics a 21% reduction in fuel consumption was achieved as well as better visibility of driver performance and better utilisation of the vehicles. The annual saving was estimated at 625k - giving a payback on the investment in less than 6 months as well as reduced carbon emissions.

# 3.6 Cloud services - media and business use cases

Media and Cloud is divided into three substantive use cases 4K Content Everywhere, Immersive Gaming and Mobile Office.

**4k Content Everywhere** encompasses video consumption through mobile devices, and interactions through social media platforms that present picture and video rich content. Demands on infrastructure are MBB but at a high capacity, and is in fact likely to drive commercial investment in MBB.

**Immersive Gaming** encompasses the nascent integrated VR and AR enhanced experiences. The UK is recognised for its innovation in gaming and there is evidence that having national infrastructure that is known to be capable of supporting gaming could reduce barriers to "mobile first" games; however, it is yet to be determined how much of the indoor gaming experience including enhancements like 360-degree experience will translate into mobile infrastructure requirement. Demands on infrastructure are predominantly MBB. The case for investment in infrastructure above MBB to secure 4k Content Everywhere is not strong.

**Mobile Office encompasses** increased worker and business efficiency in the mobile workforce. The infrastructure requirements are MBB with a relatively low peak rate demand; however, in cities the density of users drives infrastructure capacity demands. The case for investment in infrastructure may be established in the context of existing Enterprise, Service Provider and resultant business to business value chains.

# 3.6.1 Overview

### Introduction

In this section, we analyse cloud-based applications for mobile devices such as video, gaming and mobile office applications

This includes services which are delivered primarily via streaming or downloading from the cloud to a mobile device. Increasingly, as seen by the success of Spotify and Netflix, content is being streamed rather than downloaded, which puts pressure on network bandwidth, coverage and QoS.

In particular, we look into:

- Digital media and specifically 4K content to mobile devices everywhere
- Immersive Virtual Reality and Assisted Reality (VR / AR) mobile gaming
- Cloud based mobile office



We have chosen these use cases for analysis as they already exist at a basic level and they will evolve over the next 5 - 10 years. These use cases have several aspects in common - they are mass market applications, require high speed connectivity on-the-move and could support a UK leadership position e.g. the gaming industry and some types of content. They also support future business efficiency and flexibility by means of mobile/virtual office applications.

#### Scale

One of the key indicators of media usage patterns is digital advertising, one of the main ways that online and mobile connectivity is monetised.



#### Figure 28: Year-Over-Year Growth of Digital Ad Formats (UK) [91]

Figure 28 demonstrates the growth in digital advertising spend in the UK in the first half of 2016, compared to the year-ago period. Mobile is driving the highest growth, compared to other areas of advertising spending. And for the first time in the UK, the ad spend on mobile (51%) controlled a larger share of the digital display ad market than PC and tablets (49%). This is a clear indicator that marketeers are increasingly mobile-first when deciding where to shift their digital ad dollars [91].

These digital adverts will be present in many cloud based services, and will be an important way to monetise them, in addition to subscriptions, freemium systems and in-app purchases. Mobile digital advertising will also be enhanced by the same technologies which are being applied to content, apps and games, such as augmented reality and high resolution video. This means that the advertising, as well as the core content, will place new demands on the mobile network.

### Scale

#### **Digital Media**

The UK has the highest level of digital media consumption in the world apart from the US - 70% of the UK population consume digital video, according to Bain Research [92]. The UK



TV industry generated £13.2bn in revenue in 2014, an increase of 3.1% year on year. Over 90% (92%) watch TV each week, down slightly from 93% in 2013 an 56% have an internet-connected TV [93].

In 2015, 58% of all UK mobile data traffic was video [94]. Three carries the highest percentage of video traffic in the UK, reporting 78% of mobile data carried in 2015 was video [95]. By 2019, 80% of the world's mobile internet traffic is predicted to be video content [96].

#### Gaming

According to NESTA, games companies in the UK grew at an annual rate of 22% in 2011-2013, with Apple's mobile iOS being the most important platform [97]. The UK was estimated to be the sixth largest video games market in the world in 2015 in terms of consumer revenues, after China, USA, Japan, South Korea and Germany. The UK is forecast to retain its place up to at least 2018 [98].

The industry was worth nearly £4.2bn in consumer spend in 2015, up 7.4% from £3.94bn in 2014. Over half of the £500m UK app market is spent on games. Specifically, in mobile games, the UK has 5,000 full time workers producing games, out of 21,000 across the whole EU [98]. Mobile gaming is almost catching up with consoles and PCs. In the first quarter of 2016, research by GameTrack looking at UK consumer games consumption found that 24% of gamers (11.4m) play on consoles, 24% (11.2m) on computers, 21% (9.8m) on smartphones, 16% (7.8m) on tablets and 11% on handhelds (5m) in Q1 2016 [99].

The UK is increasingly successful at producing games for social and mobile platforms. Key examples include "Monument Valley" by studio Ustwo, "The Room" produced by Fireproof Studios, and "Candy Crush Saga" by King, which in November 2013 reached 500m installations on mobile and Facebook.

#### Mobile (cloud) office

The mobile office is a cloud based solution combining a number of business related applications and functions, together with security, within a web interface. This provides users with a mobile and location independent office or business, running on their mobile devices. It also supports file sharing and interactive collaboration with other users, potentially far away, over mobile networks.

There were 2.55 million businesses in the UK in March 2016 compared with 2.45 million in March 2015 (rise of 4.3%) employing 31.77 million people [100]. Owing to the large proportion of SMEs (fewer than 250 employees) in the UK, the vast majority of commercial buildings (97%) are used by small and micro-businesses. Only 3% of all UK commercial buildings are used by large business (more than 250 employees) or are public buildings [101]. The most connected business could have more than 750 wireless devices which equates to approximately one wireless device for every 1.5 m<sup>2</sup> of floor space [102], but not all of them would be mobile and support cloud office services.

Cloud services are an area of high growth – the UK cloud computing market had a value of £1.8 billion in 2014 according to IT Europe [103]. IT/software and computer services is the largest of the 'creative industries' as defined by DCMS and accounted for 43.5% of the Gross Value Added (GVA) of that sector in 2014 (£36.58 billion out of £84.1 billion) [104].

The UK was ranked as 3<sup>rd</sup> most important market in the ITA Cloud Computing Top Markets Report 2016 [105]. With 84% of UK companies using hosted services in 2015, the UK cloud



market is set to be worth £13.3bn by the end of 2016 at a compound annual growth rate of 36 % [106].

Worldwide, the average organization now uses 1,154 cloud services, an increase of 38.9% over this time last year, and enterprise cloud services account for 72.9% of those [107].

# 3.6.2 Current media and business cloud use cases

The media and cloud sectors have been transformed in the past 15 years by high speed connectivity and a widening range of smart devices particularly smartphones. The rising consumption of over-the-top and cloud-based content, consumption on mobile devices and the changing patterns of broadcast TV consumption have created new businesses and opportunities in the UK, as well as challenging established players.

The UK has the ninth highest level of smartphone penetration in the world at 69% [108], which drives a high level of sophisticated usage. According to Ofcom, smartphones have overtaken laptops as the UK's premier device for accessing the internet, with consumers, on average, spending two hours per day on smartphones and only one hour on PCs [109].

As of mid-2016, almost half of UK adults had access to at least one device used for content consumption such as a smartphone or tablet, a figure that is relevant to the 4K content and online gaming use cases [110].

## Mobile 4K content everywhere

4K adoption in TVs has already been faster than that of HDTVs in the UK [111], Netflix started 4K streaming in June 2014 and Sony introduced the world's first 4K smartphone in December 2015.

In terms of content, there has been a consolidation of the market around multiplay services, in which a TV service is delivered as part of a bundle with broadband, telephony and mobile; and multiplatform, in which broadcast and OTT TV is delivered over multiple connections to multiple screens in the house. This has seen a move by providers to secure partners or acquisitions that support converged services e.g. BT's acquisition of EE.

Terrestrial TV continues to face an increase in competition from satellite operators, new original content and new OTT providers (e.g. Now TV, BT TV, Netflix, Amazon Prime) – all using various pay-TV models. Content is increasingly being delivered through mobile and fixed IP networks, with free-to-air TV also being delivered over other methods e.g. FreeSat. Broadcast and multicast delivery over cellular networks and convergence of TV and broadband/mobile delivery is in its infancy. But Video on Demand and catch-up content over the internet, to PCs, smart TVs and mobile devices are already happening. In 2014, Ofcom noted that the UK could expect to see similar take-up of OTT TV services to that seen in China, where around 69% of internet subscribers consume OTT services. However, for now, mobile viewing of live content remains very low, as Ofcom commented: "However, these are likely to remain predominantly complementary to broadcast TV services," [112] and broadcast TV is still expected to account for 80% of viewing in 2020 (down from 92%) [113].

# Immersive mobile VR / AR gaming

Many of the serious gamers today still play on computers and consoles but mobile gaming has seen a massive increase. Virtual reality is a factor of high interest for the gaming



experience, and important because of the large number of games developers, as well as consumers, in the UK. However, according to market sources, the gaming industry is not investing a lot into fast and bandwidth hungry applications as there is a concern about suitable connectivity.

An immersive experience is important to gamers, and is moving from consoles to HD and 4K mobile devices, requiring high bandwidth and low latency connections to support virtual reality and other features such as voice and gesture recognition. Augmented reality is less immersive but can also enhance the gaming experience or support new games which rely on clues in the real world (e.g. Pokemon Go). Industry sources see a better market uptake of mobile gaming with AR than with VR.

The gaming industry has a history of introducing advanced technologies that require good quality network performance. Pokemon Go is an example of a game which has helped to make AR a mainstream function, which is now more likely to gain wide adoption in other areas such as shopping. While VR has been the preserve of high end games with specialized equipment and headsets, it is now becoming practical on mainstream smartphones and with low cost headsets. Several companies have launched VR headsets into which a phone is fitted to use as the screen, compute platform and connection to the internet e.g. Samsung VR, Google Cardboard/Daydream). The GSMA cites real time gaming as a driver for sub-10ms network latency [114].

### **Cloud based mobile office**

Cloud services enable a user to remotely access software applications from a cloud provider. The services known and used today can be broken down to:

- Software-as-a-Service (SaaS), such as MS Office 365, Dropbox and Salesforce
- Platform-as-a-Service (PaaS), such as Google's App Engine
- Infrastructure-as-a-Service (IaaS), renting someone else's server equipment e.g. Amazon web services

Cloud services are well known and established in the business world. They are particularly efficient for business people that travel and work from different locations and for companies that support/encourage home working. In 2012, 62% of the UK workforce did not go to the office every day, according to a Citrix survey [115], but employers still have issues with the quality of systems to support remote and mobile working.

Flexible working, home working and distributed enterprises are commonplace in the UK economy, impacting on working practices and productivity. Even in organisations in which most employees come to a central office, many of them need to work on the move or from home frequently.

Mobile real time collaboration has developed significantly in recent years as a key enabler of flexible working and of efficient interworking with partners, suppliers and customers. This use case involves mobile apps which enable colleagues to work together in real time on any process which requires teamwork. They can annotate and discuss a complex document or model, from their smartphones e.g. two architects collaboratively making adjustments to a virtual reality model of a building. It includes also multi-person video conferencing from mobile devices.



Cloud based working brings a number of other benefits such as disaster recovery, automatic software updates, document control, security and easy to set-up (reduces IT overhead needed). The applications generally have a web-interface or require locally installed software. Web interface based applications, real time collaboration and videoconferencing need a constant connectivity whilst other locally installed applications can work offline and synchronise once a connection becomes available. Most applications available today run on tablets and smartphones, supporting the fact that smartphones have overtaken laptops as the UK's premier device for accessing the internet.

# Summary

The status of the use cases in this area are described below:

- There is a demand for **4K content to mobile devices everywhere** but although there are strong indicators for the launch of more devices equipped with 4K and VR capabilities, consumer acceptance remains unproven. The advantage of 4K over HD on mobile devices is questionable and current networks may not always support the high speed connectivity requirement for 4K streaming on the move.
- Immersive VR / AR mobile gaming has been adopted on some mobile platforms. Past efforts to make VR mainstream have failed because of the cost and need for special headgear, though AR may be an entry point for some users, giving them a taste of the experience without the need for accessories. However, gamers have been using VR on consoles for some time and are the early adopters for AR and VR gaming. Developments like Google Daydream and Cardboard, and Samsung Gear VR, significantly lower the cost and bulk of the headgear and support open developer platforms aligned with mainstream systems like Android.
- **Cloud based mobile office** has been around for a while for PCs but has recently seen a strong increase of mobile applications availability and usage. Cloud-based business tools (e.g. Office 365), storage (e.g. Dropbox, OneDrive) and online meetings (e.g. Skype, Go-to-Meeting) can all run on mobile devices to support on-the-move and remote working.

# 3.6.3 Future media and business cloud use case

The usage of "Immersive VR / AR mobile gaming", "4K content to mobile devices everywhere" and "Cloud based mobile office" will continue to evolve during the coming decade, as consumers become accustomed to the new services, network capacities increase and users acquire supporting devices. The demand on mobile networks will rise in line with market adoption.

In terms of growth; smartphones will account for 81% of total mobile traffic by 2020 - up from 76% in 2015 - and OTT streaming will fuel the growth, as 4K video becomes the new standard for consumers [116].

# Mobile 4K content everywhere

Smartphones are currently adopting 4K (similar to Ultra-HD) screens and content. This use case supports the rising consumption of video-on-demand, streamed and broadcast/multicast video on mobile devices, while on the move, or as second screens within the home (though these may use Wi-Fi). In second screen mode, interactivity and social media links are becoming important to the experience, increasing the need for high reliable bandwidth [117].



The use of 4K was initially for high quality programming on large screens. Now it applies to premium content on multiple screens and is being driven by the need for broadcast TV and OTT providers to support multiscreen experiences (e.g. Sky's 'fluid viewing', see below). Applications of mobile 4G may include corporate presentations and, in time, user-generated content, though the main applications will be mobile viewing of TV, video-on-demand and streamed video.

4K adoption in TVs has already been faster than that of HDTVs in the UK [118], and usage on the large screen is likely to drive demand on small screens too, as well as the availability of content. According to Gfk, UK adoption of 4K was faster than that of any other European country in 2015 [119].

Globally, smartphones will be the device category with the highest growth rates after 2017, according to a survey by HIS [120].



#### Figure 29: 4K display revenues year-over-year growth rate to 2020 [120]

Videos on mobile devices are predicted to account for 67% of all UK mobile traffic by 2018, according to mobile operator EE. "We could potentially see 4K adoption and devices coming around much quicker than we were initially expecting," said Ed Ellis, head of Network Strategy and Forecasting at EE. By 2019, 80% of the world's mobile internet traffic is predicted to be video [121].

### Immersive mobile VR / AR gaming

Playing games online using VR and AR can be a demanding task for broadband services and playing games on a mobile broadband connection may not always give a smooth playing experience. For action games where speed and quick responses are essential (requiring low latency connection), this may have performance implications. Some games can be very data intensive, especially with games such as World of Warcraft or League of Legends that can often involve downloading very large patches (in some games, this will happen in the background while playing the game itself) and require very low latencies when playing



online. Serious gamers do not even use a wireless mouse out of concerns of the over-theair (wireless) latency.

"There is an emergence of VR events with 30,000 people connecting and watching. Another trend is AR and deep learning to derive the knowledge of what the gamer likes. Gaming will always be an innovator and work around connectivity issues, but certain types of features are important." However, at the moment; "coverage is a barrier to investing a lot in the mobile platform" says Paul Brain from 7League Software.





Figure 30: Distribution of type of device used for gaming

(Source: Ipsos Mori GameTrack)

Handhelds, tablets and smartphones will be on the rise to support VR and AR. These devices will require high data rates and low latency (for some games).

# **Cloud Based Mobile Office**

The future workplace is forecasted to be a dynamic, living entity that goes beyond the physical boundaries of the office and offers fluid interaction among on-site and off-site knowledge workers, and between real and virtual workers. Important characteristics of the smart workplace will include ubiquitous high-speed connectivity [102].

Most services can already be delivered using the existing networks but could be enhanced by future ones. Vodafone sees the enterprise as key to 5G (future networks). Scott Petty, Vodafone Group - Enterprise Technical Director described customer experience as "the only sustainable form of differentiation". "Any other differentiation – product features, capabilities, technology – can quite quickly be copied. And it is likely your competitors will go faster than you or a start-up will come on board and get there first," he said [122].

The 3D cyber office / 3D meetings present a challenging 'cloud-based virtual enterprise' function that uses the virtual reality to deliver a complete interactive office and to support virtual or robotic colleagues. These may be used to support temporary teams or projects rather than for full time enterprises. For instance, a Cabinet Office backed project, Cyber Security Challenge UK, launched the Cyphinx virtual skyscraper, hosted in the cloud, in 2015



[123]. This was created to recruit cyber-security talent. Candidates could create avatars, enter the building, interact with other candidates and engage with potential employers.

We don't see this as a main-stream application for the way forward. But advanced mobile networks can support virtual reality meetings and enhanced user experiences for collaboration, enabling an organisation in which all central resources and systems are in the cloud, mimicking the structures of bricks and mortar offices [149].

### 3.6.4 Network service requirements

All three use cases require Mobile Broadband (MBB) connectivity. None of them necessarily requires Mission Critical Communications (MCC) of or Machine Type Communications (MTC). The bandwidth, dependent on type of application (office versus AR / 4K streaming) is anticipated to be 1 – 25 Mbps with latency requirements of 50ms. Only in exceptional cases, for serious gamers, a latency requirement of 10ms or less would be required.

It is anticipated that – in a similar way to the Healthcare use cases – these use cases apply mostly indoors or on-the-move (see "Connected Car" and "Rail" for broadband whilst travelling). This means they would mostly take advantage of home or enterprise broadband, delivered locally by wired or wireless infrastructure.

However, only 83% of premises are now in reach of a superfast (30 Mbps or more) fixed line broadband, up from 75% in 2014 [3]. The target to reach 95% by 2017/18 becomes more challenging when rural and remote areas are addressed, yet areas defined as rural account for 22% of premises.

As 80% of mobile traffic is generated indoors, we assume that enterprises would deploy their own dedicates mobile solutions [124] for coverage and capacity, as MNOs typically cannot justify the investment. Wi-Fi is an alternative for indoor coverage, especially in the residential environment. In 2012, over 80% of smartphone-originated traffic in the UK ran over Wi-Fi rather than cellular and an even higher percentage when users are at home [125].

In this use case, we are however looking at the external network implications (when there is no building or local Wi-Fi). Based on the 800 MHz spectrum auctions, Vodafone committed to offering 98% indoor population coverage across the UK before 2016 (which translates to a higher level of outdoor coverage) and O2's 800 MHz spectrum licence came along with an obligation of 98% indoor population coverage by 2017. However due to the population concentration in cities, town and the suburbs, the area coverage percentage will usually be lower than the percentage of population coverage, meaning that there is a higher likelihood of a lack of coverage when outside populated areas. Further, the network capacities required to support these use cases are very challenging, especially if there are high user device densities. The capacity needs could be addressed by:

- Technology: e.g. the use of MIMO technology to increase spectral efficiencies
- Spectrum: e.g. increasing the amount of spectrum available at sites
- Architecture: e.g. network densification adding more sites to reduce the number of users sharing the capacity delivered by the site



#### Mobile 4K content everywhere

Based on current compression technologies, the bandwidth recommendation from Netflix for 4K streaming is 25 Mbps compared to 5 Mbps for HD [126]. Another source reported that most streaming sources of Ultra HD content require an internet connection with robust speed of at least 20 to 25 Mbps and that the 4K streams from Amazon Prime, Netflix and others won't work unless there is a consistent connectivity of at least 20 Mbps [127]. However, it appears that Netflix is already encoding 4K content at 15.6 Mbps and stated that they expect the next generation codec (HEVC/H.265) to provide a 20-30% encoding efficiency vs the H.264 codec within two years, but 40% is required to get to the 10-12 Mbps bandwidth often quoted by operators [128]. Another trick to reduce bandwidth is to reduce the frame rate from 60 fps (frames per second) to e.g. 24 or 30 fps. For the purpose of this analysis, we assume 12 Mbps for 4K streaming to mobile devices by 2025.

One of the great challenges for wireless networks is managing the growing traffic from downloads of content, especially video. If this can be done at a time when the connection is only lightly used, it can result in a better experience for the users and less strain on the network. For instance, pre-selected films, or episodes of regularly watched programmes, may be downloaded overnight.

### Immersive Mobile VR / AR gaming

**Virtual reality** makes potentially even greater demands on the network. Humans can process 52 Gbps of sound and light. At today's 4K resolution of 30 frames per second and 24 bits per pixel, using a 300:1 compression ratio; current multi-camera **VR systems generate only 300 Mbps** of imagery compared to the capabilities of human's eyes and ears [129]. This is however only what the cameras deliver as an output and not what a consumer wold usually see. It is more than 10 times the typical requirement for a high quality 4K movie. In addition, interactive online VR gaming requires lower latency for responses to seem realistic. Development of specialised VR compression will be important to reduce strain on the network, as will more intelligent allocation of network resources (e.g. Mobile Edge Computing can improve latency by bringing content close to the user). However, according to METIS the maximum end-to-end latency for cloud VR gaming is 50 ms [130].





**Figure 31: Livestreaming 360° panoramic 4K 3D video from a panoramic camera** (Source: GitHub – Conduit - Aakash Patel & Gregory Rose)

AR has a lower data demand compared to VR but with compression, VR videos can be transmitted over mobile networks. The bandwidth requirement for streaming of a 360 degree, 3D 4K video based on tests with compression was a minimum of 18 Mbps for a specific H.264 encoded video [131].



### **Cloud based mobile office**

The most demanding common applications multi-person video conferencing (real time) or synchronisation of cloud databases (high capacity but not time critical).

Video conferencing at low resolution requires only 230 kbps whereas UHD would require 4.9 Mbps. However, on a mobile device a reasonable 1920 x 1080 pixel resolution would require a 1.2 Mbps data rate for connectivity including packet overhead. Multi-person video conferencing results in multiplication of the number of participants connecting to the video conference bridge (e.g. 5 participants connecting to the bridge =  $5 \times 1.2$  Mbps = 6 Mbps) [132]. The other target performance values for acceptable video conference performance are 150 ms latency, 40 ms jitter and 1% or less packet loss [133].

# 3.6.5 Potential benefits to the UK

The potential UK benefits are large, because of the size and significance of the cloud driven business, an of the TV/video and gaming industries. In all of them, the UK has a vibrant industry and high levels of consumer uptakes. But continuing growth relies heavily on new and improved experiences to keep UK users interested and exports flowing.

The use cases will be impacted by new mobile connectivity. For instance, higher data rates and universal connectivity can:

- Encourage collaborative design processes in software development
- Enable new gaming experiences such as virtual reality
- Drive increased usage of apps and cloud services
- Add value to the TV experience
- Provide new choices and leisure activities for consumers
- Stimulate the games industry at home and for export
- Attract developers and innovators to the UK to strengthen the ecosystem
- Make businesses more efficient, flexible and competitive

### Mobile 4K content everywhere

There will be an ongoing struggle between different value chain players to secure the best revenue share and the primary customer relationship. For pay-TV providers, high quality mobile video can reduce churn and support new add-on or marketing opportunities but 4K is generally being offered to subscribers without an additional fee over HD (see Sky below). However, the appetite for 4K content, especially in sports, will drive loyalty and usage, according to CCS Insight [134].

Mobile operators may produce their own content in order to avoid merely being the 4K bitpipe but consumer brand awareness, in video, is higher for Netflix or Amazon than the MNO. Device players are also acting as aggregators and content portals (e.g. iTunes). With all these parties seeking to secure a share of customer and advertiser revenues there will be partnerships and consolidation between the parties.

### Immersive mobile VR / AR gaming

The business model has been driven by the console and content providers. Usage of the latest games is usually driven first by mobile gaming machines like PlayStation and then by handsets.



According to IHS Markit, mobile games growth in Europe is slowing, so it will be important for the UK's developers to introduce new experiences which can continue to attract players [135]. In this respect, innovations like Google Daydream will be significant for putting affordable VR technology in the hands of both consumers and developers.

Worth noting is that Newzoo expects game software revenues from VR to remain marginal for the near future and to largely substitute other game spending on console, PC and mobile. As the uptake of VR hardware plays out, game software revenues will automatically be absorbed into current PC, TV/console and mobile revenues. VR and AR will in the long term change how consumers communicate with each other and interact with content. In the short to medium term, Newzoo expects the majority share of VR revenues to be generated by hardware sales, spectator content, and live viewing formats.

The demand for VR content, for games and video, will drive supporting businesses in which the UK is strong, such as filming and video production, which will shift towards 360-degree VR formats.

Bianca Barker, MD of UK 360 film company Steadishot Facilities, said: "The 360 industry is at the fairly early stages, but six months ago it was estimated that by 2020 it would be worth \$30bn dollars across virtual reality and augmented reality. The latest figures to be released have now jumped to \$162bn by 2020 [136]."

## **Cloud based mobile office**

Cloud based offices and working gives businesses, employers and employees far more flexibility. Further, cloud based working gives the users

- Always up to date and fresh software (automatic software update)
- No need of an in-house IT and data centre
- Flexible costs; only pay for what is needed and when needed
- The services are always on; usually more reliable than if in-house
- Improved mobility; work from anywhere
- Improved collaboration; real time sharing
- Can reduce expenses; less management, logistics, hardware and space
- Flexible capacity, scale as you grow, add users as needed (push of a button)
- Less environmental impact (fewer, shared datacentres)

# 3.6.6 International perspective

Globally, the adoption of 4K smartphones will precede the availability of content, so this forecast from IHS is an important indicator of growth on the usage side [137]. IHS anticipates that by 2019 there will be almost 800 million smartphones capable of 4K video capture shipping globally.









Globally, according to Digi-Capital, VR and AR games will remain a minority segment within games revenues until 2020 and beyond, but will represent some of the fastest growth. It says that, globally, the VR market will reach \$30bn in value in 2020, with games accounting for about one-fifth of that. Games will be far less significant in the AR segment [138].



Figure 33: AR and VR revenue share forecast 2020 [138]







Figure 34: Revenue Share in the gaming market [138]



.....

Use cases	Direct (Industry/User) Benefits	Indirect Benefits (e.g. industry infrastructure)	Network Infrastructure Requirements
4K Content Everywhere	<ul> <li>Entertainment on the move</li> <li>Adding value – e.g. opportunity for digital ads industry</li> <li>Pay-TV revenues and opportunity for MNOs</li> </ul>	<ul> <li>Requires high capacity broadband network that will subsidise and support various other use cases</li> </ul>	<ul> <li>MBB application</li> <li>4K content expected to be compressed to 12 Mbps by 2025</li> <li>Only 20% consumed outdoors</li> </ul>
Immersive Gaming	<ul> <li>Better gaming experience</li> <li>Supporting VR events with many viewers connecting</li> <li>Stimulating ongoing UK leadership in gaming industry</li> </ul>	<ul> <li>Requires high capacity broadband network that will subsidise and support various other use cases</li> <li>Will help AR market to grow</li> </ul>	<ul> <li>MBB application</li> <li>Some AR and very little VR outdoors</li> <li>4K content with 360-degree VR at 18 Mbps</li> <li>0.5 Mbps for AR</li> </ul>
Mobile Office	<ul> <li>Increased worker / business efficiency and mobility</li> <li>Encourage collaborative working</li> <li>Always up to date, limited software upgrades</li> </ul>	<ul> <li>Reduced environmental impact due to centralisation as less server spaces needed</li> <li>Less local IT skills/support needed</li> </ul>	<ul> <li>MBB application</li> <li>Mostly used in offices, only 20% outdoors</li> <li>Background tasks (sync, email etc.) at 0.144 kbps, HD video conferencing 1.2-2.4 Mbps and 1 Mbps cloud applications</li> </ul>

# **3.6.7** Use case summary

# 3.6.8 Case studies

### Case study 1 – Current media streaming application to mobiles by Sky UK

Sky UK recently launched its Ultra HD service, which according to Strategy Analytics is the most comprehensive Ultra HD service available in the UK if not worldwide [139].

The UHD service is included in the existing subscription fee for premium customers of the new Sky Q service, which was launched in February 2016.

The main innovation on the Sky Q platform is its 'fluid viewing', meaning the ability to watch content on any screen in the home, including mobile.

UHD content can be watched live, on-demand and through Sky Store movie rentals. There will be 124 live Premier League games this season and over 70 movies in UHD including the UHD world premiere of 'Spectre'. There will also be 30 hours of natural history and documentaries, plus five new dramas and some comedy.





Luke Bradley-Jones, Director of TV & Content Products at Sky, said: "With Sky Q we created the world's best TV experience. Now, with the introduction of an unrivalled line-up of Ultra HD TV, the service is going to get even better, truly enhancing the customer viewing experience. Customers looking for the nextgeneration of TV viewing will love it."

Strategy Analytics estimates that 1.7 million UK homes, meaning 6% of the population, currently own an Ultra HD TV.

While the current Sky+ apps are designed mainly to allow for remote record and hard drive management, the Sky Q apps will let users pick up the programme they were watching on the big screen in real time, and continue viewing on a smartphone. They can also download shows to tablets for offline viewing, access recorded content and stream live TV on the go.



# 4. Infrastructure costs analysis

# 4.1 Introduction

Exiting mobile networks deliver services across the UK using a variety of different infrastructure types (cell sites). These include rooftop macrocells, greenfield macrocells, street furniture sites, small cells/microcells/picocells and in-building cells such as public or private venues such as shopping centres, stadium, railway stations together with large office buildings.

This study focuses on outdoor infrastructure only – the different types of in-building solutions and the wide range of costs associated with these do not figure in this study. Further, we consider appropriate proportions of the above-mentioned site types [141] in each environment to calculate the cost.

The process for identifying the need for a macro cell site to be located has evolved over the years from a primarily coverage type requirement to a primarily capacity type requirement – there are exceptions to this in rural locations where the need for coverage for even the most basic of mobile services, voice, has never been met due primarily to the high investment costs associated with building cell sites in rural locations.

The process for acquiring, designing and building macro cell sites has not changed a great deal since the first sites were deployed in the UK over 30 years ago. At the same time, the challenges associated with the acquisition of suitable cell sites at or near the locations required by the mobile networks to meet coverage and capacity requirements i.e. getting consent from landlords & building owners and getting planning consent from local authorities, have become greater in that time. The typical timescale for a cell site to be acquired, designed and built for a mobile network is 18 to 24 months but in many areas (urban, suburban and rural), this timescale can be several years, if ever.

The cost of building sites can vary greatly with significant variations in costs particularly for the provision of power, transmission (backhaul) and access to sites in rural locations for example – this would normally lead to a range of site costs of low, medium and high. For the purposes of the cost estimates in this report we have used medium costs only and it should be noted that in some areas e.g. rural or railway trackside, the cost to build some sites could be significantly higher due to wide variety of factors.

### 4.2 Costing methodology

For each of the use cases and its primary service platform, an analysis was conducted to determine an estimate for the amount and type of infrastructure that would be needed to support the mobile services required.

The approach, for this study, is to build and cost a network from scratch for each use case utilising the required service platform. The service platform design is targeted for the use case with the most demanding data rate so that the use case with the most demanding data rate can be served at the cell edge. This is similar to the approach used by mobile operators, where the network is designed to cater for the most demanding service during the busiest hour of the day. Therefore, the use cases that require lower data rates than the



most demanding data rate (within the same service platform) could achieve higher coverage areas or throughput levels than presented.



### Figure 35: Network cost model methodology

The methodology we followed to calculate the estimated infrastructure cost shown in Figure 35 and is as follows:

- Develop a link budget for the service platform. This was then used to estimate 1. the typical base station cell radius which would achieve the targeted cell edge data rate (as shown in Table 3). The cell radii are calculated using 700 MHz, 3.5 GHz and 26 GHz for low, medium and high respectively. This allowed us to estimate the number of sites that would be needed per km<sup>2</sup> - or per linear km where appropriate - to deliver the required coverage. We assumed circular cells to calculate the coverage area from a site. Note that we use 95% cell edge coverage confidence in our link budget. Although the 95% cell edge coverage confidence is a higher number compared to the coverage confidence considered in [140], we believe this is a realistic number for a maturing 5G network (applying a technology agnostic approach) around 2025. A higher coverage confidence leads to a lower cell range resulting in a higher site count compared to a network designed with a lower coverage confidence. Further, for the MCC platform we considered the cell edge coverage confidence of 99% to cater for the higher reliability required by the critical communications services, resulting in further reduction in the cell range.
- 2. Calculate the capacity of a site by multiplying the spectrum bandwidth and spectrum efficiency. We considered all the licensed mobile / IMT spectrum expected to be available by 2025. Although more than 5 GHz of spectrum is expected to be available for the mmWave spectrum bands, the spectrum bandwidth considered in the mmWave band is the amount of spectrum that can be processed by a single site rather than the amount of spectrum available in the spectrum band. Since this exercise considers the national infrastructure requirements, all the spectrum was grouped as a single entity rather than being divided up across multiple operators.



3. Calculate the expected traffic demand of the use case for the service platform (per km<sup>2</sup>) and compare this against the potential capacity of the cell site. For each use case, we estimated the expected demand by 2025. Determine the number of sites needed per km<sup>2</sup> or per linear km (for road and rail transport corridors) to support the traffic demand. The demand density is calculated based on the demand numbers shown in Table 6.

### Table 6: Demand numbers for different use cases

		Connected Car	Railway	Healthcare	Utility & Supply Chain	Media and Cloud
		use cases	use cases	use cases	use cases	use cases
Mobile Preadband	MDD	1 - 30 Mbps	1.2 - 2.7 Gbps per	10 kbps - 12 Mbps	N/A	1 - 20 Mbps / person
	IVIDD	per car	train (100 Mbps - DfT)	per person	N/A	1-201010p37 person
Machine Tune Communications	мтс	10 - 100 kbps	100 - 300 kbps	10 - 100 kbps	1 - 100 kbps per drone	0.1 - 1 Mbps / device
Machine Type Communications		per car	per train	per patient	/ truck / device	(background sync)
Mission Critical Communications	мсс	10 - 100 kbps	100 - 200 kbps	1 - 10 kbps	1 - 10 kbps per drone	1-20 Mbps / gamer
Wission Critical Communications		per car	per train	per person	/ truck / device	(low latency)

- 4. Determine if the site would be coverage or capacity limited and the resultant sites needed per km<sup>2</sup> or per linear km. We find the optimum combination of sites considering all spectrum bands as follows. We first consider the sites from the low frequency band to achieve the coverage and deploy the medium band where the additional capacity is required. mmWave sites are only deployed in the areas where the capacity requirements are not met with the low and medium frequency bands. In the absence of evidence for mobile point-to-area coverage using mmWave spectrum bands, to achieve the reliability we expect, we have increased the mmWave site count by a factor of 2 to take into account the predominantly line-of-site nature of systems in these high bands.
- 5. Calculate the overall estimated cost for all use cases based on current estimates of typical per site costs for urban, suburban and rural areas. We use the medium sites costs (shown in Table 7) based on Real Wireless sources and the adjusted figures from a report produced for Ofcom in April 2012 [141]. This include site acquisition, design, build, backhaul and power costs. For this analysis we considered the same site type costs for each environment. However, in general the cost of deploying sites in less densely populated areas, can be significantly higher.

Site type	Acquire, design & build cost	Notes
Greenfield	£110,000	Assumes 15m mast with 3 sectors
Rooftop	£95,000	Assumes 3 sectors
Street Furniture	£40,000	Assume 12m high column with 3 sectors
Small Cell	£13,000	Assumes street furniture option

### Table 7: Medium acquire, design and build cost for different cellular site types

The major part of the medium sites costs above are related to site acquisition, design and building of the site rather than the mobile base station equipment cost. We have taken an optimistic view where we assume the sites are available uniformly across the country and at the required locations. However, in practise finding the sites at the right location in some areas is extremely challenging. Sub optimised site placement will most likely result in an increased site count to meet the demand, which, in turn, increases the cost of deployment.

In the case of mid-band and high-band small cells the cost of the electronics to realise the basestation processing will tend to reduce. However, these devices are required to be



ruggedised to operate in wide ranging environmental conditions. The cost of rugedisation and antenna systems becomes a dominant cost for this type of infrastructure product.

In the real world, networks may be built to cover many of these use cases. Networks might even be upgraded to support multiple service platforms, e.g. MTC or MCC could run on a MBB network. However, these multi-service platforms introduce additional technical complexities that are not within the scope of this report.

MBB and MTC services are expected to be available in areas where people live and along the roads and rail tracks. Therefore, we assumed the geographical areas correspond to 99%<sup>1</sup> [142] population coverage outdoor. In our approach, we dimension the MBB and MTC platforms to achieve an 85% geographical area coverage which corresponds to 99% outdoor population coverage. Although, the mobile operators are expected to cover ~90% [142] of the geographical area, this is based on a network designed using a lower coverage confidence compared to the cell edge coverage confidence of 95% we implement in our approach. The service from MCC platform is expected to be available beyond the areas where people live. Therefore, for MCC platform we modelled 99% of the geographical area coverage.

# 4.3 Cost analysis by use case

# 4.3.1 Connected car use cases

In the connected car use cases, we focus on the costs for the strategic road network (SRN) for England and the UK. The SRN in England is 7040 km and we extrapolated the UK SRN (in absence of a public reference) to be 8,862 km.

Given the nature, geography and placement of dedicated infrastructure along major transport corridors, the cell ranges typical of rural areas were used independent of the location of the road. This approach was taken as there are typically fewer obstructions to radio signals when covering a motorway or major A-road (compared to propagation in suburban or urban areas).

The required capacities were calculated based for the "best-case", "average-case" and "worst-case" scenario on a 6-lane motorway with different car densities.

#### **Entertainment service**

Entertainment service, in a car or anywhere, typically requires a MBB service platform and these services are high in network capacity demand. The required capacities were driven by different user behaviour and car density on the motorway with the drivers and passengers using audio, media and internet applications on their devices. The details can be found below.

<sup>1</sup> O2's 4G licence requires it to cover at least 98% of the indoor UK population by the end of 2017 - which should also result in 99% population coverage outdoors



Descri	ptor	Best case	Average case	Worst case
ario view	Density (cars per linear km)	33	100	100
	Number of lanes	6	6	6
cen ver	Demand per car (Mbps)	8.0	8.0	25.5
νõ	Demand per km (Gbps)	1.6	4.8	15.3
	Site to site distance (m)	905	300	95
E B	Sites SRN (England)	7815	23446	N/A
Mediu ban	Cost SRN (England)	£270m	£811m	N/A
	Sites SRN (UK)	9838	29515	N/A
	Cost SRN (UK)	£340m	£1,021m	N/A
	Site to site distance (m)	510	510	510
งWave and	Sites SRN (England)	27,393	54,786	136,965
	Cost SRN (England)	£948m	£1,044m	£1,331m
a mm	Sites SRN (UK)	34,484	68,968	172,420
	Cost SRN (UK)	£1,193m	£1,314m	£1,676m

Table 8: Entertainment use case – MBB sites and estimated cost requirement

Given the requirements, the low frequency band (700 MHz) would not be able to cope with demand. Therefore, the number of sites required was calculated based on the medium (3.5 GHz) and high (mmWave) bands.

The medium band has more cell capacity than the low band and by shrinking cell ranges, the capacity can be delivered for the best-case and average-case scenario. For the worst-case scenario, only mmWave could provide the capacity. This is because the deployment using the medium band requires placing sites less than 100m apart to meet the capacity requirements. However, for both mid and high band, small inter-site-distance could be problematic. This is because, as the vehicle moves out of coverage from one cell to the next cell, the connection needs to be handed over from the current cell to the next cell. With small inter-site-distance i.e. less than 100m, frequent hand over could results in poor user experience.

But to deliver the average (4.8 Gbps) and worst-case (15.3 Gbps) capacity per km we needed to increase the number of mmWave equipment per site (on the same infrastructure with a 500 MHz channel per kit) to meet demand.

We are not forecasting the same capacity demand and importance of mobile broadband for non-SRN roads and would expect these capacities to be carried by the countrywide mobile broadband networks.

### Advanced driver assistance systems (ADAS)

ADAS requires MCC connectivity, especially in terms of high availability. The throughput level per car is assumed to be between 10 - 100 kbps. For this exercise, we assume a challenging average peak demand of 100 kbps per car in the same motorway and car density scenario as described above.

The detail for demand, sites and costs for the motorway scenario with different car densities can be found below.



Descriptor	Best case	Average case	Worst case
Density (cars per linear km)	10	33	100
Number of lanes	6	6	6
Capacity per service (kbps)	100	100	100
Demand per km (Mbps)	6	19.8	60
Sites SRN (England)	5,449	5,449	5,449
Cost SRN (England)	£189m	£189m	£189m
Sites SRN (UK)	6860	6860	6860
Cost SRN (UK)	£237m	£237m	£237m

Table 9: ADAS use case – MCC sites and estimated cost requirement

In the sites and cost analysis for this use case, we used the medium band for all cases. This is because it can serve up to 112 Mbps / km per cell and therefore satisfies the requirements of the best to the worst-case. Using the low band with 3.9 Mbps / km capacity would have been a potential different approach but only for the "best-case". However, gaining sufficient spectrum in the low band is a challenge (assumption being 7 MHz – 10% of total in the low band) or alternatively the solution would be to reduce the cell range by 35% resulting in 54% more sites, which are likely to be costlier than 3.5 GHz.

## Vehicle management

Vehicle management requires the MTC service platform. The throughput level per car is assumed to be between 10 - 100 kbps but as it is typically not such a critical application, we assume an average peak demand at 50 kbps in the same motorway and car density scenario as described above.

Due to the low cell edge capacity requirement (100 kbps), the cell ranges are larger for MTC compared to the other service platform. But typically, the spectrum for dedicated MTC networks would be less than for MBB networks.

The detail for demand, sites and costs for the motorway scenario with different car densities can be found in the Table 10 below.

Descriptor	Best case	Average case	Worst case
Density (cars per linear km)	10	33	100
Number of lanes	6	6	6
Demand per car (kbps)	50	50	50
Demand per km (Mbps)	3	9.9	30
Sites SRN (England)	624	624	1,143
Cost SRN (England)	£22m	£22m	£40m
Sites SRN (UK)	785	785	1,439
Cost SRN (UK)	£27m	£27m	£50m

### Table 10: Vehicle management use case – MTC sites and estimated cost requirement

The sites and costs above are all based on the medium spectrum band. This band was chosen as the spectrum available in the lower spectrum band is limited and the cell ranges are too large to meet the demands e.g. from a single site covering 25 km of busy 6-lane motorway.


The medium band had an ideal mix of channel capacity and cell range for this specific use case. In the average-case and best-case scenario, the medium band cell capacity was sufficient and therefore the site distance was determined by the maximum cell range for MTC applications. In the worst-case scenario, the cell ranges were reduced by around 50% to increase the capacity per km road and to meet demand.

# 4.3.2 Railway use cases

There is 16,090 km of rail route in the UK with approximately 4,043 trains. This results in about one train per 4 km. rail route in the UK.

Like the connected car (motorway) scenario, the propagation and cell range assumptions for rural areas was used given the nature, geography and placement of dedicated infrastructure along the rail routes. A further assumption is that trains will have external antennas, which is in alignment with our outdoor coverage approach for cell ranges (external mounted antennas allow us to overcome the high, and variable, penetration losses associated with railway carriages).

Further assumptions had to be made for demand distribution as the train environment is different to a motorway. In an automotive scenario, traffic is distributed along the road whilst a train is a travelling "hotspot" requiring a network to meet all its demand independent of its location along the track.

# **Passenger broadband**

The average number of passengers per train was calculated to be 560 by 2025 (based on current average numbers and passenger growth forecasts by DfT).

In a recent Real Wireless study on a 59 km single track route (with 10 trains and a GSM-R site at 3.6 km intervals) from London to a smaller city, crossing urban, suburban and rural areas, we found that GSM-R base stations were idle most of the time. The statistic for base station activity was 83.5% idle (no train in range), 12.5% of the time with a single train in the catchment (coverage area) and only 1.5% on the time with 2 or more trains in the catchment area. Given the low likelihood of this happening, we are assuming only one train per 4 km route in average

Descriptor	DfT case	Best case	Average	Worst case	
Density (trains per linear km)	0.25	0.25	0.25	0.25	
Demand per train (Gbps)	0.1	1.2	1.6	2.7	
Demand per km (Mbps)	25 290		407	679	
Sites for UK Railways	3,292	31,304	31,304	62,607	
Cost for UK Railways	£362m	£1,083m	£1,083m	£2,385m	

# Table 11: Passenger broadband use case – MBB requirements and estimated costs

Given that the entire capacity demand of the train must be delivered to the train independent of its location, a reduction of cell ranges (as applied to motorway scenario to increase capacity per km) did not apply.

We found that the low spectrum band (700 MHz) with tall greenfield sites, a 105 Mbps cell capacity would be sufficient to meet the 100 Mbps per train requirement from DfT. However, in denser areas with higher likelihood of multiple trains in the 3.8 km cell area,



this capacity would have to be shared between the trains. Given that the required low band spectrum can be obtained, this solution would come at a much lower cost compared to the scenarios with capacity requirements in excess of 1 Gbps per train.

Looking at the best-case to worst-case scenario, the medium band does not meet minimum demand requirements as the average cell capacity is just over 700 Mbps. Therefore mmWave had to be used as it is able to deliver capacities in excess of 1 Gbps and more capacity can be delivered by adding more radio equipment on the same site location (more 500 MHz channels, adding 1.6 Gbps capacity each).

For the calculation of mmWave along the railway tracks, we did not double up the number of mmWave equipment along the track (as we did in the motorway scenario). This is as rail routes are a controlled environment and as we assumed ideal track-side site locations featuring directive mmWave base station antennas and that the train would have roof mounted antennas. Therefore, a single connection for future mmWave seems feasible (with exception of railway stations and tunnels) compared to a motorway where we assumed dual connectivity for mmWave technologies.

### **Command & control**

Command and control requires a MCC service platform. The capacity requirements are very small compared to the passenger broadband demand figures but the availability requirement is far higher.

Descriptor	Best case	Worst case
Density (trains per linear km)	0.25	0.5
Demand per train (kbps)	200	200
Demand per km (kbps)	50	100
Sites for UK Railways	4,580	4,580
Cost for UK Railways	£504m	£504m

#### Table 12: Command and control use case – MCC site requirements and estimated cost

Due to the low data rate for command and control (200 kbps per train), the low spectrum band was found to be sufficient to deliver the required service. Using the low band resulted in wider cell ranges which increases the risk of obstruction. Therefore, and due to the critical nature of this service, a mix of suburban & rural propagation characteristics was used for the cell range definition (compared to rural cell ranges for MBB).

This solution will deliver sufficient capacity using the low spectrum band to support the critical nature of this service, supporting command, control, including future driverless trains where a central operator can use voice services to talk to passengers on the train.

#### **Telemetry service**

For telemetry data, a MTC network is the typical service delivery platform applied to this use case and we cost accordingly. However, a combination of service platforms for a dedicated objective such as rail should also be considered.



Table 13:	Telemetry	service use	case –	MTC site	requirements	and	estimated o	osts
-----------	-----------	-------------	--------	----------	--------------	-----	-------------	------

Descriptor	Best case	Worst case
Density (trains per linear km)	0.25	0.5
Demand per train (kbps)	300	300
Demand per km (kbps)	75	150
Sites for UK Railways	644	644
Cost SRN (England)	£71m	£71m

Due to the low data rate per train, the low spectrum band can be used. Low frequency usage results in long cell ranges but even with double the average of trains per track (one train each 2 km instead of a train per 4 km of track), there would be a lot of cell capacity left.

## 4.3.3 Healthcare use cases

Healthcare applications that use wireless, especially assisted living and remote healthcare, are services that are typically used indoors, with a wireless link (e.g. Wi-Fi) to residential broadband for connectivity. Preventative health applications can be used both indoors and outdoors (e.g. FitBit). These devices are generating very little data, are either tethered to a smartphone or start to synchronise data once back at home in the coverage area of e.g. residential Wi-Fi.

Given the low intensity of outdoor usage, the impact of health on national infrastructure is minimal. Therefore, we did not consider it necessary to carry out a comprehensive capacity calculation for the health use cases and derived the network cost only based on delivering outdoor coverage using the relevant coverage driven cell ranges.

### **Assisted living**

Assisted living relies on sensors and devices transmitting data to a database or platform, allowing GPs, family members and/or carers to monitor and/or get alarms when some changes are detected. This would typically be an indoor system in the living area of vulnerable and elderly people, backhauled by a fixed connectivity such as residential backhaul. But for exceptional cases, it could be running on a MTC platform. Given small data rates (10 - 100 kbps per patient) and the low intensity of outdoor usage, a low frequency range MTC network with 0.5 Mbps average capacity per cell is sufficient. UK wide coverage could be achieved theoretically with 515 ideally placed sites at an estimated cost of £51m.

Alternatively, given the low likelihood of it happening, it could be supported on a low spectrum range MBB network with 105 Mbps average capacity per cell together with other applications. A basic MBB network could theoretically be achieved with 5,467 sites at an estimated cost of £535m based on a pure low band and coverage driven approach.

### **Remote healthcare**

Remote healthcare is another application that would typically happen indoors, where a patient has a remote consultation with a GP in the privacy of his own home. Statistically 80% of network traffic is generated indoors, but for this use case, taking patients privacy into consideration, we assume that at least 90% of consultations would happen on residential (patient) and commercial (GP) indoor networks.



Statistically there are just over 8 consultations a year per person in the UK [143]. Based on normal working hours, Monday to Friday and 20 minutes average consultation time, the cell capacity of a basic coverage driven MBB network has on average (and depending on area) 4 - 42 times more capacity than required, even if all consultations would use 4K resolution and are happening remotely.

Therefore, a coverage driven low frequency range MBB network based on 5,467 sites and an estimated cost of £535m is sufficient.

### **Preventative health**

Connectivity for the transmission of preventative health data is not critical. It is best effort based and can be stored till the device gets back to coverage or its home (e.g. Wi-Fi) network for data to be submitted. This use case would also often happen indoor but will have the highest outdoor component to it compared to the other healthcare use cases. It is also very low data rate (1 - 100 kbps per person, even with multiple devices) and is very often based on local and body area networks that are connected to Wi-F or a smartphone. In the case of a smartphone, in some a MBB platform would be used for connectivity (if not residential Wi-Fi).

Based on the low data rates and low criticality, a basic low frequency range MBB network can carry the requested traffic with 105 Mbps average capacity per cell. This needs 5,467 sites at an estimated cost of £535m based on a pure low band and coverage based approach.

# 4.3.4 Utility & supply chain use cases

These three use cases are all IoT type of applications of relatively low data rate and would be supported by a MTC service platform.

# Smart grid

Smart meters are already being deployed widely and the smart meter driven data carried by the supporting MTC networks(s) is estimated to be in a range of 23 - 112 TB per year by 2025 [144]. Based on an average figure of 75 TB, the data rate would be no more than 2 kbps per km<sup>2</sup>, even in the densest (urban) household areas.

From a smart grip point of view, devices are in the data rate range of 1 – 200 kbps. However, most of them are of very low activity and have long periods of silence. Therefore, average MTC network load must be considered and not the peak rate when they are transmitting. The most challenging device is a Smart Grid class A device, generating 1 kbyte of data every 6 seconds [145]. This equates to a constant average data rate of 1.3 kbps per device. Assuming a forecasted 900,000 devices in the UK (all running at 1.3 kbps in the worst case) and device densities distribution aligned with population densities, the per km<sup>2</sup> average MTC data rate demand would range from less than 1 kbps in rural areas to 102 kbps in the densest (urban) areas.



# ...........

Descriptor	Urban	Suburban	Rural	Total
Device density (smart meter / km2)	2572	1956	16	4545
Device density (smart grid / km2)	79	60	1	140
Demand per km <sup>2</sup> (kbps)	103	79	0.7	N/A
Sites (all in low band)	40	68	470	577
Costs	£3.6m	£6.4m	£47.6m	£57.7m

 Table 14: Smart grid use case – MTC sites and estimated cost requirement

Given these assumptions above, an outdoor coverage driven low spectrum band MTC network would be sufficient to meet the need of smart meters and smart grids.

## **Road haulage**

For the road haulage use case, we assumed the same motorway scenario as for the connected cars use case. We also assumed rural type of cell ranges as in the other motorway scenario due to the nature of typical SRN roads. But instead of 100% cars on the road, we assumed that 20% of vehicles on the SRN would be LGVs and HGVs (used for logistics) requiring a MTC service platform supporting 100 kbps per vehicle. More detail to the motorway scenario can be found in Table 15 below.

Descriptor	Best case	Average case	Worst case
Density (LGV/HGV per linear km)	2	7	20
Demand per LGV/HGV (kbps)	100	100	100
Demand per km (Mbps)	0.2	0.7	2.0
Sites SRN (England)	281	281	322
Cost SRN (England)	£31m	£31m	£35m
Sites SRN (UK)	354	354	405
Cost SRN (UK)	£39m	£39m	£44m

#### Table 15: Road haulage use case – MTC sites and estimated cost requirement

We found that a coverage driven low spectrum band MTC network can support the data demand in the best-case and average-case scenario. However, for the worst-case scenario, the cell range had to be reduced by 10% to meet demand which had a site count and cost impact.

### **Drone delivery**

According to Amazon, delivery drones will fly in a 200 – 400 ft above ground corridor. We assumed the delivery drone requirement to be limited to urban and suburban areas as this is likely a population density and distribution centres location driven use case.

We used our urban and suburban outdoor MTC cell ranges for our coverage and capacity calculations. This is because coverage is needed in the sky and also terrestrial to connect with the drones when they take-off or land. We also assumed that most infrastructure would be roof mounted with specialised antennas featuring a weaker "upwards" side lobe (less gain needed for LOS) to cover the sky.

The drones will fly mostly autonomously based on a pre-determined flight path and there may also be a data and spectrum need for V2V with no impact on infrastructure. However, there is a need for a low data rate MTC to support location data, deliver potential alarms



and allow emergency control. In the absence of solid and referenceable data, as systems are proprietary and still experimental with no published standards, we assumed a data rate range of 1-50 kbps per drone. Note that higher data applications are not supported, e.g. a picture of a delivered item is assumed to be downloaded when the drone returns to its base.

For this potential future use case, we assumed 100 drones per km<sup>2</sup> (or km<sup>3</sup>). At a data rate of 1 - 50 kbps and the given density, the demand would be 0.1 - 5 Mbps / km<sup>2</sup>.

Descriptor	Urbar	n area	Suburban area			
Descriptor	Best case Worst case		Best case	Worst case		
Density (drone per km <sup>2</sup> )	100	100	100	100		
Demand per Drone (kbps)	1	50	1	50		
Demand per km <sup>2</sup> (Mbps)	0.1	5	0.1	5		
Sites – Low band	40	-	180	-		
Sites – Medium band	-	1,122	-	5,106		
Costs	£3.8m	£107m	£17m	£485m		

#### Table 16: Drone delivery use case – MTC sites and estimated cost requirement

As the data rate demand for the two scenarios is very different, we had to calculate a low band (for the best-case) and medium band (for the worst-case) infrastructure based network to support demand.

# 4.3.5 Media and cloud use cases

The media and cloud use cases are all high data rate broadband applications, typically cloud related, requiring sufficient outdoors MBB capacity, independent of location.

These MBB broadband networks utilise mmWave spectrum for all use cases in urban areas to deliver the peak capacities that would challenge low and medium spectrum bands. In the suburban and rural areas, low and medium spectrum bands prove to be sufficient to meet the demand.

### 4K content everywhere

This is built on the emerging 4K standard and its expected market adoption, some question the need for 4K resolution on a portable device with a limited screen size, however we see a credible level of investment on the supply side and general level of interest on the demand side thus a reasonably high demand per km<sup>2</sup> is established.

4K streaming is expected to require 12 Mbps of constant capacity by 2025 (based on future compression technologies) with up to 40% of the population streaming in peak hours, but only 20% of these are expected to be outdoors using the MBB network.

#### Table 17: 4K content use case – MBB sites and estimated cost requirement

Descriptor	Urban	Suburban	Rural	Total
Demand per km <sup>2</sup> (Gbps)	5.6	1.1	0.01	N/A
Sites	53,148	16,367	3,035	72,550
Costs	£1,187m	£695m	£308m	£2,190m



The results in Table 17 above show the MBB network cost to satisfy a challenging nationwide 4K content streaming use case. The urban number is high as it was assumed that commuters and people in the city would be streaming more than people in suburban and rural areas.

#### **Immersive** gaming

Gaming with high availability, reliability and data rate requirements, as used by seasoned gamers, is typically using high speed residential broadband. Seasoned gamers have learned to avoid wireless and would prefer not to use wireless external controls (e.g. mouse) due to perceived latency issues affecting the gaming experience. However, these gamers are a minority and even if the MBB network would support it, a serious gamer would usually play in a controlled indoor environment.

VR is expected to grow a lot, especially with the emergence of gaming events attracting thousands of virtual spectators. However, VR will very rarely be used outdoors as the user can't see their environment. VR would typically be used in a stationary and controlled indoor environment such as a home, gaming centre or potentially in cars and trains. Despite that and to analyse worst case network demand, we assume 2.5% of the population playing VR at 18 Mbps in an outdoor environment.

AR is far more likely to be used outdoors and we assume 25% of the population using AR outdoors at an average of 0.5 Mbps (typically 100 kbps – 1 Mbps) in peak time.

Descriptor	Urban	Suburban	Rural	Total	
Demand per km <sup>2</sup> (Gbps)	3.4	2.6	0.02	N/A	
Sites	33,191	39,524	3,035	75,750	
Costs	£931m	£1,535m	£308m	£2,775m	

#### Table 18: Immersive gaming use case – MBB sites and estimated cost requirement

Like "4K content everywhere", gaming is driving high network demand and results in a need of substantial mmWave sites in urban areas. But estimated costs are particularly high in suburban areas as a denser medium and low band deployment is needed.

### **Mobile office**

The mobile office use case is based on (mostly cloud based) business applications running on portable devices. These applications include background tasks (backup, updates, synchronisation etc.) at 1.44 Mbps, cloud based applications (email, remote storage etc.) at 1 Mbps and video conferencing at 2.4 Mbps.

Aligned with the statistics of 80% of traffic generated indoors, we assume that the professional mobile office user would spend up to 20% of time outdoors.

We increased the population density in urban areas for this use case to reflect the behaviour of professionals commuting to the cities in working hours. Suburban and rural population densities remain the same.

#### Table 19: Mobile office use case – MBB sites and estimated cost requirement

Descriptor	Urban	Suburban	Rural	Total		
Demand per km <sup>2</sup> (Gbps)	9.3	0.5	0.004	N/A		



Sites	86,654	7,661	3,035	97,350
Costs	£1,797m	£379m	£308m	£2,483m

Compared to the other use case in the media and cloud use cases section, mobile office is driving network densities the highest in urban areas, which is not surprising given the nature of use, the increase working population densities and their associated usage behaviour.

# 4.4 Potential for combining use cases and infrastructure costs

With reference to Table 20 we provide the following high level guidance on use case and associated infrastructure combining.

		Cor	nnected	Car		Railway	'	н	ealthca	re	Utility	& Supp	ly Chain	Med	ia and C	loud
		L	ise case	S	L	ise case	S	L	ise case	S	l. I	ise case	!S	L	ise case	S
		Entertainmen t Service	Driver Assistance	Vehicle Management	Passenger Broadband	Command & Control	Telemetry Service	Assisted Living	Remote Healthcare	Preventative Health	Smart Grid	Road Haulage	Drone Delivery	4K Content Everywhere	Immersive Gaming	Mobile Office
Mobile Broadband	MBB	>	(✓)	(✓)	×	(✓)	×	(✓)	>	>	*	×	×	~	>	×
Machine Type Communications	мтс	(✓)	×	<b>~</b>	*	(✓)	×	×	(✓)	(✓)	<b>~</b>	×	×	×	x	(✓)
Mission Critical Communications	мсс	×	×	×	*	×	*	(✓)	×	*	(✓)	(✓)	(✓)	×	(✓)	×

#### Table 20 use cases and service platforms

Use cases that require the MBB platform have the highest demand among the use cases we considered in this study, and therefore the highest capacity requirements. If a network is deployed to serve these high demanding use cases, with further minor capacity upgrade, it will be possible to support services requiring the MTC service platform. An example of an equivalent approach from today's networks is that which has been applied in the case of Telefonica-O2 to support the smart metering project in the UK [146].

Use Cases utilising the MCC service platform require greater coverage to additional geographical areas and a higher coverage confidence compared to MBB and MTC. To achieve these network performance requirements necessitates the deployment of additional infrastructure to extend the coverage. An example of an equivalent approach from today's networks is that which has been applied by EE for provision of enhanced coverage for the emergency communications network in the UK [147].

To dimension a combined MBB capable infrastructure that would deliver a consistent level of service to users along roads, rail and all geographic areas is out of scope of the quantitative analysis undertaken for this report. However, qualitatively we can with confidence state that by combining the dimensioned infrastructure of 4k content everywhere, connected car – entertainment, and railway – passenger broadband, there would be synergies in deployment that would significantly decrease the cost of infrastructure when compared to a simple summation of costs. However, the total cost would still be substantially more than the standalone cost of 4k content everywhere.

In general, combining of use cases when they utilise the same service platform type is a realistic approach that may yield synergies and cost benefits. A national MBB capable infrastructure that provides media and cloud use cases would be adequate to provide the majority of healthcare use cases at no incremental cost of infrastructure. Similarly, a national MTC supporting infrastructure for utility and supply chain would likely be adequate for vehicle management as road haulage is included in supply chain use cases. However,



telemetry services along rail corridors may require supplementary infrastructure, which wouldn't be at the full cost of the telemetry service estimate, but exactly how much lower is not quantified.

Combining of use cases across service platform types should be carried out with caution. If one were to establish a MBB service platform infrastructure, the cost of upgrading to an MCC capability would primarily be based on densification. However, a replanning of the existing MBB infrastructure would also be required as the requirements in terms of reliability of communications are significantly greater. Starting from a MBB infrastructure supporting 4k Everywhere an overlay of MTC smart grid may be viable as these are both national level coverage systems. However, this would depend on a number of factors including the spectrum planning, prioritisation of the heterogeneous traffic in the network and others. Further considerations in terms of multi-service and multi-tenant dynamics would also be in scope of such a combining analysis. Detailed combining analysis has not been carried out for this report, but is viable based on state of the art modelling capabilities.

Re-using existing infrastructure is likely to be the most logical and cost effective way to provide future services. However, if a common network infrastructure is used to serve different network platforms and use cases complexities may be introduced due to the heterogeneous nature of the resultant traffic that is carried over a network. Technical approaches to manage traffic prioritisation are enabled on maturing 4G networks with further enhancements expected for the nascent 5G. However, traffic heterogeneity also introduces network policy and operations complexities.



# 4.5 Summary

Table 21 shows the cost of infrastructure (in £millions) for each use case.

# Table 21: Cost of infrastructure (£millions)

	Use cases	Coverage type		Transport corridor (road/rail)				UK geography*								
			B	lest	A	verage	٧	Vorst	Tot	al	Ur	ban	Su	burban	Rui	ral
	Entertainment Service: med (hi)**		f (£1	340 .,193)	f (£	E1021 1,314)	(£	N/A 1,676)								
Car	Driver Assistance	km)	£	237	£	237	£	237								
	Vehicle management		£	27	£	27	£	50								
	Passenger Broadband		£	1,083	£	1,083	£	2,385								
Railway	Command & Control	UK Rail (16090 km)	£	504			£	504								
	Telemetry Service		£	71			£	71								
	Assisted living								£	51 to 535	£	7 to £64		£4 to £164	£4 £30	1 to )8
Healthcare	Remote Healthcare	UK geography							£	535	£	64	£	164	£	308
	Preventative Health								£	535	£	64	£	164	£	308
	Smart Utility	UK geography							£	58	£	4	£	6	£	48
Utility & Supply Chain	Road haulage	UK SRN (8862 km)	£	39	£	39	£	44								
	Drone Delivery	UK geography									f	E3.8 to £107	1	£17 to £485		
Media and Cloud	4K everywhere								£	2,190	£	1,187	£	695	£	308
	immersive gaming	UK geography							£	2,775	£	931	£	1,535	£	308
	mobile office	<u> </u>			<u> </u>		[		£	2,483	£	1,797	£	379	£	308

\* MBB and MTC has a geographic coverage of 86% (99%population outdoor), MCC has 99% geographic coverage

\*\* med = medium band solution, hi = mmWave band solution



# 5. Conclusions

Our study initially identified forty-eight use cases. Through a process of prioritisation and then determination of representative use cases in various sectors of interest a set of fifteen use cases were identified for detailed treatment. This prioritisation was achieved by considering the potential benefits and take up of the use case.

To establish the basis for costing of infrastructure three service platform definitions were derived that would adequately support these fifteen use cases. The service platforms are:

- **Mobile Broadband (MBB)** which supports a full range of mobility and significantly enhanced user data rates over those that are experienced today
- Machine type communications (MTC) which supports typically lower data rates, large numbers of end points and low costs
- **Mission Critical Communications (MCC)** which supports reliability and availability at significantly higher levels than MBB and MTC

MBB is driven by the Connected Car, Railways and Cloud based applications such as Media and Business services. Healthcare also drives MBB but it would be mostly used indoors. MTC is mainly driven by Railways, Utilities and Logistics but also brings benefits to Connected Cars. MCC is driven mostly by Connected Cars and Railways but Healthcare and Smart Utilities could also get strong benefit from its implementation.

From the fifteen use cases one use case has been identified for each of the three service platforms which is likely to be at the leading edge in terms of adoption of the supporting national infrastructure. For MBB, 4K everywhere builds upon the current growth in dominance of video over mobile networks and increases the required capacity of today's networks. For MTC, the vehicle management use case benefits from the rapidly increasing interest in the utilisation of connectivity in automotive. For MCC, again the connected car provides a focus by way of Advanced Driver Assistance Systems (ADAS).

Cost analysis for connected car use cases identifies that mid-band equipment at the roadside can adequately deliver capacity until the very highest demand figures at which point mmWave becomes a necessary solution. However, the estimated costs associated with delivery of low end demand forecasts at £340m escalate substantially to meet the highest demand to beyond £1.5bn. The case for provision of such high capacity along the roadside for entertainment will be a question for industry to resolve as entertainment would not be an area of priority for the NIC. Of greater interest to the NIC will be the ADAS and vehicle management use cases as these promise improvements in safety and efficiency of transport systems and the capacity demands are lower. With lower capacity demands the mid-band is sufficient and even low-band for MTC like systems with substantially lower estimated costs at £237m and £50m respectively.

The railway use cases illustrate a significant spread in estimated costs from £362m to beyond £2bn for all rail routes in the UK depending on satisfying the lower or high demand for passenger broadband. These estimated costs are driven by projected demands well beyond existing DfT targets. In reality, similar to the SRN concept on the roads, provision of high capacity broadband to railways should be based on the major high traffic routes. Command and control along with telemetry use cases offer benefits in terms of transport system capacity and reliability gains and with costs for infrastructure from £500m down to £71m they are worthy of further consideration.



Healthcare presents three major use cases – assisted living, remote health care and preventative health. Whilst there is evidence of trials to apply connectivity based solutions in the sector, several respondents we interviewed highlighted that they did not see evidence of an early adopter appetite in the sector. The sector is more likely a late adopter of maturing 3G and 4G technologies. Most applications in the sector are based on indoor connectivity, outdoor mobile connectivity requirements are not sufficient to justify investment in network infrastructure.

Utility and supply chain use cases demonstrate the diversity of benefits from a predominantly M2M or IoT oriented connectivity. The estimated costs for the provision of such networks is £103.1m. Drones delivery demonstrates a more demanding use case for infrastructure - urban and sub-urban area coverage for drones could have costs of £592m – however this is likely a high estimate as drone delivery is at a very early stage of definition; we chose to take a conservative view on the infrastructure implications.

Media and cloud use cases represent the greatest demands on a national level infrastructure beyond the road and rail corridors. To achieve the peak capacity that may be required mmWave solutions would be necessary. Costs show a wide spread because of the uncertainty of demand and we have calculated costs to be in the £2-3bn range for each use case.

During this study, we have re-confirmed well understood conventions in the mobile telecoms industry relating to the appropriate utilisation of spectrum bands.

- It is evident yet again from this study that there is a high value in the low-band for cost optimal coverage. We have limited the height of antenna sites based on UK regulations. The cost/coverage balance could be further enhanced by the relaxing of height restrictions.
- There is a great deal of utility in the mid-band for capacity, this band will serve a great deal of the demand for future mobile communications.
- There are still several technical challenges with delivering reliable connectivity in high-band (mmWave). Only where necessary to reach high capacity do we utilise high-band. We have found that we can avoid the use of high-band in rural environments, for rural villages mid-band would suffice. High-band has utility in urban, and for some high demand cases sub-urban deployments.

We provide a summary of our findings for each use case in the following table.



# Summary table with findings from all use cases

Use Cases		Direct Benefits (Industry/User)	Indirect Benefits (Infrastructure Implications)	Network Infrastructure Requirements	Network Infrastructure Cost
l Car es	Entertainment Service	<ul> <li>New one off and recurring revenues</li> <li>Enhanced services for driver and passengers</li> </ul>	<ul> <li>Children entertained leads to less driver distraction and improved safety</li> </ul>	<ul> <li>MBB service, 0.5 – 25.5 Mbps per car</li> <li>On SRN requires 1.6 Gbps in the best-case and 15.3 Gbps in the worst-case per km</li> </ul>	<ul> <li>£1bn for the average scenario UK SRN using the medium spectrum band</li> </ul>
Connected use case	Driver Assistance	<ul> <li>Reduction in deaths and injuries</li> <li>Congestion reduction, improved average speeds</li> </ul>	<ul> <li>Road operators have improved real time control of traffic</li> </ul>	<ul> <li>Primarily MCC application</li> <li>Mix of vehicle to vehicle and vehicle to infrastructure, 10 - 100 kbps for V2I per car</li> </ul>	• £237m for best-case to worst-case UK SRN using the medium spectrum band
	Vehicle Management	<ul> <li>Maintenance schedule aligned vehicle diagnostics</li> </ul>	<ul> <li>Reduction in component failures</li> </ul>	<ul> <li>MTC service – mostly gathering performance data from vehicle</li> <li>10 - 100 kbps per car</li> </ul>	• £27m for the medium-case UK SRN using the medium band
Railway use cases	Passenger Broadband	<ul> <li>Convenience and attractiveness of connected rail travel</li> <li>Enabling passengers to work, stream and access social media</li> </ul>	<ul> <li>Might require to build more sites than are available which can be used for MCC and MTC</li> </ul>	<ul> <li>MBB application for all UK rail routes</li> <li>DfT is planning 100 Mbps per train</li> <li>We suggest 1.2 – 2.7 Gbps for 2025 per train</li> </ul>	<ul> <li>£362m for DfT scenario at 700 MHz and £1.1bn for the average scenario at using mmWave</li> </ul>
	Command & Control	<ul> <li>Increased safety, 80% fewer "Signals Passed At Danger"</li> <li>40% more train capacity at 30% lower cost</li> <li>35% reduction in signalling caused delays</li> </ul>	<ul> <li>Will delay the need to build out rail network</li> <li>Reduced power consumption, hence delay in power grid upgrade</li> </ul>	<ul> <li>MCC application for all UK rail routes</li> <li>Vital services, needs high availability (99.999%)</li> <li>200 kbps per train</li> </ul>	<ul> <li>£504m for best-case and worst-case scenario using the low band</li> </ul>
	Telemetry Service	<ul> <li>Condition based maintenance and less failures</li> <li>Reduction of signalling maintenance spend (currently £3bn spent every five years)</li> </ul>	<ul> <li>Less stocking of spares</li> <li>Removal of physical signalling infrastructure</li> <li>Better use of facilities as less maintenance</li> </ul>	<ul> <li>MTC application for all UK rail routes</li> <li>Best effort traffic, when service available</li> <li>300 kbps per train</li> </ul>	<ul> <li>£71m for best-case and worst-case scenario using the low band</li> </ul>

# . . . . . . . . . . . . . . . . . .

	Use Cases	Direct Benefits (Industry/User)	Indirect Benefits (Infrastructure Implicat <u>ions)</u>	Network Infrastructure Requirements	Network Infrastructure Cost
	Assisted Living	<ul> <li>Dramatic reduction of hospital admissions</li> <li>25% of hospital in patients are dementia sufferers and could potentially be cared for remotely</li> <li>Estimated cost of £26 billion a year to the UK (NHS and private individuals) from dementia which could be reduced</li> </ul>	<ul> <li>In home wireless network with home gateway compatible with all monitoring devices and providing end to end security of data transferred</li> <li>Peace of mind for carer and family that patient is monitored and can stay longer at home</li> </ul>	<ul> <li>MTC application, typically using fixed broadband, rarely MBB</li> <li>Data rates of 10 – 100 kbps per patient (sensors 1 – 10 kbps) and low intervals</li> <li>Alarm application may require high availability</li> <li>Typically all indoors, little external network impact</li> </ul>	<ul> <li>£51m for a UK wide network at low spectrum band</li> <li>£535m alternative for a UI wide basic MBB network</li> </ul>
Healthcare use case	Remote Healthcare	<ul> <li>Fewer missed appointments which costs the NHS over £1bn per year</li> <li>More efficient care for chronic conditions such as Type 2 diabetes (NHS spends £10 billion a year, 10% of budget)</li> </ul>	<ul> <li>Ensures end to end security for exchange of patient information and interconnectivity with existing medical records systems</li> <li>More convenient and efficient for patient</li> <li>MBB application if needed outdoors (assumed to be an indoor fixed broadband case)</li> <li>GP video conferencing, SD at 1.2 Mbps, HD at 2-3 Mbps and 4K @ 12 Mbps (by 2025)</li> </ul>		<ul> <li>Ideally using the existing N network</li> <li>£535m for a UK wide low band MBB network</li> </ul>
	Preventative Health	<ul> <li>High potentially of reduced health needs if consumers take better control of own health</li> <li>Reduced strain on NHS from UK having highest obesity rate in Western Europe</li> <li>Less health costs and reduced insurance premium</li> </ul>	• Ensures end to end security for exchange of patient information and interconnectivity with existing medical records systems	<ul> <li>MBB application if outdoors (often using indoor Wi-Fi)</li> <li>Low availability needs, buffering, best effort</li> <li>Typically, smartphone tethered wearables</li> <li>Low data rate traffic, 1 – 100 kbps per person (best effort traffic)</li> </ul>	<ul> <li>Ideally using the existing N network</li> <li>£535m for a UK wide low band MBB network</li> </ul>
upply Chain cases	Smart Utility	<ul> <li>Aligns generation to demand in real time</li> <li>Faster fault repair and recovery</li> <li>More accurate lower consumer's bills</li> </ul>	<ul> <li>Less central generation capacity required</li> </ul>	<ul> <li>Smart metering is MTC, 2 kbps / km<sup>2</sup> max, 1 kB/day household</li> <li>Smart grid is MTC &amp; MCC (focus on MTC), 1 kbps / km<sup>2</sup> rural, 100 kbps / km<sup>2</sup> urban</li> </ul>	<ul> <li>£58m for a UK wide low spectrum band</li> </ul>
Utility & S use	Road Haulage	<ul> <li>Reduction in carbon emissions</li> <li>Shortened delivery times</li> </ul>	<ul><li>Improved competitiveness</li><li>Reduced congestion</li></ul>	<ul> <li>MTC application</li> <li>100 kbps per vehicle</li> <li>20% of vehicles related to logistics (LGV/HGV)</li> </ul>	<ul> <li>£39m for best-case to average-case scenario of L SRN using the low band</li> </ul>



Use Cases		Direct Benefits (Industry/User)	Indirect Benefits (Infrastructure Implications)	Network Infrastructure Requirements	Network Infrastructure Cost
	Drone Delivery	<ul><li>Reduced road congestion</li><li>Shortened delivery times</li></ul>	Reduced carbon emissions	<ul> <li>Mix of MCC and MTC for urban and suburban only</li> <li>Focus on MTC with 100 drones per km<sup>3</sup></li> <li>1 – 10 kbps each</li> </ul>	<ul> <li>£21m for best case using low band and £592m for medium band</li> </ul>
lia and Cloud use cases	4K Content Everywhere	<ul> <li>Entertainment on the move</li> <li>Adding value – e.g. opportunity for digital ads industry</li> <li>Pay-TV revenues and opportunity for MNOs</li> </ul>	<ul> <li>Requires high capacity broadband network that will subsidise and support various other use cases</li> </ul>	<ul> <li>MBB application</li> <li>4K content expected to be compressed to 12 Mbps by 2025</li> <li>Only 20% consumed outdoors</li> </ul>	<ul> <li>£2.2bn for UK wide mixed band network</li> </ul>
	Immersive Gaming	<ul> <li>Better gaming experience</li> <li>Supporting VR events with many viewers connecting</li> <li>Stimulating ongoing UK leadership in gaming industry</li> </ul>	<ul> <li>Requires high capacity broadband network that will subsidise and support various other use cases</li> <li>Will help AR market to grow</li> </ul>	<ul> <li>MBB application</li> <li>Some AR and very little VR outdoors</li> <li>4K content with 360-degree VR at 18 Mbps</li> <li>0.5 Mbps for AR</li> </ul>	<ul> <li>£2.8bn for UK wide mixed band network</li> </ul>
Me	Mobile Office	<ul> <li>Increased worker / business efficiency and mobility</li> <li>Encourage collaborative working</li> <li>Always up to date, limited software upgrades</li> </ul>	<ul> <li>Reduced environmental impact due to centralisation as less server spaces needed</li> <li>Less local IT skills/support needed</li> </ul>	<ul> <li>MBB application</li> <li>Mostly used in offices, only 20% outdoors</li> <li>Background tasks (sync, email etc.) at 0.144 kbps, HD video conferencing 1.2-2.4 Mbps and 1 Mbps cloud applications</li> </ul>	<ul> <li>£2.5bn for UK wide mixed band network</li> </ul>

### **Recommendations for follow on work**

- We believe there may be benefits in using 470 MHz and the spectrum currently used by Airwave for future provision of wide area coverage and deep penetration for MTC and low capacity MCC services e.g. railway telemetry
- Evaluate the potential benefits and challenges of building the MCC and MTC platforms on the same infrastructure as the MBB platform. This would reduce overall costs and the need for additional sites. This might require additional spectrum which such a benefit analysis would need to consider.
- Undertake a detailed analysis of the benefits and challenges in deploying cell sites along the rail and road corridors using land owned by the rail and road operators. This approach would use as much existing infrastructure as possible to reduce costs and deployment timescales. This work should highlight the opportunities of deploying shared infrastructure where rail and road networks run close to each other.
- A detailed analysis of all existing MNO sites at a UK level to identify which combination of existing and new sites can deliver the optimal mix of services, geographic and population coverage. The analysis should also identify where capacity enhancement would be desirable.
- A detailed exercise to assess the feasibility and cost of infrastructure that can support multiple use cases, thus establishing a heterogeneous capability. Such a study could reveal where there is potential for synergies between the fifteen use cases in this report, and potentially an extended list, to realise a cost optimal national infrastructure.
- Within the wireless industry there is significant ongoing research into the viability
  of the application of so called mmWave technologies for mobile use cases. Given
  this ongoing research it is strongly recommended that further evidence is
  gathered before predicating any infrastructure investment on the availability of
  this technology.



# 6. Annex

# 6.1 Summary of all use cases

# 6.1.1 List of all use cases

# Table 22: List of all use cases with priority rating

Use Case
GP consultations with remote monitoring
Fixed wireless access (fibre alternative, DSL replacement)
Education: remote, online or shared resources
Cloud working from anywhere, cloud-based virtual enterprise
Mobile real time collaboration
Virtual reality shopping mall
Content / broadcast pre-download / OTA (e.g. at night)
8K video and beyond to mobile devices incl inhome second screens
Context-aware mobile marketing and advertising - extreme personalization
Smart surveillance (incl mobile cameras)
Cloud delivered content - 8k being a challenging application
AI - enabled mobile services e.g. chatbots
Immersive mobile gaming (VR)
Indoor connectivity for Enterprises (building penetration issue)
Video delivery and sharing in dense environment
3D cyber office / 3D meetings
Enterprise deployed networks in factories (facility owned 5G)
Communications drones / HAP (infrastructure control & backhaul)
Connected public transport and V2I - sensors in roads, rail, bus stops + vehicles
Consumer real time health monitoring (personal) - preventative medicine based on big data / Al
Assisted living (keeping people out of hospitals)
Proactive maintenance
Smart supply chain
Ubiguitous asset tracking, telematics, smart logistics
Complex biometric authentication
Smart home monitoring and management
Identity management IoT
Bidirectional remote control in M2M
Mobile broadband for railway passengers
New generation connected car services - consumer (e.g. interactive or on-demand infotainment)
Driverless vehicles - fully autonomous / pre-programmed
Maritime (to users on vessels)
Real time tactile Internet
Driverless vehicles - remotely controlled (real time) - e.g. drone
Real time plant control
Next gen smart factory automation and robots
Remote surgery
Collaborative robots
Live broadcast/multicast to mobiles (localised, e.g. sports event)
New connected car services - safety and navigation. V2X
Critical infrastructure control e.g. grid. railway
Emergency services communication
Ubiguitous smart M2M (e.g. underground parking)
Next Gen Rail command and control
Machine control in hazardous areas (replace humans) e.g. mines, rigs
Air traffic control, ground-to-air and aircraft-to-aircraft
Delivery drones / agricultural drone
Redundant backup for critical communications e.g. trading



The list in Table 22 shows all Use Cases that were identified and analysed, based on the Use Case rating methodology explained in section 2.1.

# 6.1.2 Use case description and rating

## Fixed Wireless Access (FWA; fibre alternative, DSL replacement)

**Description** -Fixed wireless access encompasses any use of a wireless broadband connection for non-mobile purposes (though the same connection may also support mobility).

Fixed wireless access is typically adopted as:

- An alternative to fibre or copper where these are too costly or difficult to deploy, in order to extend the reach of broadband to remote areas;
- A replacement for DSL where fibre is non-viable
- An extension of a mobile-only network into the home or office to support multiplay services
- A redundant back-up solution for fibre in high availability scenarios like financial transactions.

It is notable that this is the first use case to be commercially trialled in the USA, trials which may be influential on UK operator thinking. In July 2016 Ofcom issued a Call for Input on fixed wireless [148], pointing out that the "majority of fixed wireless links in the UK" are used to support mobile services (backhaul) so increasing demand for mobile broadband may affect the fixed wireless access service sector [149,150].

**Rating: high** - Fixed wireless access (FWA) scores high because it can satisfy an unmet need for broadband connectivity which will have significant social benefits through reducing the isolation of geographically remote areas and increasing societal inclusion for those without good broadband. We recognise that FWA deployment in the UK has been limited up to now, but the prospect of new technologies that may deliver next generation broadband speeds cost effectively could transform its prospects. A successful next generation broadband service could also have a broader impact by increasing effective competition for fixed broadband services on a national basis and perhaps spur higher quality in the wired broadband infrastructure.

### Education; remote, online or shared resources

**Description** - Advanced mobile networks have several potential uses in the education sector, driven by the rise in young population and the risks of digital divide as well as the need for adults to reskill in response to industrial change, and the rise of adult education in general.

Use cases include:

- Sophisticated virtual learning environments to support remote communities or students unable to attend school regularly (e.g. hospital inmates). Harnessing mobile apps, virtual reality, interactive communications even when there is no fixed broadband link.
- Flexible access to virtual learning resources such as online lectures, MOOCs (massive open online courses) so that students can study from anywhere.



• Sharing of educational resources such as study guides or essays via social media and other mobile-first methods.

**Rating: high** - The combination of the large economic impact (given the number of educational establishments), the potential to get more out of an essential public resource, or reduce the costs of provision at a time of pressure on public finances and the social benefits of increasing access to education resources make education a high priority use case for the UK.

### Virtual reality shopping mall

**Description** - The use of virtual reality and augmented reality is becoming important to retailers to make the online shopping experience more compelling and to collect more contextual data about customers, to feed AI engines and personalized promotions. The VR shopping mall allows multiple online stores to be toured by the user, who can receive personalized offers, use virtual dressing rooms etc. This use case allows online retailers to be more competitive and bricks and mortar retailers to add an augmented reality layer to their in-store experience as consumers increasingly shop from their smartphones. The mall allows smaller retailers to participate without building and marketing their own virtual store.

Bricks and mortar malls are also using VR techniques which harness shoppers' mobile devices e.g. Westfield Stratford City ran a pilot called Future Fashion in 2015 which allowed users to find clothes from any of the retail outlets and experience them using mobile apps and Oculus Rift headsets.

**Rating: medium** - This use case could clearly bring economic benefits, however it is an evolution of what is already being done with today's infrastructure and technologies. In addition, retailers and owners of shopping malls have strong incentives to make it happen regardless of government involvement, hence our medium rating.

#### 8K video and beyond to mobile devices

**Description** - Smartphones are currently adopting 4K/Ultra-HD screens and content and with high bandwidth and good QoS, 8K will be practicable to advanced smartphones and tablets. This use case would support the rising consumption of video-on-demand, streamed and broadcast/multicast video on mobile devices, while on the move, or as second screens within the home (though these may use WiFi). In second screen mode, interactivity and social media links are becoming important to the experience, increasing the need for high reliable bandwidth [151].

**Rating: medium** - On the one hand, broadcasting is an important industry for the UK and technology leadership is therefore important too. On the other hand, 8K video is expected to come to market more through technology push than demand pull and the wider benefits to society are limited, hence our overall rating is medium.

#### Cloud working from anywhere, cloud-based virtual enterprise

**Description** - Flexible working, home working and distributed enterprises are commonplace in the UK economy, impacting on working practices and productivity. Even in organisations in which most employees come to a central office, many of them need to work on the move or from home frequently.



In 2012, 62% of the UK workforce did not go to the office every day, according to a Citrix survey [152], but employers still have issues with the quality of systems to support remote and mobile working. Advanced mobile networks can support virtual reality meetings and enhanced user experiences for collaboration and enable an organisation in which all central resources and systems are in the cloud, mimicking the structures of bricks and mortar offices [149,153].

**Rating: high** - Cloud working scores highly because it addresses several pinch points in the UK economy and transport infrastructure. It reduces commuting and its related environmental impact, reduces traffic congestion with benefits for other travellers and reduces pressure on sometimes congested office space in cities. Although there may be reluctance from some companies to moving towards a more virtual enterprise (issues of monitoring and managerial control) attitudes have already begun to change towards home working. There is also the social benefit of getting more of the population back working by supporting teleworking (i.e. working parents) and an economic impact due to improved productivity of allowing employees to work anywhere hence making the most of travel time.

## Mobile real time collaboration

**Description** - Related to the above, collaboration has developed significantly in recent years as a key enabler of flexible working and of efficient interworking with partners, suppliers and customers. This use case involves mobile apps which enable colleagues to work together in real time on any process which requires teamwork. They can annotate and discuss a complex document or model, from their smartphones e.g. two architects collaboratively making adjustments to a virtual reality model of a building. Other applications would include product design, publishing, academic research etc. [149,151].

**Rating: high** - This use case scores highly because of the potential for significant increases in business efficiency and, similarly to cloud working, the potential impact on reducing travelling timing, congestion and their related environmental impacts.

### Context-aware mobile marketing and advertising

**Description** - Context awareness is a great hope for many marketeers, retailers and advertisers, enabling them to harness the data they collect from users, via AI engines, to provide extremely personalized and relevant information, promotions, suggestions etc. Much of this activity is inherently mobile as brands want to target users as they move around, with their location being a key aspect of the context. The more sophisticated the use of big data and AI analytics, the more information must be transferred between the end user devices and the cloud in near-real time, to create a detailed picture of the consumer's context at any one moment.

This creates high demand for bandwidth. Fog computing (processing data at the edge rather than transferring it all to the cloud) will help alleviate the pressure on the core and backhaul, but will place new demands on the edge network. This is a key focus of 5G and pre-5G work on Mobile Edge Computing (MEC). In the UK, the 5G Innovation Centre has published a Flat Distributed Computing blueprint which enables high levels of context awareness [151].

**Rating: medium** - Context-aware mobile marketing and advertising is a development of existing practice and has few wider benefits for society. However, it may be important for



business given that the effectiveness of some advertising is being challenged by changes in the way media is consumed. As a result, the overall rating is medium.

#### Smart surveillance

**Description** - This use case covers applications which involve camera surveillance of citizens, which could be enhanced by connectivity. Typical use cases include surveillance by public and private security agencies and police, and private home surveillance. Smart connected cameras could relay data in real time to aid crime detection. Machine vision provides a highly realistic view for remote staff, as well as enabling automatic actions to be triggered by the smart camera e.g. the camera senses unusual motion and locks the doors of the home.

In 2015, The Home Office established the Video Analytics for Law Enforcement (VALE) initiative to identify ways to harness CCTV data more effectively using analytics and smarter connected cameras [154].

Traffic cameras could also fall into this category. When connected to smart city systems, they can be used for real time management of traffic flow e.g. directing drivers to available parking spaces [149].

**Rating: medium** - Smart surveillance is important especially given the current security situation, however it is an extension of existing capabilities and not a fundamental change in capability, therefore we give it a medium rating.

#### **Cloud-delivered content**

**Description** - This use case includes any content services which are delivered primarily via streaming from the cloud to a mobile device, an important sub-section of the more general use case described by Ericsson as 'media everywhere'. In some cases, this will intersect with the mobile 8K use case. Increasingly, as seen in the success of Apple Music or mobile Netflix, content is being streamed rather than downloaded, which puts pressure on network bandwidth, coverage and QoS. Music, video/TV, other audio and games are included in streamed content [149,151,153]

**Rating: medium** - As with 8K video, cloud-delivered content rates medium because, although broadcasting is an important industry for the UK the push for cloud-delivered content is more likely to come from technology push than demand pull and the wider benefits to society are limited. Hence it does not rate more highly than medium.

#### Al-enabled mobile services (e.g. chatbots)

**Description** - This use case encompasses the emerging category of applications which deliver information or recommendations to users by drawing on artificial intelligence engines. Key categories are chatbots and digital assistants. Intelligent chatbots can transform customer service costs and quality with virtual helpers accessing complex sets of data about the caller in order to make the most relevant suggestions. Banks, retailers and others are using chatbots in the UK [155].

Digital assistants include Apple Siri, Amazon Alexa, Google Now and Microsoft Cortana. They 'learn' a user's preferences and habits and so provide increasingly personal answers to questions. In future, these digital assistants are expected to evolve into more sophisticated virtual companions which could be embedded in humanoid robots as well as smartphones.



All these applications will rely on constant communications with the service provider's big data engine in the cloud to evolve as envisaged.

**Rating: medium** - The economic importance attached to this use case is uncertain. For example, it could disrupt services such as search, but it is difficult to predict the likelihood and size of any impact.

#### GP consultations with remote monitoring

**Description** – This use case involves patients consulting with their GPs remotely, via a secure internet or mobile link, and subsequently being monitored on an ongoing basis by the GP. This can be achieved through smartphone apps, wearables or body-based sensors depending on the symptoms to be monitored. It would particularly apply to remotely located areas or patients with limited mobility. In future, it is envisaged that the consultation experience could be made more realistic with virtual reality, and that the diagnostics could make use of AI engines to improve accuracy.

**Rating: high** - This use case could enable a significant area of health service activity to be delivered more effectively and at lower cost. It might also bring additional benefits in reducing the number of missed appointments and provide more convenience for patients. Hence there is a strong case for this use case on economic and social grounds.

## Content / broadcast pre-download / OTA (e.g. at night)

**Description** – One of the great challenges for wireless networks is managing the growing traffic from downloads of content, especially video. If this can be done at a time when the connection is only lightly used, it can result in a better experience for the users and less strain on the network. For instance, pre-selected films, or episodes of regularly watched programmes, may be pre-downloaded overnight.

**Rating: medium** - Although broadcasting is an important industry where the UK leads internationally, this use case scores no higher than medium because the capabilities already exist, even though there have been problems with handset compatibility and diffusion of the technology.

#### Video delivery and sharing in a dense environment:

**Description** - This use case relates to the need to deliver increasingly high quality video as users consume more on their mobile devices, and also share video clips via social media. In a dense environment such as a stadium, during an event, or a crowded station or mall, the challenges of maintaining QoS become even higher, but these are often environments where users most want to use mobile video (e.g. uploading clips at a sports event). In April 2016 EE reported 580 GB of video traffic at an FA Cup semi-final in Wembley Stadium, up from 380GB at the same event a year earlier [149,150].

**Rating: medium** - If consumers increasingly expect good performance in dense environments, it will become important for service providers to meet those expectations even if the impact on revenue is unlikely to compensate for the increased cost. To some extent, therefore, competitive pressure may incentivise operators to fulfil this use case anyway. Hence although it may bring significant benefits to consumers, it does not rate more highly than medium.



#### Immersive mobile gaming

**Description** - Virtual reality is a major factor in the gaming experience, and important because of the large number of games developers, as well as consumers, in the UK. According to NESTA, games companies in the UK grew at an annual rate of 22% in 2011-2013, with Apple's mobile iOS being the most important driver [156]. An immersive experience is important to gamers, and is moving from consoles to mobile devices, requiring high bandwidth, low latency connections to support virtual reality and other features such as voice and gesture recognition.

Several companies have launched VR headsets in which the smartphone can be slotted, primarily addressing gamers (e.g. Samsung VR, Google Cardboard/Daydream). The GSMA cites real time gaming as a driver for sub-10ms latency [149,151,153].

**Rating: high** - Gaming is an important industry for the UK and this use case is important because it could help maintain UK leadership in the sector. It also requires a step change in the wireless network performance hence this is a high priority for development in the UK.

### 3D cyberoffice / 3D meetings

**Description** - This is a sub-use case of the 'cloud-based virtual enterprise' but takes the virtual reality aspect a step further to deliver a complete interactive office and to support virtual or robotic colleagues. These may be used to support temporary teams or projects rather than for full time enterprises. For instance, a Cabinet Office-backed project, Cyber Security Challenge UK, launched the Cyphinx virtual skyscraper, hosted in the cloud, in 2015 [157]. This was created to recruit cyber-security talent. Candidates could create avatars, enter the building, interact with other candidates and engage with potential employers [149,150,153].

**Rating: medium** - 3D cyberoffice / meetings are similar to the virtual enterprise (cloud working) use case in that they also may reduce commuting, traffic congestion, office space limitation and bring associated environmental benefits. However, it does not rate as highly because we consider that take up is likely to be much slower due to the 3D element of the use case and as it is not seen as critical for daily business.

### Indoor connectivity for enterprises

Poor mobile penetration inside buildings is a significant challenge for all kinds of enterprises. This use case covers high quality coverage and capacity which can reach every corner of a building including difficult areas such as basements, or very large, dense environments such as airports [149,150].

**Rating: high** - Similarly to FWA, this use case could make a big difference in the ability to fully enjoy the benefits of mobile communications to those businesses affected by poor indoor connectivity. It is also highly rated as the UK has a history of innovation and leadership in small cells and pioneered development of femtocells and picocells.

### **Enterprise-deployed networks in factories**

**Description** - Smart factories rely on connectivity and sensors in every machine, robot and component, transmitting data to an on-site or cloud-based platform to monitor factors such as component location, failure rates – and take proactive action. A potential approach to these critical, low latency networks is for the manufacturing organisation to own their own



5G network, either physically or as a virtualised 'slice'. This network would then be optimised for the particular requirements of a manufacturing application.

The UK's first Industry 4.0 smart factory incubator opened in 2015 at the Manufacturing Technology Centre in Coventry [151].

**Rating: medium** - We believe there could be significant demand for such networks in the manufacturing sector because of the potential efficiency benefits it could bring and the need to maintain international competitiveness. However, large manufacturers are likely to deploy enterprise networks themselves assuming the economic benefit is significant, even if a private network would be more expensive than a public network. On the other hand, SME manufacturers may be less able to afford a private network and lack the skills necessary to maintain it. As a result, we have rated this use case medium.

#### **Communications drones / HPA**

**Description** – In this category, we could include high altitude platforms (HAP) where both backhaul and radio access communication has to be considered. But this is a specific drone-based use case in which drones are used to provide internet access over large, usually remote or underserved areas. Some stakeholders are looking for drone-based form factors to be included in 5G developments, and Ericsson and China Mobile are among the companies which have demonstrated 5G communications drones. In 4G, UK-based EE has trialled drones equipped with mini-base stations, working with Nokia and sees this as a way to reach rural areas [149,158].

**Rating:** low - This use case scores low because it is essentially a niche application. Longer events are currently covered by cell on wheels (COWs). Although it may be an important part of providing a communications service in certain situations (e.g. short duration events or hard to access locations), the overall economic and social benefits are a lot smaller compared to other use cases.

#### Smart supply chain

**Description** - Transparent interworking between every element in the supply chain, involving ubiquitous connectivity between every human and component, the latter based on sensor tracking. This can boost efficiency and delivery times, and help coordinate a complex project, such as building an aircraft, in which scores of suppliers and thousands of components may be involved, all coming from different locations.

Other benefits include greater ability to oversee the whole supply chain to ensure legal compliance e.g. on workers' conditions or energy efficiency. The ability to identify and monitor all the links in the supply chain is a significant issue e.g. for clothing manufacturers since many small suppliers may be unconnected.

Many use cases in this category relate to the Industry 4.0 initiative which originated in Germany but is gaining profile in the UK. Consultancy Gambica estimates it could generate an additional £20 billion in revenues for UK manufacturers [159]. Supply chain transparency is a cornerstone. For example, before a car is built, it is assigned a sensor tag which is associated with a specific customer. The 'car' tells robots along the production line how to build it to the customer's specifications. The smart factory will know where all the necessary components are, and whether any have been damaged in transit.



**Rating: high** - We see this as important for increasing efficiency and essential for retaining international competitiveness in UK manufacturing particularly. The ability to gain more information throughout the production process opens up the possibility of perhaps far reaching improvements in production processes that may emerge with the passage of time (and are difficult to predict at this point). Hence we see this as a high priority.

#### **Connected public transport and V2I**

This use case hinges on V2I (vehicle-to-infrastructure) communications with sensors in roads, rails, bus stops and other infrastructure. Vehicle sensors then communicate in real time as they pass these physical elements, supporting applications like intelligent routing, accident avoidance etc.

Some of these projects are part of wider smart city initiatives, like Manchester's CityVerve, which includes smart bus stops.

**Rating: high** - Connected public transport rates as a high priority because it improves efficiency in two critical areas of infrastructure in the UK, road and rail, and may bring considerable social benefits through reducing congestion, commuting and the impact of transport on the environment.

### Consumer real time health monitoring (personal)

**Description** - This user group describes personal health monitoring but is also allowing preventative medicine based on big data and AI. It is based on health monitoring via a connected mobile device, managed by the consumer rather than a healthcare provider. These applications are often smartphone based but in future will encompass body area networks and wearables to gain more detailed data on vital signs and symptoms. Monitoring may include heart rate, blood pressure, sugar levels etc. and may be used for ongoing health management or for fitness [149,151].

The Department of Health has identified two apps which integrate patient and clinical information to support home-based healthcare – these are Patients Know Best and HealthFabric [160].

**Rating: high** - This use case targets preventative healthcare, an important goal in UK health policy, particularly well and builds on observed trends in consumer interest and acceptance of devices that help individuals manage their health and fitness. The addressable market is large and the associated benefits in terms of better health outcomes and reducing the burden on the NHS could be significant. There is an added potential for improvements in public health through enabling access to "big data" analysis of nationwide health trends.

### Assisted living (and keeping people out of hospitals)

**Description** - An extension of health monitoring, but managed and monitored remotely by a healthcare provider, social care provider or family member. The main scenarios are to enable someone to stay in their home, rather than a hospital or care home, for longer when living with dementia or disability; and to enable patients to return home from hospital at an earlier stage after major treatment.

Sensors around the home can provide insights on a vulnerable person's movements and habits to raise alerts to any unusual behaviour (e.g. failure to get out of bed at the usual time). Automated connected devices such as fridges which order groceries when they run



low can help housebound people or those with dementia. Wearables or body sensors can allow for health monitoring outside the hospital for those who would not use a smartphone app.

A UK example of an assisted living trial is at the University of West of England (UWE) – this includes CASA, an Innovate-backed project focused on elderly assisted living, and Anchor Robotics Personalised Assisted Living Studio, an in-house facility to develop, test and implement assistive robots and sensor systems in a realistic environment [151,161].

**Rating – high** - Assisted living rates highly because care of the elderly is an ever more important priority for government and citizens given the UK's ageing population. There is the potential for considerable cost savings the longer people can stay in their homes as opposed to in hospital or residential care and there is a large benefit to individuals themselves in terms of increasing their independence and quality of life.

#### **Proactive maintenance**

**Description** - This is an important use case to improve economics and customer satisfaction for suppliers on high value, complex items such as cars, aeroplanes, large machinery etc. By monitoring and analysing data from hundreds of sensors within the vehicle or machine, the manufacturer (or a provider offering 'car-as-a-service' or similar) can detect likely problems before they occur and proactively fix them. This may also apply to home equipment e.g. British Gas's Connected Home subsidiary has a proactive maintenance programme for boilers [151].

**Rating: high** - This use case could bring significant productivity gains in maintenance for the UK sectors that can benefit from it. The benefits are also likely to be easier to realise than for other enterprise applications which might lead to a relatively faster take-up.

### Smart home monitoring and management

**Description:** This use case concerns smart home systems which are monitored and managed from a remote, usually cloud-based platform, rather than locally managed by the home owner. Smart home services are expected to evolve towards automated, real time management of key home systems such as security, temperature control, lighting etc., which can be done from the cloud, according to user preferences 'learned' by an AI engine. Some of this connectivity will via a fixed link to an in-home network (e.g. ZigBee). This also relates to assisted living (see above). Providers such as British Gas and Telefonica O2 have already launched smart home services based on current technology and new networks should enable additional functions in future.

**Rating: medium** - There already is a market for connected home management systems, so smart home management and monitoring is merely an extension of current trends. In addition, social benefits are limited, hence, we rate this use case as medium.

#### **Complex biometric authentication**

**Description** - Biometric authentication has the potential to revolutionise security and access control in areas like retail payments and access to real or virtual buildings. It has started with iris or fingerprint recognition but complex multidimensional biometrics are expected to take this a stage further. These will require low latency connectivity. The UK Biometrics Working Group (BWG) co-ordinates the Communications Electronics Security



Group (CESG) Biometrics Programme, the goal of which is to enable the use of biometric authentication for future government services [162].

**Rating: medium** - This use case undoubtedly has important applications for security, particularly online transactions and access to personal data. However, it scores medium because it is an extension of existing security meaning that the economic impacts are likely to be incremental.

#### Identity management in the IoT

**Description** - An extension of the case above, new and automated security methods like biometrics will also be an enabler of 5G-enabled developments like mobile IoT. For instance, Huawei [163] says: "There is a need of a more stringent authentication method to prevent unauthorised access to IoT devices. For example, biometric identification could be part of the authentication in smart homes."

The identity management use case is summed up by the Cloud Security Alliance [164]: "The IoT introduces the need to manage exponentially more identities than existing IAM systems are required to support. The security industry is seeing a paradigm shift whereby IAM is no longer solely concerned with managing people but also managing the hundreds of thousands of "things" that may be connected to a network. In many instances these things are connected intermittently and may be required to communicate with other things, mobile devices and the back end infrastructure."

**Rating: medium** - Although this is an important enabler for some IoT services, it is only a component of the IoT value chain hence the economic impact is limited. Social benefits are limited and there is no specific UK leadership opportunity. On balance we consider this to be a medium priority.

#### Ubiquitous asset tracking, telematics, smart logistics

**Description:** These use cases all rest on an extension of current telematics and M2M networks, to provide a greater amount of information and intelligence about the items being tracked. Monitoring takes place via data transmitted by sensors in vehicles, containers, packages, components and people (via wearables). These systems can detect the location, progress and condition of the items (e.g. whether a container of ice cream has been exposed to refrigeration failure). They can then support intelligent actions such as rerouting consignments, ordering replacement items, communicating issues to a customer proactively, alerting security forces to stolen goods at an early stage [149,151,161].

**Rating: high** - Although applications already exist for online asset tracking, we consider that the future wireless asset tracking etc. applications offer significantly more potential for efficiency gains in logistics and associated social benefits through reducing the effects of transport on the environment. This use case is rated high as a result.

#### **Bidirectional remote control in M2M**

**Description** - Many wireless M2M use cases revolve around single-direction remote control from cloud to device but others require bidirectional connectivity, allowing information to be transmitted from a device like a smart meter. This puts additional requirements on the connectivity. Applications include security and fire alarm systems, industrial controls and long-range telecontrol [153].



**Rating: medium** - This application could be quite important for those industry sectors where it might be applied, however, like enterprise deployed networks, there is a question whether it is an appropriate area for government intervention because, if the benefits to individual businesses are significant, they will have strong incentives to deploy their own networks.

### Mobile broadband for railway passengers

**Description** - The ability to work, communicate or consume content (e.g. games and video) while travelling on trains is a major passenger requirement, but is only partially delivered by current on-train WiFi systems. Accessing cloud services or content while travelling at high speeds, as well as making unbroken voice calls, would be a significant competitive asset to train operators while improving productivity [149].

**Rating: high** - General business productivity should improve due to passengers who are able to work more effectively on trains. The impact on consumer welfare could be significant given the volume of rail passengers and the impact of higher quality mobile access on enjoyment of entertainment and information services on their devices. However, mobile operators may see little increase in direct revenue from improving railway coverage, hence this could be an important area for government intervention. Overall, therefore, this use case is rated high.

#### New generation of consumer connected car services

**Description** - This use case relates to infotainment and wireless applications consumed within the car, but not related to safety or car operations such as navigation. Infotainment is likely to evolve in the same way as other fixed and mobile consumer services to include precise contextual awareness and delivery of personalised suggestions and promotions; interactive entertainment; support for augmented reality; high quality video and gaming; communications with other passing vehicles for social media or group gaming [153].

**Rating: high** - Similarly to mobile broadband for railway passengers, connected cars could drive some productivity benefits for business and consumer welfare – both due to improved network performance. We therefore rate new generation connected cars as high, though we note that the automotive industry's level of support for connected cars is likely to be determined outside the UK.

#### Driverless vehicles – autonomous:

**Description** - This use case covers driverless vehicles which are pre-programmed to control their own movements rather than controlled remotely. In 2013, the Treasury's Autumn Statement included a £10 million support to establish a testbed for driverless cars, primarily focusing on pre-programmed vehicles and the efficiencies and safety benefits they claim [165]. Other autonomous vehicles include warehouse forklift trucks, factory vehicles, trains/metro [149,150,153,161].

**Rating: medium** - Autonomous vehicles may be very important for the automotive sector, however wireless communications use is likely to be intermittent and fully autonomous vehicles (recognising that there are various levels of autonomy) should, by definition, not be solely reliant on continuous wireless connectivity to function. Because of this limited, if important, communications requirement autonomous vehicles as rated a medium priority.



#### Maritime (to users on vessels):

**Description** - The maritime use case we have defined involves wireless communications, including delivery of cloud-based services and content, to people on ships and boats near shore. Note, there are also existing satellite-based use cases for enhancing connectivity to ships on the ocean and for automated M2M ship-to-ship communications. These have not been considered in detail.

**Rating; low** - Improved maritime communications, though it may bring benefits to maritime users, it is a small market relatively to other use cases, and has limited wider economic and social benefits, hence it is rated low.

#### Real time tactile internet

**Description:** One of the more futuristic use cases, but there is potential for the Tactile Internet to change the way people interact with digital and virtual worlds, and there is significant UK input from Kings College London's 5G Tactile Internet Lab. Mischa Dohler, the professor leading the effort, sums up the use case [166]: "Sufficiently responsive, reliable network connectivity and advanced edge-haptics will enable us to deliver physical, tactile experiences remotely. Imagine our best surgeons performing operations remotely; our best engineers maintaining cars on the other side of the planet; somebody teaching me how to paint or me teaching somebody how to play the piano ... This will be an enabler for skillset delivery and therefore pave way for an unprecedented *Internet of Skills*" [149,151,153].

**Rating: medium** - There is considerable uncertainty over what tactile Internet applications will emerge and whether they will be taken up in the short to medium terms, especially given questions over consumer acceptance. Medical applications are discussed under remote surgery. One of the main benefits is increasing access to medical care where hospital facilities are not widespread. However, this is not an issue in the UK. Hence we rate this use case medium overall.

#### Driverless vehicles - remotely controlled

**Description:** As opposed to driverless vehicles which are autonomous and preprogrammed, these vehicles are remotely controlled in real time, either by humans or automatic systems driven by AI algorithms. Examples include consumer, commercial and military drones. A sub-set of this use case is Delivery Drones [161].

**Rating: low** - Other technologies already exist for remote controlled vehicles, particularly drones. One of the largest users, the military, makes extensive use of this technology and we believe will develop the technology itself regardless of developments in public mobile/wireless networks. Hence this use case is rated low.

#### Real time plant control

**Description** - Related to smart factory, and an evolution of current wireless plant control systems based on 2G or proprietary networks. This involves real time monitoring and management of every component and machine that is fixed within a factory, chemical plant, power station or other major plant (i.e. not goods and components which are passing through, as in smart logistics). Important applications, enabled by the collection and analysis of increased amounts of data, include proactive maintenance, security, accident prevention [151].



**Rating: medium** - Similar arguments apply to real time plant control as to enterprise deployed networks, i.e. there are potential productivity benefits for manufacturers, large manufacturers may have incentives to deploy private networks (reducing the case for intervention), but SMEs will be less able to afford to do so. Hence this use case is also rated medium.

#### **Collaborative robots**

**Description** - Collaborative robots, or cobots, are designed to work with humans rather than autonomously. They are typically used for training humans in a particular task, or for assisting humans e.g. moving heavy parts before a human works on them. For instance, UK firm Universal Robotics worked on a system for robot-enhanced camera work for the Rio Olympics [167]. Many cobots are pre-programmed, but there is potential for them to be remotely controlled from the cloud, enabling less repetitive tasks. Some companies envisage future workplaces in which robots collaborate with humans in mixed teams. One UK project is at the University of Birmingham, where 'Bob' is a robot security guard that patrols the workplace, scanning rooms in 3D and reporting any anomalies to human security managers [149].

**Rating: low** - Demand for this technology is currently uncertain and there are no significant UK leadership trends or associated social benefits. Primarily due to the demand uncertainty, therefore, we rate this use case as low.

#### Next generation smart factory robots

**Description** - Robots are heavily used in manufacturing, but in the next generation smart factory use case, they are envisaged to be more integrated with humans, more intelligent, and controlled from the cloud so they can react to unexpected developments. This evolves towards 'cloud robotics', which makes intelligent robots less expensive and easier to control by placing most of the intelligence in the cloud and deploying simplified, wirelessly connected robotics on the factory floor. This is outlined in the Ericsson Technology Review 2016 [151,168]. UK innovators in this area include Coventry-based Ortelio.

**Rating: medium** – We believe there could be significant demand for these next generation robots in the manufacturing sector because (similarly to enterprise networks) it could bring efficiency benefits and help maintain international competitiveness. However, large manufacturers are likely to deploy the necessary communications infrastructure themselves assuming the economic benefit is significant, even if a private network were more expensive than a public network. On the other hand, SME manufacturers may be less able to afford a private network and lack the skills necessary to maintain it. As a result, we have rated this use case medium.

#### **Remote surgery**

**Description** - Remote surgery allows surgeons to perform operations while not physically near the patient, using telepresence and robotics. This may be a way to conduct urgent surgery on people in remote locations or even in dangerous locations (e.g. trapped in a fallen building). In 5G, remote surgery is seen as a use case for Tactile Internet as demonstrated by Kings College London and Ericsson in London this year [169]. In this, a robotic finger identified cancer tissue and sent information to the surgeon as haptic feedback over a low latency network [149,151].



**Rating: medium** - One of the main benefits is increasing access to medical expertise where in countries where it is not widespread. However, in the UK, hospital provision and availability of surgical expertise is already good nationwide. Remote surgery could enable reductions in costs through enabling specialists to leverage their skills more widely, however these cost savings are likely to be smaller than in other health related use cases. Hence we rate this use case medium overall.

#### **Ubiquitous smart M2M**

**Description** - This relates to any machine-to-machine applications which require absolutely ubiquitous coverage i.e. the service would fail if any user or device were unreachable at any one time. Examples include safety monitoring in mines, or smart parking in underground car lots [149,150].

**Rating: high** - Can have some critical use characteristics, but the economic importance is uncertain. Could potentially be used as a driving case for a IoT platform.

### Redundant back-up for critical communications

**Description** - A specific sub-use case within "fixed wireless access" (see above) requiring only standard connectivity as it is only used in emergencies as a fail over. It applies typically to financial institutions, cloud providers and other organisations with critical data transmission requirements.

**Rating – low** - Although this use case has value in certain sectors, we consider this as a niche market relative to many of the other use cases. In addition, it does not require particularly advanced performance and many of the large financial services firms have self-provided similar communications services in the past (reducing the case for intervention). Hence, we rate this use case as low.

### Delivery drones and agricultural drone

**Description** – There are many emerging applications for drones but this use case refers to a specific category, where the unmanned vehicles are pre-programmed to deliver items which have been ordered on ecommerce sites, or to provide crop spray or animal feed to remote farming areas.

**Rating: medium** - Similarly to autonomous vehicles, delivery drones are considered to have only an intermittent requirement for wireless communications. Given that they are preprogrammed, they should, by definition, not be reliant on continuous wireless connectivity. However, there may be situations in which wireless connectivity is necessary such as when manual operation needs to be re-applied. Because of this, we rate the use case as medium.

#### Live broadcast/multicast to mobiles (localised)

**Description** - Like the 'cloud-delivered content' use case, this concerns the rising consumption of video on mobile devices but focuses on broadcast or multicast systems rather than streamed systems. These might use specialised networks or optimised strands of a 4G or 5G network (like LTE-Broadcast) and is usually used locally, e.g. at sports events and stadia [149,151].

**Rating: medium** - On the one hand the potential market for this use case is large and broadcasting is an industry where UK companies are leading international players. On the other hand, multicast capabilities exist already, but there may be commercial issues that



have delayed uptake of these technologies to mobile. As a result, our consensus on overall rating is medium.

#### New connected car services – safety and navigation

**Description** - As opposed to consumer infotainment, this connected car use case is concerned with safety and navigation, and so is more critical and more reliant on real time communications. It involves V2X communications to support functions such as intersection collision avoidance, optimum speed advisory, blind spot and lane change warnings, and pedestrian alerts, which look ahead to autonomous driving [149,161].

**Rating: high** - Although navigation and safety services based on other technologies, e.g. satellite, DSRC, ITS, radar and cameras, already exist, the market potential for enhanced safety and navigation services (e.g. in-car systems integrated with city or highway traffic management systems) delivered over mobile/wireless infrastructure is large. This use case could also generate substantial social benefits in terms of reducing: congestion; the impact of congestion on the environment and the incidence and impact of road traffic accidents. Hence we rate this use case highly.

#### Machine control in hazardous areas (replace humans)

**Description** - This use case concerns the replacement of humans in hazardous scenarios which could lead to loss of life – e.g. in disaster relief, mining, oil exploration, landmine detection. Humans in these use cases can be replaced by remote controlled robots or drones [151].

**Rating: medium** - Although this use case could have considerable benefits for operations in hazardous areas, economically this is a niche area and there would be a strong incentive for companies in these areas to develop services themselves, therefore it is only a low priority for government.

#### Critical infrastructure control (e.g. rail, grid)

**Description** - Similar to the 'real time plant control' use case, this one refers to critical infrastructure such as the national grid, power stations, railways etc., rather than factories. As in plant control, this involves real time monitoring and management of every component and piece of equipment in the infrastructure via sensor networks, to support security and problem alerts, proactive maintenance, accident prevention etc. [149,151,161].

**Rating: high** - Rail and energy are important areas of UK infrastructure and this use case will help both sectors address important issues for UK energy and transport policy. For example, load balancing in energy networks can help meet targets for emissions by reducing consumption overall. Better utilisation of rail infrastructure can reduce congestion, as well as increasing cost effectiveness, and this may also have spin-off benefits for road congestion. Hence, this use case is rated high.

#### **Emergency services communication**

**Description** - The Emergency Services Network (ESN) programme is moving towards a cellular-based system to augment, and eventually replace, the voice-based TETRA service. This use case includes urgent, real time communications between emergency services personnel (police, ambulance, search and rescue, fire, coastguard etc.), including evolving aspects such as video and augmented reality communications, real time collaboration, communications with machines and robots [149,153].



**Rating: high** - Although this use case is an evolution of existing emergency service communications, we rate it high because of the possibility that substantial social benefits could arise, e.g. from the use of video for remote diagnosis in the ambulance and enabling emergency services to operate more efficiently hence saving more lives, reducing injuries and reducing damage to properties from emergency situations.

### Next generation rail command and control

**Description** - This use case starts with digitising the railway command and control system, for instance with the ERTMS (European Rail Traffic Management System) but future evolutions are envisaged as enabled by advanced wireless communications. These include driverless trains beyond light metro systems; intelligent signals; more effective train-to-infrastructure communications [149].

**Rating: high** - This use case has similar advantages to critical infrastructure control, but is focused on the rail industry. As a result, it is also rated high.

## Air traffic control

**Description** - This use case includes ground-to-air and aircraft-to-aircraft communications as well as cellular systems to control drones [149].

**Rating: medium** - This use case is an evolution of existing services that would bring higher performance and new capabilities. It is also an economically important sector for the UK. We rate it at medium, chiefly because of the fact that the need for new services is not critical. It may also be the case that specific services are developed within aviation, because of a reluctance of aviation authorities to move to public networks due to safety considerations.

# 6.2 Capacity and cell range assumptions

# 6.2.1 Spectrum ranges

The chose spectrum ranges are the following:

- Low (Sub 1 GHz) This low frequency range considers the 700, 800 and 900 MHz FDD bands
- Medium (1.4 3.5 GHz)
   The medium frequency range considers the 1800, 2100, 2600 MHz FDD bands and the 1400, 2300, 2600 and 3500 MHz TDD bands
- High (mmWave 26 GHz and above)
   The high frequency range considers a number of frequency bands but the relevant frequency bands are not defined yet the timeline in the ITU for defining bandwidth requirements and technical characteristics for 5G is May 2017

The volume of spectrum that might be available in each of the above bands was also determined. This assumed that all current spectrum allocations for mobile/cellular services will be available. As this exercise is considering national infrastructure requirements all the spectrum was grouped as a single entity rather than being divided up over multiple operators.

For the low and medium frequency range, there is enough information available to come up with evidence based spectrum volumes per frequency range.



In the high frequency range, we had to make a number of assumptions to derive the spectrum that will likely be available by 2025. Stakeholders at a UK Spectrum Policy Forum (SPF) workshop in September 2016 discussed spectrum bandwidth demands for 5G and mentioned figures in the range of 3 – 18 GHz for future mobile mmWave applications [**35**]. In terms of suitable spectrum; the pioneer band is the 26 GHz band (24.25 – 27.5 GHz, bandwidth: 3.25 GHz) followed by the 32 GHz band (31.8 – 33.4 GHz, bandwidth: 1.6 GHz) get significant support in the UK and EU by:

- the EU's Radio Spectrum Policy Group (RSPG) when discussing priorities for 5G Bands [170]
- the UK SPF in defining UK Pioneer Bands and input to 5G PPP
- Ofcom discussing Priority Bands [171] with a high likelihood of becoming available by 2025

By contrast, 42 GHz is getting less focus but there are also number of other bands above 42 GHz. The 60 GHz band (bandwidth: 10 GHz) is standing out with least opposition and the likely fastest market adoption due to the eco system support e.g. chipsets in similar frequencies available. However, some of the bands mentioned might only get partially freed up and harmonised in the timescale under consideration, hence it is unlikely that the total 14.85 GHz (3.25 GHz + 1.6 GHz + 10 GHz) will become available. We therefore assume a range of 7.5 – 10 GHz of mmWave spectrum available in the UK by 2025.

Table 23 summarises the estimated spectrum bandwidth allocation, spectrum efficiency [172] and (typical) average capacity per cell for each of the three bands. This capacity expectation clearly varies with the spectrum bandwidth available and also the spectrum efficiency of the technology that is assumed.

Capacity vs Band	Quantum of Spectrum [MHz]	Spectral Efficiency [bps/Hz]	Average Cell Capacity [Gbps]
Low (700 - 900 MHz)	95	1.4	0.1
Medium (1.4 – 3.5 GHz)	365	2.6	0.7
mmWave (26 - 60 GHz)	500	4.1	1.6

# Table 23: Mobile downlink spectrum and cell capacity versus frequency band

The figures above are used to calculate the cell site infrastructure requirements as defined in the following sections.

# 6.2.2 Cell ranges

The frequencies used for the cell edge (cell range) calculations are within the ranges defined in Table 23 above.

- 700 MHz was chosen as it represents the maximum cell range achievable in the lower band.
- 3.5 GHz represents the highest (future) mobile licensed band in the mid-band and it sits in the middle of the mid-band range.



• 26 GHz represents mmWave and is a band that gets a lot of support in the UK and EU by the RSPG EC (Primary 5G Bands), the 5G PPP & SPF (Pioneer Bands) and Ofcom (Priority Bands), with a high likelihood of becoming available.

Spectrum assumptions	Cell edge coverage confidence assumption (%)					
Frequency	МТС	MCC	MBB			
700 MHz	95%	99%	95%			
3.5 GHz	95%	99%	95%			
26 GHz	95%	99%	95%			
Cell edge UL data rate	100 kbps	10 Mbps	25 Mbps			

#### Table 24: Some assumptions for cell range calculation

Road/rail use cases require coverage to roads and rail tracks. Specialised solutions such as two sector narrow beam antennas with higher gain (compared to the antennas used in a typical mobile operator site provides area coverage) and roof mounted antennas enable better signal reception for the moving vehicle and train. These improvements in the link budget extends the cell range enabling the reduction in the number of sites and the cost. However, we belives these gains are limited in medium and high frequency bands. For instance, 4x4 (used in medium frequency band) and 8x8 (used in high frequency band) MIMO gain is difficult to achieve for the fast-moving vehicles/trains. Only diversity gain (which is lower compared to the MIMO gain) can be expected in medium and high frequency band deployments for such fast moving users. Further, mmWave band does not provide sufficient channel coherence to realise its full cell range. We would also like to note that the multi band antennas do not provide the optimum gain for the specific frequency band.

Network deployments using the low band do not provide sufficient capacity for the MBB platform. For the MTC platform we already use large cell ranges. Terrain limitations will not allow signal to travel very long distances along the roads/rail tracks since they are not always long and linear. x.

As an illustration, we carried out a short study applying a gain of ~2dB gain gives 6% (£18 million) reduction in the cost for the MBB-Connected car-entertainment services. However, deviations from the standardised solutions will result in increasing the unit cost of the equipment. This will in turn increase the cost of deployment. Further, in this high-level study, we did not consider the cost of infrastructure increase to provide the coverage to tunnels and cuttings, since special coverage solutions may be required. Therefore, we have applied reasonable values for this high-level costing exercise and a detailed study is necessary to assess the exact net benefit to the cost.

For the MBB platform we considered typical mobile operator network. For the MCC platform, we considered additional equipment such as battery backup etc. for increased reliability, in additional to the higher coverage confidence compared to MBB platform. For the MTC platform, large cell ranges (compared to the MBB and MCC platforms) achieved from very low (i.e. approximately 100 kbps) and less frequent (100 bytes every hour) data transmission.



# References

**1** "The Communications Market Report", Ofcom, August 2016,

https://www.ofcom.org.uk/\_\_data/assets/pdf\_file/0024/26826/cmr\_uk\_2016.pdf

2 "Global Mobile Data Traffic Forecast Update, 2015–2020", Cisco Visual Networking Index, Cisco, February 2016

3 "Connected Nation 2015", Ofcom, December 2015

4 "UK Broadband Impact Study", SQW, November 2013,

https://www.gov.uk/government/uploads/system/uploads/attachment\_data/file/257006/ UK\_Broadband\_Impact\_Study\_\_Impact\_Report\_\_Nov\_2013\_-\_Final.pdf

5 "Wireless in Buildings", Commscope, February 2016

6 "Rail Usage Statistics", Office of Rail and Road, June 2015, <u>http://orr.gov.uk/news-and-media/email-alerts/2015/rail-passenger-journeys-reached-a-record-high-of-1.65-billion-between-2014-2015</u>

7 "Road Traffic Estimates 2015", Department for Transport, May 2016, <u>https://www.gov.uk/government/uploads/system/uploads/attachment\_data/file/524261/</u> <u>annual-road-traffic-estimates-2015.pdf</u>

**8** "5G PPP use cases and performance evaluation models", A living document, 5GPPP, Version 1.0, April 2016, <u>https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-use-cases-and-performance-evaluation-modeling\_v1.0.pdf</u>

**9** "5G empowering vertical industries", 5GPPP, supported by the European Commission, February 2016, <u>https://5g-ppp.eu/roadmaps/</u>

10 "NGNM 5G White Paper", NGMN, February 2015,

https://www.ngmn.org/uploads/media/NGMN\_5G\_White\_Paper\_V1\_0.pdf

11 "Ericsson Mobility Report", Ericsson, June 2016

https://www.ericsson.com/res/docs/2016/ericsson-mobility-report-2016.pdf

**12** "Connected and Autonomous Vehicles: The UK Economic Opportunity", KPMG, March 2015, <u>https://www.smmt.co.uk/wp-content/uploads/sites/2/CRT036586F-Connected-and-Autonomous-Vehicles-%E2%80%93-The-UK-Economic-Opportu...1.pdf</u>

**13** "Connected cars: worldwide trends, forecasts, and strategies 2014-2024", Analysys Mason, June 2014

**14** "Road Use Statistics - Great Britain 2016", Department for Transport, Statistical Release, April 2016

**15** "Britons spend more time driving than socialising", The Telegraph, January 2011 **16** "Far from home and help", RAC, November 2015, <u>http://www.racfoundation.org/media-centre/far-from-home-help-mobile-phone-coverage-GB</u>

**17** "Road Lengths in Great Britain 2015", Department for Transport, May 2016 <u>https://www.gov.uk/government/uploads/system/uploads/attachment\_data/file/524087/r</u> <u>oad-lengths-in-great-britain-2015.pdf</u>

**18** "Northern Ireland transport statistics 2015-2016 road network", Department for Infrastructure, accessed: October 2016, <u>https://www.infrastructure-ni.gov.uk/articles/northern-ireland-transport-statistics</u>

**19** "Road Traffic Estimates in Great Britain:2015 tables", Department for Transport, May 2016, <u>https://www.gov.uk/government/statistics/road-traffic-estimates-in-great-britain-</u>2015

20 "Connected Living – Every Car Connected", GSMA, November 2012


**21** "Deutsche Telekom and BMW edge towards the truly connected car", Telecom TV, August 2016, <u>http://www.telecomtv.com/articles/automotive/deutsche-telekom-and-bmw-edge-towards-the-truly-connected-car-13812/</u>

**22** "Wireless Communications V2X", Siemens for Highways UK, November 2015 <a href="http://www.highways-uk.com/content/huk/docs/ib2-connected-car-part-2.pdf">http://www.highways-uk.com/content/huk/docs/ib2-connected-car-part-2.pdf</a>

23 "Connected Cars to Cause Mobile Network Traffic Jams", Teoco, May 2015
24 "Connected and Autonomous Vehicles: The UK Economic Opportunity", KPMG, March 2015

**25** "Strategy for Automated and Connected Driving", German Federal Ministry of Transport and Digital Infrastructure, September 2015

**26** "App Strategies and Ecosystem Development", Jaguar Land Rover, accessed October 2016, <u>http://www.connected-in-vehicle-infotainment-2013.com/media/downloads/36-new-d1-1430-peter-virk-jaguar-land-rover.pdf</u>

**27** "Connected Cars: How Jaguar Land Rover Works With BearingPoint to Benefit Drivers", IDC, December 2014, <u>http://www.bearingpoint.com/ecomaXL/files/IDC\_buyer\_case\_study-</u> <u>Connected\_cars-Jaguar\_Land\_Rover\_BearingPoint.pdf</u>

**28** "Jaguar Land Rover Demonstrates All-Terrain Self-Driving Technology", Jaguar Land Rover, July 2016, <u>http://media.jaguarlandrover.com/news/2016/07/jaguar-land-rover-demonstrates-all-terrain-self-driving-technology?q=&start=0&brand=corporate</u>

**29** "Britain's railways now safest in Europe, but regulator highlights priorities for improvement", Office of Rail and Road, July 2015

**30** "Rail Trends Factsheet, Great Britain 2014/15", Department for Transport and Office of Rail and Road, December 2015

**31** "20 countries with the highest rail network density (as of 2009)", Statistica, accessed October 2016, <u>https://www.statista.com/statistics/268159/20-countries-with-the-highest-rail-network-density</u>

**32** "The Digital Railway Programme", Digital Railway, funded by Network Rail, accessed October 2016, goo.gl/zQaEbW

**33** "Rail passenger number and crowding into selected cities: 2015", Department for Transport and Office of Rail and Road, December 2015

34 "About us", Translink NI Rail, accessed October 2016,

http://www.translink.co.uk/Services/NI-Railways/About-us/

**35** "Frequency bands for 5G", UK Spectrum Policy Forum - Cluster 1, Meeting Notes, September 2016, https://www.techuk.org/insights/meeting-notes/item/9269-uk-spectrumpolicy-forum-cluster-1-frequency-bands-for-5g

**36** "Rail Users Factsheet, 2014/15", Department for Transport and Office of Rail and Road, December 2015

37 "Mobile Connectivity on Rail: Show and Tell", Department for Transport, August 2016

**38** "As GSM-R trundles towards the buffers, a new solution is required", Telecoms TV, August 2016

**39** "Future Railway Programme Solutions Catalogue", Network Rail and RSSB, November 2015

**40** "The Gigabit Train", Meeting Notes And Presentations, TechUK, March 2016, https://www.techuk.org/insights/meeting-notes/item/8136-the-gigabit-train-2

**41** "Next Generation of Railways and Metros wireless communication systems" Alcatel-Lucent, 2012

42 "Amtrak Advancing Wi-Fi Technology", Amtrak, March 2016,



**43** "Project SWIFT (Superfast Wi-Fi In-carriage for Future Travel)", Cisco, accessed October 2016, <a href="https://cisco-create.squarespace.com/swift/">https://cisco-create.squarespace.com/swift/</a>

44 "Digital Health in the UK", Deloitte study for Office of Life Sciences, September 2015, https://www.gov.uk/government/uploads/system/uploads/attachment\_data/file/461479/ BIS-15-544-digital-health-in-the-uk-an-industry-study-for-the-Office-of-Life-Sciences.pdf
45 "Five Year Forward View", NHS, October 2014, <u>https://www.england.nhs.uk/wp-</u>content/uploads/2014/10/5yfv-web.pdf

**46** "Johnson and Johnson admits insulin pump known to be vulnerable to cyber-attack", E&T, October 2016

**47** "Cybersecurity spending on connected medical devices still low but set to triple by 2021", ABI Research, October 2016,

https://www.telecomtvtracker.com/insights/cybersecurity-spending-on-connectedmedical-devices-still-low-but-set-to-triple-by-2021-7325/

**48** "Pimp my ambulance – putting life saving portable equipment into the hands of paramedics", Telecom TV, October 2016, <u>http://www.telecomtv.com/articles/internet-of-healthcare/pimp-my-ambulance-putting-life-saving-portable-equipment-into-the-hands-of-paramedics-14033/</u>

49 "Who Uses Telecare?", Strategic Society Centre, September 2012,

http://strategicsociety.org.uk/wp-content/uploads/2013/01/Who-Uses-Telecare.pdf 50 "Vitality GP", Vitality, accessed October 2016, <u>https://www.vitality.co.uk/health-insurance/core-cover/vitality-gp/</u>

51 "Health Care Industry post", Earnest and Young, 2014,

http://www.ey.com/Publication/vwLUAssets/EY-shaping-your-telehealth-

strategy/%24FILE/EY-shaping-your-telehealth-strategy.pdf

52 "5G Use Cases and Requirements", Nokia, 2016,

http://resources.alcatel-lucent.com/asset/200010

53 Diabetes digital coach test bed website, NHS England, accessed October 2016,

https://www.england.nhs.uk/ourwork/innovation/test-beds/diabetes-digital-coach/

54 "The Tactile Internet is on its way...", Professor Mischa Dohler, January 2016, http://www.21stcentury.co.uk/technology/the-tactile-internet/

**55** "Five Year Forward View", NHS, October 2014, <u>https://www.england.nhs.uk/wp-content/uploads/2014/10/5yfv-web.pdf</u>

**56** "How the NHS is finally unlocking the power of barcoding", GS1 UK, May 2016, <u>https://www.gs1uk.org/our-industries/news/2016/05/19/13/30/how-the-nhs-is-finally-unlocking-the-power-of-barcoding</u>

57 "About the National Health Service", NHS, accessed October 2016,

http://www.nhs.uk/NHSEngland/thenhs/about/Pages/overview.aspx,

58 "Customer Case Studies", Spok, accessed October 2016,

http://www.spok.com/resources/customer-case-studies#healthcare

**59** "Number of people with diabetes reaches over 4 million", Diabetes UK, January 2016, <u>https://www.diabetes.org.uk/About\_us/News/Number-of-people-with-diabetes-reaches-over-4-million/</u>

**60** "Britain: The fat man of Europe", NHS, based on United Nations Food and Agricultural Organization Report, 2013, <u>http://www.fao.org/docrep/018/i3300e/i3300e.pdf</u>

**61** "About obesity - UK and Ireland prevalence and trends", Public Health England, https://www.noo.org.uk/NOO\_about\_obesity/adult\_obesity/UK\_prevalence\_and\_trends, accessed October 2016.



62 "Our 2014-15 annual report", NHS, July 2015, <u>https://www.england.nhs.uk/wp-content/uploads/2015/07/nhse-annual-report-2014-15.pdf</u>

**63** "NHS to reveal cost of missed appointments to patients", BBC, July 2015, <u>http://www.bbc.co.uk/news/uk-33375976</u>

64 "Personalised Health and Care 2020", National Information Board, November 2014, https://www.gov.uk/government/uploads/system/uploads/attachment\_data/file/384650/ NIB\_Report.pdf

65 "Super-aged nations", CNN, accessed October 2016,

http://money.cnn.com/interactive/news/aging-countries/

66 "Singapore Is Taking the 'Smart City' to a Whole New Level", The Wall Street Journal, April 2016, <u>http://www.wsj.com/articles/singapore-is-taking-the-smart-city-to-a-whole-new-level-1461550026</u>

67 "Smart devices trial extended to 3,200 households in Yuhua", Channel News Asia, April 2016, <u>http://www.channelnewsasia.com/news/singapore/smart-devices-</u>trial/2724842.html

**68** "mHealth App Developer Economics 2016", Research2Guidance, October 2016, http://research2guidance.com/product/mhealth-app-developer-economics-2016/

69 "Asthma and COPD Management Made Simple", CarTRx, website, visited October 2016, https://www.caretrx.com/

**70** "Teva Pharmaceuticals buys smart inhaler company Gecko Health Innovations", Jonah Comstock at MobiHealthNews, September 2015,

http://www.mobihealthnews.com/47039/teva-pharmaceuticals-buys-smart-inhalercompany-gecko-health-innovations

**71** "TIHM for dementia - using technology to improve the quality of life for people with dementia", TIHM, Surrey and Borders Partnership, accessed October 2016, http://www.sabp.nhs.uk/tihm

**72** "TIHM for dementia – technology trial", Eagle Radio, accessed October 2016, <u>https://www.964eagle.co.uk/dementia-nhs-trial.php</u>

73 "Dementia UK update", Alzheimer's Society, November 2014,

https://www.alzheimers.org.uk/site/scripts/documents\_info.php?documentID=418

74 "Better Care Technology – results of call for evidence", ADASS, July 2015,

https://www.adass.org.uk/media/4233/call-for-evidence-report-july-2015.pdf

75 "Local account – living at home", Blackburn with Darwen council,

<u>http://www.yoursupportyourchoice.org.uk/i-need-help-with/living-at-home/local-account-</u> --living-at-home.aspx

76 "UK Future Energy Scenarios", National Grid, July 2014

http://www2.nationalgrid.com/UK/Industry-information/Future-of-Energy/Future-Energy-Scenarios/

**77** "Smart Metering Implementation Programme – Fourth Annual Report on the Roll-out of Smart Meters", DECC, November 2015

**78** "Building a smart metering network for Great Britain", Data Communications Company, October 2015

**79** "Ofgem – Smart Metering Implementation Programme Statement of Design Requirements", Ofgem, <u>https://www.ofgem.gov.uk/ofgem-publications/63543/smart-metering-statement-design-requirements.pdf</u>

**80** "Energy Networks Association – DNO – Smart Grid Communications Requirements", Energy Networks,



http://www.energynetworks.org/assets/files/electricity/engineering/telecoms/eitc/restrict ed/Reference%20Doc/Telent.pdf

81 "DECC - Fourth Annual Report on the Roll-out of Smart Meters", DECC,

https://www.gov.uk/government/uploads/system/uploads/attachment\_data/file/477258/ Smart Meters Implementation Programme Annual Report 2015.pdf

82 "", <a href="https://www.smartgrid.gov/the-smart\_grid/smart\_grid.html">https://www.smartgrid.gov/the-smart\_grid/smart\_grid.html</a>

83 "IoT for Utilities", Business Insider, October 2016

http://uk.businessinsider.com/internet-of-things-utilities-water-electric-gas-2016-10 84 "Van travel trends in Great Britain", RAC Foundation, April 2014

**85** "Provisional Road Traffic Estimates – Great Britain: July 2015 – June 2016", DfT, August 2016

86 "Logistics Report 2016", FTA (Freight Transport Association), 2016,

http://www.fta.co.uk/export/sites/fta/\_galleries/downloads/logistics\_report/lr16-web-030616.pdf

87 "Amazon Prime Air", Amazon, accessed October 2016,

https://www.amazon.com/b?node=8037720011

**88** "European Truck Platooning Challenge 2016", Lesson Learn Booklet, European Truck Platooning, June 2016, <u>https://www.eutruckplatooning.com/default.aspx</u>

89 "Platooning combines advanced technologies to improve safety and fuel efficiency", Peloton Technology, accessed October 2016, <u>http://peloton-tech.com/how-it-works/</u>
90 "Drone project: delivery terminal", DPD Group, accessed October 2016,

https://www.dpd.com/home/news/latest\_news/drone\_project\_delivery\_terminal

91 "Mobile video drives UK digital ad growth", BI Intelligence, October 2016

**92** "Creative UK: Overview of the Digital Transformation of the UK Creative Economy", Bain & Company for Creative UK, March 2014,

http://www.bain.com/Images/REPORT\_Creative\_UK.pdf

93 "The Communications Market Report", Ofcom, August 2015

**94** "Video Accounts for Majority of UK Mobile Data Traffic", eMarketer, January 2016, <u>http://www.emarketer.com/Article/Video-Accounts-Majority-of-UK-Mobile-Data-Traffic/1013424</u>

**95** "The Mobile Internet – Building the UK's Most Reliable Mobile Network", IET Lecture, Bryn Jones, CTO Three UK, June 2015

**96** "Cisco Visual Networking Index: Forecast and Methodology, 2014-2019", Cisco, White Paper, August 2015

97 "A Map of the UK Games Industry", Nesta, September 2014,

http://www.thecreativeindustries.co.uk/media/274111/map\_uk\_games\_industry\_wv.pdf 98 "The games industry in numbers", UKIE, accessed October 2016,

http://ukie.org.uk/research

99 "GameTrack Digest", ISFE Gametrack, Ipsos Connec, Quarter-1 2016,

http://www.isfe.eu/sites/isfe.eu/files/attachments/gametrack\_european\_summary\_data\_ 2016\_q1.pdf

**100** "UK business; activity, size and location: 2016", Office for National Statistics, accessed October 2016

**101** "Identification of the market for radio equipment operating in licence-exempt frequency bands to assess medium and long-term spectrum usage densities", European Commission, June 2016



**102** "Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe", Real Wireless & Partners for the European Commission, September 2016

**103** "UK spends more on SAAS in 2016", ITEuropa, January 2016, http://www.iteuropa.com/?q=uk-spends-more-saas-2016

**104** "Creative industries add £84bn to UK economy", The Creative Industries, January 2016, <u>http://www.thecreativeindustries.co.uk/uk-creative-overview/news-and-views/news-creative-industries-add-%C2%A384bn-to-uk-economy</u>

**105** "2016 Top Markets Report -Cloud Computing", U.S. Department of Commerce, April 2016

106 "Cloud Revenue To Top £13bn By End Of 2016", Tech Week Europe, February 2015, http://www.techweekeurope.co.uk/cloud/cloud-management/cloud-revenue-2016-160627
107 "Cloud Computing Trends 2016" & "Cloud Adaptation Risk Report", Skyhigh Networks, Q4 2015, <u>https://www.skyhighnetworks.com/cloud-computing-adoption-trends/</u>

**108** "Smartphone Ownership Usage and Penetration by Country", SMS Global, October 2015, <u>http://thehub.smsglobal.com/smartphone-ownership-usage-and-penetration</u>

**109** "Communications Market Report 2015", Ofcom, August 2015, <u>http://stakeholders.ofcom.org.uk/market-data-research/market-data/communications-market-reports/cmr15/</u>

**110** "Global Mobile Consumer Survey 2016: UK Cut", Deloitte, accessed October 2016, http://www.deloitte.co.uk/mobileuk/

**111** "CTA: 4K adoption faster than HD", Advanced Television, September 2016, <u>http://advanced-television.com/2016/09/21/cta-4K-adoption-faster-than-hd</u>

**112** "New service developments in the broadcast sector and their implications for network infrastructure ", Analysis Mason for Ofcom, November 2014,

http://stakeholders.ofcom.org.uk/binaries/research/infrastructure/2014/broadcastdev.pdf

**113** "UK Spectrum Usage & Demand", Real Wireless for UK Spectrum Policy Forum, December 2015

**114** "Understanding 5G: Perspectives on future technological advancements in mobile", GSMA Intelligence, GSMA, December 2014,

https://www.gsmaintelligence.com/research/?file=141208-5g.pdf&download

**115** "Death of the office and rise of the telecommuter", ZDNet, June 2014,

http://www.zdnet.com/article/death-of-the-office-and-rise-of-the-telecommuter/ 116 "By 2019, 80% of the World's Internet Traffic Will Be Video", Tubular Insights, June 2015, http://tubularinsights.com/2019-internet-video-traffic

**117** "5G Use Cases", Ericsson, accessed: September 2016,

https://www.ericsson.com/res/docs/2015/5g-use-cases.pdf

118 "CTA: 4K adoption faster than HD", Advanced Television, September 2016,

http://advanced-television.com/2016/09/21/cta-4K-adoption-faster-than-hd

**119** "UK sees tenfold increase in UHD sales", Advanced Television, September 2016, http://advanced-television.com/2015/09/29/ten-fold-increase-in-uhd-sales

**120** "The worldwide 4K display market to reach \$52 billion in 2020 according to industry researchers", 4K News, April 2015, <u>http://4K.com/news/4K-tv-market-to-reach-52-billion-in-revenues-by-2020-6655/</u>

**121** "Cisco Visual Networking Index: Forecast and Methodology, 2014-2019", Cisco, White Paper, August 2015



**122** "Vodafone sees the enterprise as key to 5G", Mobile World Live, October 2016, <u>http://www.mobileworldlive.com/featured-content/top-three/enterprises-key-for-5g-opportunity/</u>

**123** "UK unveils world's first virtual skyscraper to help solve the cyber security skills gap", Information Age, September 2015, <u>http://www.information-age.com/uk-unveils-worlds-first-virtual-skyscraper-help-solve-cyber-security-skills-gap-123460247/</u>

124 "In-Building Wireless", ABI Research, April 2014

125 "UK Spectrum Usage & Demand", Real Wireless, December 2015

126 "Can I stream Netflix in Ultra HD?", Netflix, accessed October 2016,

https://help.netflix.com/en/node/13444

**127** "Ultimate 4K Movies and UHD Content Guide. Watch 4K Netflix, Amazon & More", 4K.com, August 2016, <u>http://4K.com/movies/</u>

**128** "The Adoption Of 4K Streaming Will Be Stalled By Bandwidth, Not Hardware & Devices", Streaming Media Blog, Dan Rayburn, January 2015,

http://blog.streamingmedia.com/2015/01/4K-streaming-bandwidth-problem.html **129** "Why The Internet Pipes Will Burst When Virtual Reality Takes Off", Forbes (Tech), February 2016, <u>http://www.forbes.com/sites/valleyvoices/2016/02/09/why-the-internet-</u> pipes-will-burst-if-virtual-reality-takes-off/#60debb0e64e8

130 "Updated scenarios, requirements and KPIs for 5G mobile and wireless system with recommendations for future investigations", Deliverable D1.5, METIS, May 2015
131 "Efficient Video Compression for Live VR Streaming", Aakash Patel & Gregory Rose,

GitHub, Accessed October 2016, <u>https://avp.github.io/conduit/</u>

**132** "Preparing Your IP Network for High Definition Video Conferencing", White Paper, Polycom, 2014

**133** "Video conferencing bandwidth requirements for the WAN", SearchEnterpriseWAN, Accessed October 2016, <u>http://searchenterprisewan.techtarget.com/tip/Video-</u> conferencing-bandwidth-requirements-for-the-WAN

**134** "Virtual Reality, 4K and HDR Will Be the Major Themes at IBC 2016", CCS Insight, September 2016, <u>http://www.ccsinsight.com/press/company-news/2710-fitness-bands-and-basic-smartwatches-fuel-sales-of-wearable-devices</u>

**135** "Reported publisher revenues up 29% in 2015: Mobile Games Market Monitor", IHS Markit, April 2016

**136** "Getting in on the ground floor of a growth industry – virtual reality", Real Business, October 2016, <u>http://realbusiness.co.uk/business-growth/2016/10/05/getting-ground-floor-virtual-reality-growth-industry/</u>

137 "Beyond LTE: Advancing to 5G Wireless Technology", HIS Markit, December 2015
138 "Augmented/Virtual Reality revenue forecast revised to hit \$120 billion by 2020", Digi-Capital, January 2016

**139** "Sky Q platform 'long overdue", Digital TV Europe, January 2016,

http://www.digitaltveurope.net/488622/sky-q-platform-long-overdue/

140 "Ofcom consultation on assessment of future mobile competition and proposals for the award of 800 MHz and 2.6 GHz spectrum and related issues Annexes 7-13", Ofcom, March 2011, <a href="https://www.ofcom.org.uk/">https://www.ofcom.org.uk/</a> data/assets/pdf file/0019/55900/annexes-7-13.pdf
141 "Techniques for increasing the capacity of wireless broadband networks: UK, 2012-2030", Real Wireless for Ofcom, April 2012

142 "Mobile networks commit to 90% coverage by 2017", 10 February 2015, http://www.choose.net/media/guide/news/mobile-networks-ofcom-commitment-90-

coverage-2017.html



**143** "Increase in number of GP consultations has been 'modest', think-tank claims", Pulse Today, March 2015, <u>http://www.pulsetoday.co.uk/home/finance-and-practice-life-news/increase-in-number-of-gp-consultations-has-been-modest-think-tank-claims/20009337.fullarticle</u>

**144** "Smart Metering Implementation Programme: Statement of Design Requirements", Ofgem, July 2010, <u>https://www.ofgem.gov.uk/ofgem-publications/63543/smart-metering-statement-design-requirements.pdf</u>

**145** "DNO - Smart Grid Communications Requirements", Telent, December 2011, <u>http://www.energynetworks.org/assets/files/electricity/engineering/telecoms/eitc/restrict</u> <u>ed/Reference%20Doc/Telent.pdf</u>

**146** "O2 and Arqiva win £2.1bn smart meter contracts", The Telegraph article, Thursday 10 November 2016,

http://www.telegraph.co.uk/finance/newsbysector/energy/10243513/O2-and-Arqiva-win-2.1bn-smart-meter-contracts.html

**147** "EE selected to deliver critical new 4G voice and data network for Britain's Emergency Services", EE Press release on 10 December 2015, http://newsroom.ee.co.uk/ee-selected-to-deliver-critical-new-4g-voice-and-data-network-for-britains-emergency-services

**148** "Fixed Wireless Spectrum Strategy", Call for Input, Ofcom, September 2016, http://stakeholders.ofcom.org.uk/consultations/call-for-inputs-fixed-wireless-spectrum-

strategy/

149 "NGNM 5G White Paper", NGMN, February 2015,

https://www.ngmn.org/uploads/media/NGMN\_5G\_White\_Paper\_V1\_0.pdf

**150** "5G Use Cases from METIS-II Project", METIS-II, Salah Elayoubi, accessed 16/09/2016, <u>https://5g-ppp.eu/wp-content/uploads/2015/11/1-METIS-II-5G-use-cases\_presentation-with-verticals.pdf</u>

151 "5G Use Cases", Ericsson, accessed: September 2016,

https://www.ericsson.com/res/docs/2015/5g-use-cases.pdf

**152** "Death of the office and rise of the telecommuter", ZDNet, June 2014,

http://www.zdnet.com/article/death-of-the-office-and-rise-of-the-telecommuter/

**153** "Understanding 5G: Perspectives on future technological advancements in mobile", GSMA Intelligence, GSMA, December 2014,

https://www.gsmaintelligence.com/research/?file=141208-5g.pdf&download

**154** "Expressions of Interest sought: Video Analytics for Law Enforcement workshop", Innovate UK Network, February 2015,

https://connect.innovateuk.org/web/defence/article-view/-/blogs/expressions-of-interestsought-video-analytics-for-law-enforcement-workshop

**155** "11 best ways UK businesses are using chatbots", Techworld, August 2016, http://www.techworld.com/picture-gallery/personal-tech/9-best-uses-of-chatbots-inbusiness-in-uk-3641500

156 "A Map of the UK Games Industry", Nesta, September 2014,

http://www.thecreativeindustries.co.uk/media/274111/map\_uk\_games\_industry\_wv.pdf 157 "UK unveils world's first virtual skyscraper to help solve the cyber security skills gap", Information Age, September 2015, http://www.information-age.com/uk-unveils-worldsfirst-virtual-skyscraper-help-solve-cyber-security-skills-gap-123460247/

**158** "Nokia and EE – pushing the limits of technology with drones", Nokia, August 2016, <u>https://blog.networks.nokia.com/partners-and-customers/2016/08/11/nokia-ee-pushing-limits-technology-drones/</u>



**159** "Industry 4.0: Vital for UK manufacturing growth", Gambica, December 2015, <u>http://www.gambica.org.uk/resourceLibrary/industry-4-0---vital-for-uk-manufacturing-growth.html</u>

**160** "Connected Health – How digital technology is transforming health and social care", Deloitte, April 2015, <u>http://www2.deloitte.com/content/dam/Deloitte/uk/Documents/life-</u>sciences-health-care/deloitte-uk-connected-health.pdf

161 "5G Use Cases and Requirements", Nokia, 2016,

http://resources.alcatel-lucent.com/asset/200010

**162** "Biometric authentication in the real world", NPL, accessed September 2016, <u>http://www.npl.co.uk/upload/pdf/biometrics\_psrevho.pdf</u>

163 "5G Security : Forward Thinking", White Paper, Huawei, 2015,

http://www.huawei.com/minisite/5g/img/5G Security Whitepaper en.pdf

**164** "Identity and Access Management for the Internet of Things - Summary Guidance", IoT Working Group, CSA, accessed September 2016,

https://downloads.cloudsecurityalliance.org/assets/research/internet-of-things/identityand-access-management-for-the-iot.pdf

**165** "Self-driving cars: A £10m punt that could transform the UK", Nesta, December 2013, <u>http://www.nesta.org.uk/blog/self-driving-cars-ps10m-punt-could-transform-uk</u>

**166** "The Tactile Internet is on its way...", Professor Mischa Dohler, January 2016, http://www.21stcentury.co.uk/technology/the-tactile-internet/

167 "UR robot employed in Rio Olympics TV coverage", Universal Robots, August 2016, <a href="http://www.universal-robots.com/blog/ur-robot-employed-in-rio-olympics-tv-coverage/">http://www.universal-robots.com/blog/ur-robot-employed-in-rio-olympics-tv-coverage/</a>
168 "Cloud Robotics: 5G paves the way for mass-market automation", Ericsson Technology

Review, issue 5 - 2016, June 2016, <u>https://www.ericsson.com/res/thecompany/docs/publications/ericsson\_review/2016/etr-</u> 5g-cloud-robotics.pdf

**169** "Ericsson and King's College London demonstrate 5G tactile robotic surgery", Ericsson,1 June 2016, <u>https://www.ericsson.com/news/2023409</u>

**170** "Strategic Roadmap towards 5G for Europe", European Commission, Radio Spectrum Policy Group, Doc: RSPG16-031 Final, June 2016

**171** "Mobile Data Strategy - Update on our strategy for mobile spectrum", Ofcom, June 2016

**172** "Deliverable D2.2 -Evaluation methodology for architecture validation, use case business models and services, initial socio-economic results", 5G PPP, 5G NORMA, October 2016





Copyright ©2016 Real Wireless Limited. All rights reserved.

..... Real Wireless Ltd PO Box 2218 Pulborough West Sussex RH20 4XB United Kingdom

t +44 207 117 8514 f +44 808 280 0142 e info@realwireless.biz www.realwireless.biz