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OPEN NETWORKS RESEARCH AND DEVELOPMENT FUND BASELINE STUDY

A report prepared for the Department for Science, Innovation and Technology

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Executive summary

The Open Networks Fund

The Open Networks Research and Development Fund (ONF) is a £250m R&D programme aimed at building a more competitive, dynamic and diverse telecoms equipment supply chain. It aims to accelerate the development of Open RAN (ORAN) solutions in the UK and to step up the efforts to shape technology standards, in partnership with key industry and international partners. Open RAN is a new approach to defining and building mobile radio access network (RAN) solutions based on a general-purpose, vendor-neutral hardware and software-defined technology with open interfaces between all the components.

Baseline evidence collection

Objectives of this study

Frontier Economics was commissioned by the then Department for Digital, Culture, Media and Sport (DCMS) to provide baseline evidence on the UK's Open RAN market. This evidence will support future monitoring and evaluation of the ONF. Assessing whether the ONF has had an impact on certain outcomes requires understanding the status quo or baseline for those outcomes, so that in the future it is possible to measure how outcomes have evolved compared to the baseline, and to what extent the ONF has contributed to that evolution.

This study included the definition of a set of success measures and the collection of evidence on these measures, which took place in November and December 2022. The success measures aim to assess the intended outputs, outcomes and impacts of the ONF, as set out in a logic model developed by DCMS. These include:

- Measures on the UK's Open RAN innovation ecosystem, including for example investment in R&D, academic research outputs, academic spin-outs, research papers;
- Measures on the size and overall maturity of the supply of Open RAN solutions, including:
  - The number of Open RAN products on offer in the UK and their technological maturity;
  - The number of vendors of Open RAN components and systems integrators active in the UK, and the confidence that market participants, including Mobile Network Operators (MNOs), have working with these organisations;[1]
- Measures of testing and demonstration activity;
- Measures of adoption of Open RAN solutions, e.g. whether MNOs have invited vendors of Open components to bid in their latest equipment procurement rounds.

[1] A systems integrator is an organisation that integrates different software and hardware components from different vendors into a cohesive, end-to-end network solution.

Further estimates of deployment of Open RAN solutions by UK MNOs are being collected by DCMS in a process separate from this study.

Approach to evidence collection

The baseline evidence draws on a combination of:

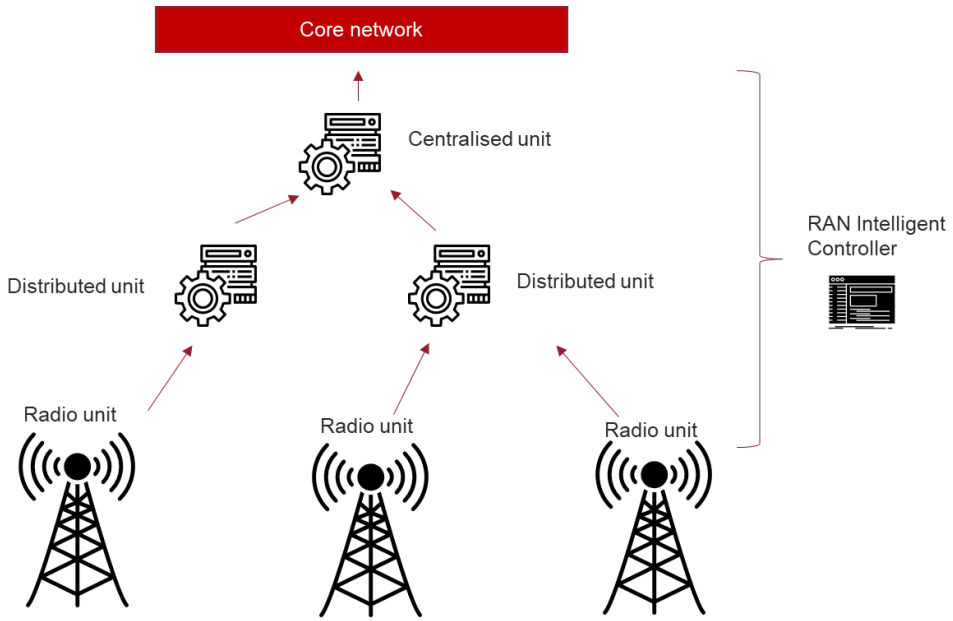
- Primary evidence collection, including:
  - An online survey questionnaire sent to 22 market participants, including potential Open RAN vendors, systems integrators and incumbent RAN providers (Nokia and Ericsson);
  - A broader questionnaire shared with four MNOs: BT/EE, Three UK, Virgin Media O2 and Vodafone; and
  - Three interviews with academics at UK institutions.
- Secondary data collection, including data on patents and academic publications.

Summary of baseline findings

Open RAN effectively implies that the vendor market is disaggregated into multiple sub-markets split by product type

Open RAN is a new approach to defining and building mobile RAN solutions based on a general-purpose, vendor-neutral hardware and software-defined technology with open interfaces between all the components. While in the traditional RAN market, all equipment (including hardware and software) is integrated and provided by the same vendor, in the Open RAN market different parts of equipment are provided by different vendors of Open RAN components. The figure below provides a stylised representation of the Open RAN architecture. Please see the Glossary for a definition of all terms used in the diagram and other terms used in this report.

Figure 1 Stylised representation of Open RAN architecture



Source: Frontier Economics

As shown in the figure, the key elements of an Open RAN architecture are: **Radio Unit** (RU), **Distributed Unit** (DU), **Centralised Unit** (RU), and **RAN Intelligent Controller** (RIC) software. RU, DU and CU include both hardware and software, and the software can run locally (radio application software) or remotely (cloud application software).[2] Moreover, the hardware in this architecture often requires specialised **chip sets**. Therefore, **there are 11 product types** that are required for Open RAN deployment.[3]

Based on the evidence available to us, there are no Open RAN vendors that provide all product types required for Open RAN deployment. **Each ORAN component vendor tends to specialise in 1-2 product types**: this is the case for 84% of the ORAN component vendors that MNOs are aware of. According to MNO input, the most diversified ORAN component vendor provides six product types (RU hardware, DU and CU radio application software, DU and CU cloud application software, and RIC).[4] Therefore, multiple component vendors are required in order to provide an end-to-end solution. For example, Vodafone is currently deploying Open RAN masts in South West England in a partnership with Dell, Intel, Samsung, Wind River, and Capgemini.[5]

The role of system integrators

2 RIC software is generally run remotely and therefore we consider all RIC products as part of the same product type.

3 Hardware: RU, CU, DU; Radio application software: RU, DU, CU; Cloud application software: RU, DU, CU; RIC software; chip sets.

4 Based on responses provided by MNOs. These findings are broadly consistent with the data we have gathered from Open RAN component vendors, although vendors typically reported providing more product types compared to MNO's understanding of their offer.

5 https://www.vodafone.co.uk/newscentre/press-release/openran-deployed-in-urban-locations-in-european-first/

In principle, the service of integrating components from different vendors can be provided to MNOs by a separate organisation – a systems integrator. However, while all MNOs indicated awareness of systems integrators operating in the UK, their view was that **no systems integrator is currently providing a fully integrated service**. One MNO elaborated on this view, stating that they are aware of several organisations that can undertake software integration, but none that can also carry out hardware integration and therefore provide an end-to-end solution.

Although there are several vendors of Open RAN components currently, the general consensus is that **the market is at a nascent stage of its development**. As the market becomes more mature, it might undergo consolidation, with some vendors of components exiting, merging, or expanding into other component types.

MNOs' views on Open RAN

There is a marked difference of strategy among MNOs. **One MNO is actively testing and deploying ORAN,** and some have started inviting Open RAN vendors to participate in their procurement, but **others are not actively engaging with vendors of ORAN components yet** as they have other priorities. However, most MNOs plan to invite vendors of Open RAN components/ system integrators to take part in their next procurement rounds.

As described above, measuring the existing deployment of Open RAN solutions in UK networks was beyond the scope of this study. However, **there was a consensus among MNOs that Open RAN solutions, although they are improving, are not yet ready for commercial deployment on a large scale** (particularly in high-density environments). While MNOs believe that ORAN technology will improve and costs will decline, there is little clarity on when this will occur and whether ORAN would then be extensively rolled out.

Some of the issues mentioned by MNOs that may be holding back wider Open RAN deployment included the following:

- A lack of availability of comprehensive, cost-efficient systems integration (as discussed above);
- Concerns around the costs and performance at scale of Open RAN solutions were mentioned by three MNOs, with two of them specifically citing performance in high-density environments.

While all MNOs recognised the importance of diversification in the long term, some saw it as a relatively low short-term priority compared to challenges such as delivering returns above the cost of capital, falling Average Revenues Per User (ARPUs) and the removal of Huawei equipment.

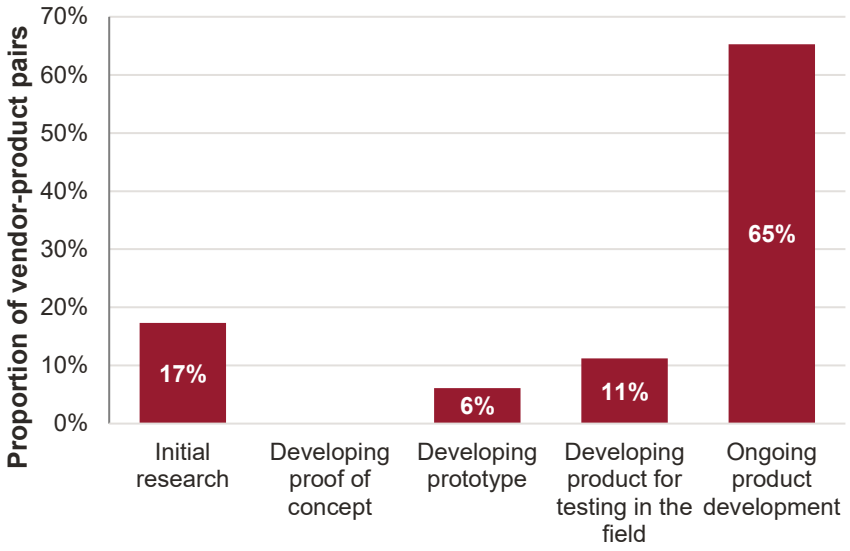
Innovation activity

Our research also gathered evidence on the extent and type of innovation in the UK Open RAN landscape.

This evidence suggests that there is **innovation taking place in the private sector focused on testing and developing existing products**. This is likely to account for a majority of businesses' innovation activity:

- Nine out of 12 vendors of ORAN components who responded to our survey said they have testing facilities used for Open RAN products in the UK;
- For a large majority of product types, vendors indicated that their efforts are focused on ongoing product development (primarily, 65% of product-vendor combinations) or testing new products in the field (11% of combinations);
- At the same time, a sizeable minority of innovation undertaken by component vendors focuses on earlier-stage research, namely initial research (17% of product-vendor combinations) and developing prototypes (6% of combinations);
- One of the incumbent RAN providers indicated that they are testing Open RAN solutions with customers;
- Three out of four MNOs reported that they are testing Open RAN equipment in the UK.

Figure 2 Stage of development of technology – Open RAN component vendor assessment



Source: Frontier analysis of Open RAN component vendors' survey responses
Note: Sample size: 7 Open RAN component vendors

The **focus on testing and development in the private sector** is also indicated by MNOs, who see testing and product development as priorities for Open RAN to ensure that products can be competitive from a performance and cost point of view. This was echoed by one of the Open RAN component vendors we engaged with. Another vendor indicated that testing in a real environment with MNOs is particularly important because each operator works differently, so vendors have to be able to adapt to specific requirements.

There were **mixed views from market participants on the extent to which testing Open RAN solutions is significantly burdensome**. **Half of the vendors of Open RAN components and systems integrators that responded to our survey said that it was**,[6] and two of them said they had abandoned product development efforts in the past due to the high cost of testing. Among MNOs three out of four respondents said that Open RAN testing involves significant costs, primarily due to the requirement for skilled staff and the need to test interoperability, which does not apply to closed RAN solutions.[7]

Academic activities

Our secondary data analysis identified a **small number of academic publications directly related to Open RAN** and relatively few patents. Bristol and Surrey universities were mentioned as two institutions that carry out research directly related to Open RAN. But the academics we interviewed indicated that many researchers see Open RAN as a specific implementation of a radio system and too close to commercialisation for academic research. The academics were more interested in researching ways to improve general radio systems; their innovations would then be applicable to different radio systems rather than specifically to Open RAN.

However, the academics indicated that the diversification strategy pursued by the UK and other countries may lead to increased academic interest in Open RAN. Moreover, **some of the stakeholders we interviewed said that there is potential for greater university-industry collaboration and thought that government support for collaborative research could have a positive impact**. Therefore, while Open RAN may not be a major area of interest for most academic researchers, it would be helpful for future monitoring and evaluation of the ONF to track whether the fund has led to increased applied research on this topic.

Lessons learnt for future monitoring and evaluation of the ONF

Our online survey elicited a high response rate of 82% (18 responses from 22 recipients of the questionnaire), and we received very detailed, informative input from MNOs. This suggests that it will be feasible to collect high-quality data on the evolution of the UK Open RAN sector as part of future monitoring and evaluation exercises. To maximise response rates and minimise the burden on respondents, it would be beneficial to identify as early as possible relevant individuals within the target organisations; to explain the purpose and scope of the data collection in advance of disseminating surveys; and to test questionnaires in advance with a handful of respondents to ensure that questions are phrased in a way that is meaningful and easy to understand for market participants. It would also be useful to engage with industry bodies (e.g. techUK) at an early stage of the evaluation process to get their input and contact details in relevant organisations if possible.

We note that most respondents to our survey did not provide financial information on their investment in R&D or revenues from Open RAN in the UK. Although we reassured respondents that their

6 The other half reported that testing is not significantly burdensome. Both groups (organisations for which testing is burdensome and those for which it isn't) included a similar mix of large and small organisations. Note: based on 12 responses to this question.

7 One MNO specifically mentioned IP engineering and security skills as areas where there are gaps currently.

information would be used only to generate aggregate data on the market, their reticence was likely due to confidentiality concerns. Indeed, this was explicitly cited by some respondents as the reason for not providing financial information. Consequently, before rolling out future market surveys we would recommend engaging with a selected number of market participants to explore what processes could be put in place to mitigate their concerns, or what alternative measures could be collected (e.g. employment in Open RAN activities rather than revenues).

Engagement with MNOs also revealed that other Open RAN component vendors and systems integrators may be active in the UK, in addition to those we surveyed. Future data collection should seek to include these market participants. This was not possible within the timeline of this study because data gathering from Open RAN component vendors and MNOs took place in parallel. Future monitoring and evaluation may benefit from a staged approach: engaging initially with MNOs will ensure that all vendors that the MNOs are aware of are invited to participate in the data collection survey.

1 Introduction

Objectives of this study

The then Department for Digital, Culture, Media and Sport (DCMS) commissioned Frontier Economics to support the definition and collection of baseline evidence for the Open Networks R&D Fund (ONF).[8] The ultimate objective of the study is to support the future monitoring and evaluation of the ONF. Assessing whether the ONF has had an impact on certain outcomes requires understanding the status quo or baseline for those outcomes, so that in the future it is possible to measure how outcomes have evolved compared to the baseline, and to what extent the ONF has contributed to that evolution. Therefore, we have been asked to refine and expand a set of success measures prepared by DCMS prior to the start of this study and to collect baseline information for each of these measures.

This study does not in itself provide evidence on the impact of the ONF. Data and evidence collected at later stages of the evaluation will be needed to draw conclusions on its effectiveness.

This study was conducted in two phases:

- In Phase One (October 2022), we built on existing work undertaken by DCMS to develop a framework for collecting the data, setting out the success measures to be baselined and the source(s) of data used to do so;
- In Phase Two (November 2022-January 2023), we implemented this framework, collecting the baseline figures.

In Phase One we identified the calendar year 2022 as the relevant baseline period for the ONF. While some of the initiatives of the ONF had started in 2022, it is unlikely that they will have already significantly altered the baseline measures being collected as part of the study. The success measures of the ONF (listed in Annex C also include measures of the deployment of Open RAN solutions by Mobile Network Operators (MNOs). These are being estimated by DCMS in a separate exercise and are not listed in this report.

As part of defining the appropriate success measures, we identified the following ones to be collected through ONF monitoring data. They are **not collected in this baseline study** as, by definition, they will be zero:

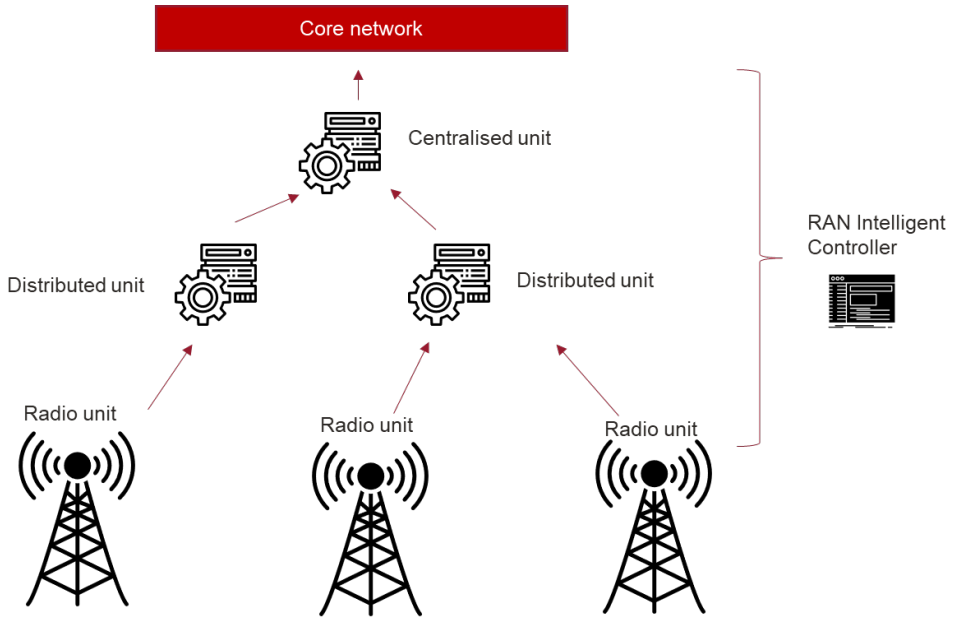
- Number of new products developed that meet interoperability requirements, split between those from UK R&D projects and those from international collaborations;
- Number of new products developed that meet security requirements, split between those from UK R&D projects and those from international collaborations.

The Open Networks Fund

[8] https://www.gov.uk/guidance/open-networks-research-and-development-fund

Open RAN (ORAN) is a new approach to defining and building mobile RAN solutions based on a general-purpose, vendor-neutral hardware and software-defined technology with open interfaces between all the components.

Figure 3 Stylised representation of Open RAN ecosystem



For the open ecosystem to foster innovation and the development of new technologies, while also driving costs down, it is necessary that product development efforts are shared by all stakeholders. Coordination is required to ensure the full interoperability of multi-vendor solutions. In this context, systems integration becomes particularly important, as there is no longer a single entity responsible for the complete end-to-end product.

To address these challenges, DCMS has embarked on a range of projects including testbeds, development of standards, studies, research projects and use cases. A key element of DCMS's overall strategy is the Open Networks R&D Fund (ONF), a c.£250m R&D programme aimed at building a more competitive, dynamic, and diverse telecoms equipment supply chain. It aims to accelerate the development of Open RAN solutions in the UK and to step up the efforts to shape technology standards, in partnership with key industry and international partners. Funded activities aim to address critical barriers - including power efficiency, spectrum management, software platforms, systems integration, and security – to ensure that the development of innovative telecoms solutions meets the performance and security requirements of MNOs and other network builders.

The programme focuses on the following five areas:[9]

- **Evolving the Innovation Ecosystem**: This involves investing in the wider UK ecosystem to support innovation and the development of technical standards, for example through the UK

[9] Based on the July 2022 DCMS Guidance on the Open Networks Research and Development Fund.

Telecommunications Innovation Network (UKTIN). The UKTIN will act as an information and ideas hub for industry and academics looking to access funding or R&D testing facilities and to explore opportunities to collaborate on developing new mobile and broadband technology.

- **Accelerating Maturity**: This involves supporting the development, scaling up and commercialisation of open-interface solutions, which is driven by the Future RAN Competition (FRANC) and the Future Open Networks Research Challenge (FONRC). Other initiatives will also be supported, including work to develop a balanced set of UK-specific Open RAN requirements for end-to-end deployments in high-demand density (HDD) environments.

- **International Research and Development**: This includes international partnerships and collaborative R&D. The first international partnership has been launched with the Republic of Korea.

- **Developing Facilities and Demonstration Capabilities**: This includes the SmartRAN Open Networks Interoperability Centre (SONIC) and UK Telecoms Lab (UKTL), which will be operated by the National Physical Laboratory (NPL) through to March 2025.

- **Driving Adoption**: This involves helping to create a dynamic proving ground in the UK for the industry to test and demonstrate the performance and capabilities of innovative telecoms solutions across a range of environments, use cases and applications. This includes the NeutrORAN project, which aims to demonstrate the performance of a “neutral host” Open RAN solution in outdoor rural settings; further funding for integration of open-interface solutions beyond the laboratory; and Open RAN trials in HDD environments.

The remainder of the report is structured as follows:

- Section 2 presents our methodology;

- Section 3 reports findings on the UK Open RAN research ecosystem;

- Section 4 includes findings on the size and characteristics of the Open RAN market, including a summary of the views of MNOs;

- Section 5 presents lessons learnt from this baseline study and recommendations for the future monitoring and evaluation of the ONF.

2 Methodology

In this section, we set out our overall approach to the study, starting with a high-level overview of the logic model and the list of indicators we need to collect. We then explain our approach to data gathering, comprising:

- primary evidence collection (gathered by us from relevant stakeholders via surveys and interviews); and
- secondary data collection (data from publicly available sources).

2.1 Overview of approach

In the first phase of the project, we reviewed a logic model and initial list of success measures shared with us by the DCMS Diversification Strategy Unit. The model provides a framework for understanding how an intervention could lead to relevant impacts. It can also be used to help identify interim outputs and outcomes which can form useful success measures.[10] We reviewed the logic model and the list of success measures. We agreed with DCMS on some updates to the list that would make it as useful as possible for future monitoring and evaluation. These included:

- Refining the definition of a number of success measures to ensure that it would be feasible to collect data on these measures over time; and
- Adding other measures to ensure that all outputs and outcomes identified by the logic model would be captured by at least one and ideally several success measures.

Please see Annex D for a summary version of the logic model.

When reviewing the logic model and the success measures, we also considered the best way of obtaining the baseline information, either using existing publicly available data (referred to as 'secondary data collection') or collecting our own data from a range of relevant stakeholders ('primary data collection').

In principle, there are several types of stakeholders whose views we wanted to capture. These are:

- Vendors of Open RAN components, which provide hardware and software for Open RAN networks;
- Systems integrators, which integrate different Open RAN components;
- Incumbent RAN providers, which may incorporate Open RAN principles in some of their operations;
- MNOs, which would ultimately benefit from Open RAN development; and

[10] Outputs are the immediate result of a programme's activities, e.g. number of R&D projects funded. Outcomes (e.g. development of new products through the R&D projects) follow from outputs and are expected to contribute to the programme's overall impacts (e.g. a more mature UK Open RAN market).

- Academics who work in the field and are expected to contribute to Open RAN development and innovation.

Before going on to define and implement our data collection strategy, we finalised the list of success measures, grouped as follows:

- Measures on the UK's Open RAN innovation ecosystem, including for example investment in R&D, academic research outputs, academic spin-outs, research papers;
- Measures of the extent and maturity of the supply of Open RAN solutions, including:
  - Number of Open RAN products on offer in the UK and their technological maturity, including Radio Units (RU), Centralised Units (CU), Distributed Units (DU), RAN Intelligent Controllers, and both hardware and software;
  - The number of vendors of Open RAN components and systems integrators active in the UK, and the confidence of market participants (including MNOs) working with these organisations;
- Measures of testing and demonstration activity;
- Measures of adoption of Open RAN solutions, e.g. whether MNOs have invited Open RAN vendors to bid in their latest procurement rounds.

It is worth noting that the evolution of success measures will need to be interpreted in the round and take into account qualitative inputs from secondary sources and market participants. An increase or decrease in a given success measure should not necessarily be interpreted as a sign of the success of the ONF or of the increasing/decreasing commercial sustainability of the Open RAN market. For example, a fall in the number of vendors of Open RAN components active in the market may be a sign of growing sustainability, if coupled with evidence of wider adoption of Open RAN technology and growth in the average size of active Open RAN vendors. Such nuances will need to be considered when using the evaluation results to judge the overall effectiveness of the programme.

A full list of success measures and their values as collected through this study is available in Annex C .

2.2 Primary evidence collection

Our primary evidence collection consisted of:

- Designing and disseminating a survey questionnaire to 26 organisations, including five systems integrators, the two incumbent RAN providers (Nokia and Ericsson), 15 Open RAN component vendors and four MNOs. The questionnaire was tailored to each of these four groups of respondents with one response being collected per organisation; and

- four interviews with academics based at UK research institutions.

Our aim in all cases was to include a complete/comprehensive set of relevant organisations in our survey. For example, we were able to collect information from all four MNOs in the UK. However, Open RAN component vendors and systems integrators operate in a new and evolving market, where

entry and exits (mergers) are relatively frequent. Therefore, it was not possible to capture all Open RAN component vendors in our survey. Instead, we focused our efforts on the most established ones.

The online survey was sent to the following organisations:[11]

- **Systems integrators**: IBM, Accenture, Cisco, WiPro, Radisys;
- **Incumbent RAN providers**: Nokia, Ericsson;
- **Vendors of Open RAN components**: Mavenir, Parallel Wireless, DenseAir, Altiostar, Samsung, NEC, Airspan, Wind River, Dell, Fujitsu, Rakuten, Qualcomm, Capgemini Engineering, VMWare, Keysight;
- **MNOs**: BT/EE, Three UK, Virgin Media O2, Vodafone.

Survey responses were collected between November 23rd and December 16th. We received replies from 18 of the 22 systems integrators and RAN providers/component vendors (an 82% response rate) and from all four MNOs.

Table 1 Number of survey responses by organisation category

Organisation type	Number of potential respondents	Number of responses
Systems integrators	5	4
Incumbent RAN providers	2	2
Vendors of Open RAN components	15	12
Mobile Network Operators	4	4

Limitations

While we achieved a high response rate, there are some limitations in the data we gathered. We describe these below and set out in section 5 the lessons we learnt for future data collection.

Even with a high response rate, the survey sample is relatively small due to the fact that not many organisations are currently active in this market.

Some replies were not comprehensive. We contacted respondents to ascertain whether this was because of difficulties in filling in the questionnaire, or simply because their organisation has limited Open RAN activity and so regarded most questions as not relevant. Unfortunately, in most cases we did not receive further clarification, meaning the data we were able to use from these responses was limited.

[11] The list was agreed with DCMS.

Most respondents did not provide the financial information we asked for: only three organisations shared how much they had invested in R&D in the UK in the last year, and only four disclosed their sales of ORAN products in the UK.

It is also worth noting that one of the MNOs was going through a procurement process at the time of our data collection and therefore could not share information on who they had invited or whether they had asked Open RAN component vendors to participate in recent procurement rounds.

Annex A provides further detail on the data collection process.

2.3 Secondary evidence collection

Success measures

We identified secondary data as the best source for the following success measures:

- UK university ranking for telecommunications globally and in Europe;
- Number of telecoms patents filed in the UK;
- Number of Open RAN patents filed in the UK;
- Number of UK Open RAN research papers published in international high-impact journals;
- Number of relevant academic papers authored or co-authored by UK-based researchers.

Approach to data collection

For the indicator **UK university rankings for telecommunications globally and in Europe**, we used two sources: EduRank and Shanghai Ranking. Annex B provides further detail on the source selection.

For the indicators **Number of telecoms patents filed in the UK** and **Number of Open RAN patents filed in the UK,** we used Espacenet, a patent search database maintained by the European Patent Office that includes patents filed in the UK. To identify telecoms patents, we filtered via the country code in the patent application number and used the Cooperative Patent Classification system in our search. We included data on patents filed between 2018 and December 2022.

For the indicators **Number of relevant academic papers authored or co-authored by UK-based academics** and **Number of UK Open RAN research papers published in international high-impact journals**, we investigated two possible approaches:

- Consulting broad databases of academic publications; and
- Consulting specific journals or publishers.

For the “Number of UK Open RAN research papers published in international high impact journals” indicator, we use Institute of Electrical and Electronics Engineers (IEEE) journals and Communications magazine, and track the number of research papers on Open RAN published in these journals by academics at UK universities. For “Number of relevant academic papers authored

or co-authored by UK-based academics", we used standard keywords from the online IEEE publications database, IEEE Explore to identify Open RAN related papers.

For both indicators, we focused on papers published between 2018 and 2022 to ensure we could establish a pre-ONF time series.

Limitations

The main limitation of this exercise is that there is a degree of subjectivity in determining exactly which publications or patents are relevant or not to Open RAN. Academic publications, for example, span a broad spectrum: some are directly and specifically related to the functioning of Open RAN systems, while others investigate the use of machine learning in networks, which is relevant to both open and closed RAN systems. Classifying patents and publications as either "relevant" or "not relevant" was a necessary simplification to make the data collection exercise manageable in the time we had and repeatable at a reasonable cost to DCMS and future evaluators.

Further detail on academic publication databases

We investigated several database options beyond the IEEE Xplore website, including sources available for free (Google Scholar, Core.ac.uk, Arxiv) and others that can be accessed for a licence fee (Researchfish, Scopus, Web of Science). These fees range between £10k and £50k. Since these databases would be used for only two of the baseline success measures, our assessment is that the fees are too high given the resources available for the baselining, monitoring and evaluation of the ONF. Therefore we propose using IEEE Xplore, which is available for free and offers a readily available export function. Other sources do not provide this functionality. Among these, Google Scholar is the most comprehensive. Core.ac.uk focuses on open access papers only, and Arxiv on specific disciplines.

3 The Open RAN research ecosystem

In this section, we examine success measures that capture the state of development of the Open RAN research ecosystem. This covers:

- Academic research and outputs (university rankings, ORAN-related academic papers, and qualitative evidence from academic interviews);
- ORAN-related patents; and
- ORAN-related R&D in the private sector (ORAN-focused university spin-outs, private sector R&D spending).

3.1 Academic research and outputs

Quantitative data

3.1.1 UK university rankings for telecommunications globally and in Europe

We collected data from EduRank and Shanghai Rankings on the number of UK universities in the top 100 for telecommunications in Europe and worldwide. Averaging these two sources, we found that:

- 9 UK universities are featured in the global top 100;
- 29 UK universities are featured in the European top 100.

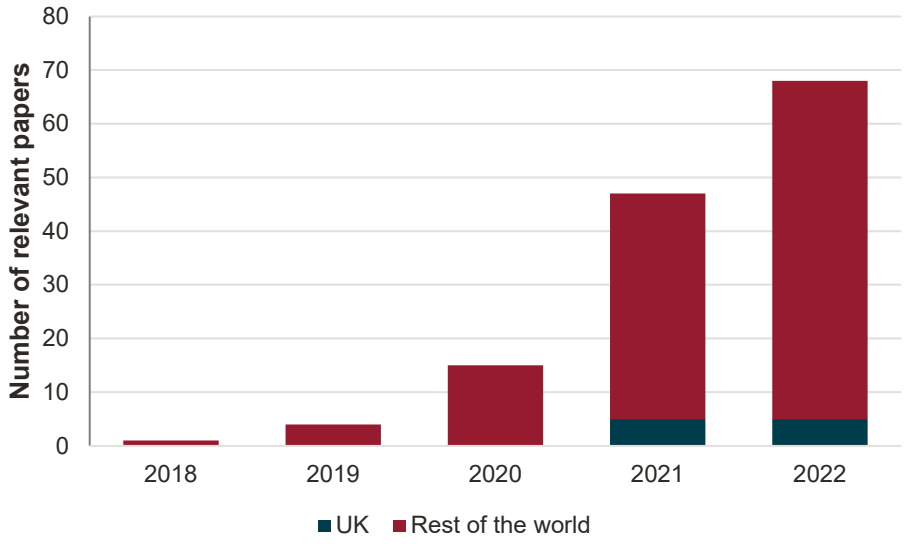
The results are similar across the two rankings. Further detail on the data is available in Annex B

3.1.2 Number of relevant (high-impact) academic papers authored or co-authored by UK-based academics

Our secondary data collection identified relatively little evidence of academic publications focused specifically on Open RAN, in the UK and elsewhere. This suggests that, even where academic research institutions are directly involved in projects related to Open RAN, this work may not lead to published research outputs specific to Open RAN. We understand that this is due to the fact that Open RAN projects are more focused on testing and deployment. On the other hand, academic research focuses on more fundamental issues that benefit telecoms networks generally, and not ORAN networks exclusively. However it would still be useful to monitor the quantity of research outputs in the future, to check whether there has been an increase from this baseline (The full data collection process is explained in Annex B.3).

An index search on IEEE Xplore yielded 135 Open RAN papers published in the last five calendar years including 2022 (2018-2022), as shown in the Figure below. Of this total, 99 (74%) were conference papers while the others were published in IEEE journals. **Ten of the 135 (7.5%) were produced by at least one co-author based at a UK research institution**. None of these 10 papers were published in relevant high-impact IEEE journals (as described in Section 2).

Figure 4 Open RAN academic papers listed on IEEE Xplore digital library, 2018-2022



Source : IEEE Xplore, Frontier analysis

For comparison, a search on IEEE Xplore using the "Massive MIMO" keyword yielded 1,114 papers published in 2022 only.

A further check on Google Scholar confirmed that the approach described above captures a very large majority of relevant academic publications. We reviewed 50 results from a **Google Scholar** search on "Open RAN" to understand whether our analysis of IEEE papers may have missed a significant number of publications in peer-reviewed journals. A large majority of the results were papers already identified through the IEEE Xplore search, working papers, conference papers or policy briefs. The 50 results included only seven relevant[12] papers (15% of the total results and 5% of the number identified through IEEE Xplore) published in a non-IEEE academic journal, all between 2019 and 2022.

While we have focused on the most highly-regarded publications, in principle this search could have been extended to other institutions and other repositories of academic papers. Some of these are freely available, others for a fee. However, given the relatively small number of publications identified through the searches described above, it was decided that collecting more academic data would be disproportionate.

3.1.3 Qualitative evidence

We contacted three academics in their capacity as researchers (Izzat Darwazeh at University College London, Rahim Tafazolli at the University of Surrey, and Mahesh Marina at the University of Edinburgh).

[12] Plus an additional paper on the geopolitics of Open RAN, which was not considered to be relevant.

Our engagement suggests that most academics in the communications field in the UK are doing research on broader, earlier-stage topics rather than concentrating specifically on Open RAN solutions. Open RAN is a specific implementation of a radio system and is considered, at this stage, to be close to commercialisation. The academics were more interested in researching ways to improve general radio systems, so that any innovations would be applicable to different radio systems rather than just to Open RAN. Bristol and Surrey were mentioned as two universities carrying out research more directly related to Open RAN. According to our interviewees, Open RAN is typically not a specific area of exploration for academic researchers in other countries either. However, the US, Sweden and to some extent Germany are generally regarded as stronger than the UK in translating research/experimental research into commercial products, due to the presence of large communications companies and possibly to differences in public policy (i.e. greater incentives for private sector funding of academic research/university-industry collaboration).

We were told that one team of academics had decided to spin out an SME to provide small-scale radio systems to entities with specific needs that mainstream suppliers could not meet. However, these were not Open RAN systems in a strict sense since the intended customers had limited need for openness due to their bespoke requirements.

Another team of academics had engaged with government-funded Open RAN schemes as part of consortia working on larger projects. They have used these projects to fund further development of more widely applicable technologies which could be applied to Open RAN. Hence, this is not strictly research into Open RAN, but the use of Open RAN as a platform to help implement research results.

In the area of Open RAN some academics participate in trials, often sponsored by the government, and in discussions and debates hosted by bodies such as TechUK. As might be expected, some universities engage more in industrial activities depending on their capabilities, the priorities of their leadership and their success in winning funding. However, while there is academic engagement it is generally at the trial stage and not at the point of commercial deployment. Hence, academics tend not to have insights into areas such as the difficulties of integration or the relative costs of Open RAN versus conventional systems.

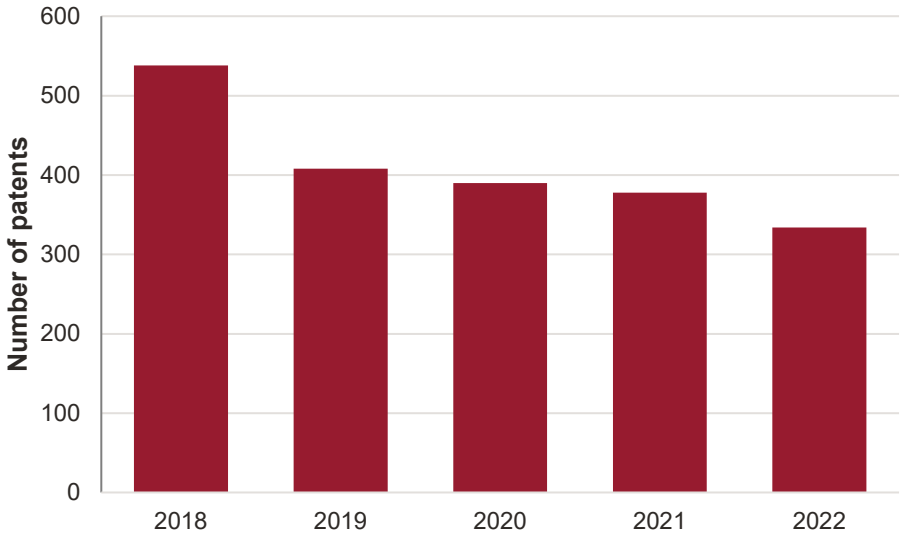
3.2 Patents

For both indicators on patents, we relied on Espacenet, the European Patent Office database. We collected data for 2018 to 2022, to reflect the formalisation of Open RAN as a concept in 2018 (the year the O-RAN Alliance was founded).

Number of telecoms patents filed in the UK

In the period, we identified 2,048 telecoms patents filed in the UK.

Figure 5 Telecoms patents filed in the UK by year, 2018-2022



Source: Espacenet, Frontier analysis

Number of Open RAN patents filed in the UK

We identified **24 Open RAN patents filed in the UK between 2018 and November 2022**, including 11 in 2019 (see Table 2 below).

We identified **269 telecoms patents filed by Open RAN component vendors in the same period**. However, the list of vendors included some very large companies, such as Fujitsu and Samsung.[13] Open RAN is likely to account for a small part of the activity of these companies and therefore for a small proportion of the patents they have filed.

Indeed, reviewing a 10% sample of the telecoms patents filed by the larger vendors, several included techniques that can be applied to 5G in general and so would appear in ORAN equipment, but none were ORAN specific.

Excluding the large companies that operate in several telecoms fields and focusing on smaller Open RAN component vendors, we identified **24 patents filed in the UK.**

[13] The organisations that we classified as large organisations are: Samsung, NEC, Dell, Fujitsu, Capgemini Engineering, IBM.

Table 2 Number of telecoms patents filed by organisations operating in the Open RAN field, 2018-2022

	# of patents filed	2018	2019	2020	2021	2022
Total (ORAN component vendors only)	269	46	40	58	63	62
Total (excl. larger companies)	24	2	11	6	2	3

Source: Espacenet, Frontier analysis

3.3 Research & Development in the private sector

In this section we set out our findings regarding R&D undertaken in the private sector, which rely primarily on data from the baseline survey, complemented with desk research. Here we focus on R&D by ORAN component vendors, systems integrators, and academics; findings on R&D by MNOs are reported in Section 4.4.

3.3.1 Number of Open RAN-focused university spin-outs and capital raised by them

Our desk research and conversations with academics identified two start-ups whose technology can be included in advanced wireless communications systems and therefore contribute to the development of the ORAN ecosystem. These companies, however, do not provide ORAN equipment:

- Zeetta Networks, a firm based in Bristol that specialises in network slice management, co-founded in 2015 by Dimitra Simeonidou and Reza Nejabati, professors at the University of Bristol; and
- Accelercom, a semiconductor IP-core company founded as a spin-out from the University of Southampton in 2016.

According to Crunchbase, a database of start-ups and innovative companies, the two businesses have raised £14m in total funding from external investors to date. A broader search on Crunchbase for companies that mention “Open RAN” in the description of their activities did not identify any other academic spin-outs.[14]

[14] This search did identify an Open RAN component vendor, Picocom, but this company was not founded by a (former) researcher at a UK institution, to the best of our knowledge.

3.3.2 Private sector involvement in Open RAN R&D

Out of 16 businesses that responded to our survey (12 Open RAN component vendors and four systems integrators), at least seven conduct R&D[15] and nine said they have testing facilities in the UK, (one respondent has two sites, making 10 in total). Only three respondents provided information on the value of their annual R&D spending and so we are not able to estimate total ORAN R&D investment in the UK.[16]

Four survey respondents provided information on the approximate percentage change in their organisations' global annual investment in Open RAN R&D. Two vendors said that their investment had remained broadly constant, while the other two reported increases over 30%. This suggests that the total amount spent on Open RAN R&D in the UK may have risen in the last year, but the sample size is too small to draw firm conclusions.

On average, respondents felt that knowledge sharing within the UK Open RAN ecosystem occurs "to some extent". Twelve respondents provided free text comments elaborating on this matter, with mixed views. Three respondents thought that "substantial knowledge sharing" is taking place, while two saw scope to do more, potentially with a role for government to play. When it comes to knowledge sharing on Open RAN specifically, some respondents indicated that this is most useful within the context of particular projects, partly because commercial sensitivities prevent broader knowledge sharing in some instances.

15 Measured as the number of respondents who reported that they have prototypes or new products in development, or that they undertake ongoing development of existing products, as reported in further detail in section 4.2.

16 The figures reported were: around £20m (25% of their global ORAN R&D investment); around £1m (10% of their global investment), and £5m-£8m (unknown proportion of their global investment).

4 The Open RAN market in the UK

In this section, we describe the current state of development of the Open RAN market in the UK. This includes:

- The size of the market (measured as the number of Open RAN component vendors and systems integrators known to MNOs);
- The number of different Open RAN products available (by category);
- Development and testing of Open RAN technology in the UK;
- MNOs' confidence in Open RAN vendors/solutions.

This evidence would form the starting point of any future evaluation of the impact of the ONF.[17]

4.1 Overall extent of Open RAN activity

4.1.1 Number of Open RAN component vendors

Table 3 overleaf reports how many Open RAN component vendors each MNO is aware of for each product category, across both low- and high-capacity sites. For example, on average, each MNO said that they are aware of four distinct vendors providing radio units (RUs) for small cells and seven vendors providing RUs for macro cells. For product categories beyond RUs, MNOs are aware of three to five component vendors. However, it is important to note that:

- Based on the evidence collected through this study, no Open RAN component vendor provides the full range of components required for a RAN deployment (see Figure 6 overleaf). Therefore, several vendors are required to deploy an end-to-end Open RAN solution;

- Not all the component vendors MNOs are aware of would currently be viable suppliers to MNOs. Three out of the four MNOs did not indicate that they would be confident deploying Open RAN solutions in their network, in both rural and urban locations. We discuss MNOs' levels of confidence in ORAN component vendors in more detail in Section 4.3.2 below.

Indeed, to the best of our knowledge, the only Open RAN deployment under way in the UK is a project Vodafone is currently working in a partnership with five entities (Dell, Intel, Samsung, Wind River, and Capgemini) to deploy Open RAN masts in South West England.[18]

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17 As the market evolves and matures, we expect to see changes in these indicators. However, it is important to ensure that any such changes are interpreted with caution, taking the wider picture into account. For example, as the market matures, the number of ORAN component vendors might decline if the market becomes more concentrated. This decline (if it materialises) should not be seen as a negative outcome, but as a natural evolution of a maturing market.

18 Source: https://www.vodafone.co.uk/newscentre/press-release/openran-deployed-in-urban-locations-in-european-first/. Note: estimating current levels of Open RAN deployment in the UK was beyond the scope of this report.

Table 3 Number of Open RAN component vendors known to each MNO by product type

	RU small cell	RU macro cell	DU	CU	RIC	All
Hardware	4	7	3	3	0	N/A
Cloud application software	0	0	4.5	4.5	4	N/A
Radio application software	0	0	5	5		N/A
Chip sets					N/A	3

Source : Frontier analysis of MNO questionnaires

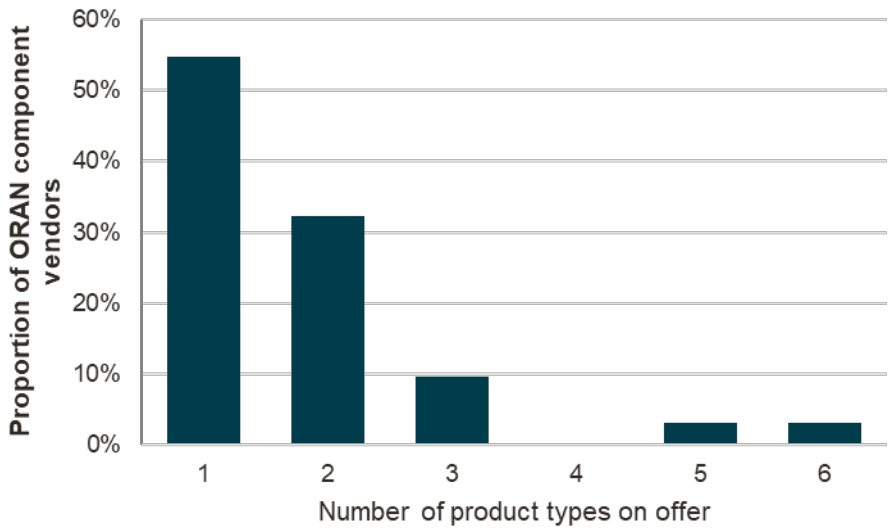
Note: Based on responses from four MNOs. The number of DU and CU cloud application software vendors includes a decimal point because this is the mean of the number of component vendors indicated by the four MNOs. "All" columns are N/A because adding responses across columns may lead to double-counting (for example, some of the vendors providing DU software may also provide CU software) and therefore we do not add the columns to provide a total. Chip sets is an exception because we only asked for an overall number of chip sets providers without breaking this down into RU, DU, etc. In this table we separate out RU into small cell and macro cell because the number indicated by MNOs differs significantly between the two categories

The offer of component vendors known to MNOs includes both hardware and software products, and the number of vendors offering hardware and software are broadly comparable (although the number of vendors offering DU and CU software is slightly higher than those offering DU and CU hardware).

It is worth noting that there was relatively little difference in the vendors named by MNOs as offering products for high-capacity versus low-capacity environments. Three of the four MNOs provided a single list of vendors that applied to both settings. The fourth MNO did list 11 additional vendors under "low capacity", but six of these were also mentioned by other MNOs as providers of high- capacity products. However, most MNOs have greater confidence in Open RAN solutions as applied in low-capacity (rural) environments compared to high-capacity (urban) settings, as described in the next section.

The chart below shows that 84% of Open RAN component vendors that MNOs are aware of offer one or two product types (typically, only RU hardware or DU and CU software). According to MNO input, the most diversified ORAN component vendor provides six product types (RU hardware, DU and CU radio application software, DU and CU cloud application software, and RIC).

Figure 6 Number of product types offered by Open RAN component vendors



Source: Frontier analysis of MNO responses
Note: Sample size: 32 Open RAN component vendors that MNOs are aware of and for which MNOs specified the product types offered.

4.1.2 Number of systems integrators

MNOs and survey respondents (Open RAN component vendors and systems integrators) said they are aware of 21 distinct systems integrators operating in the UK. The MNOs listed 12 systems integrators and survey respondents 17.

As with ORAN component vendors, the fact that there are multiple system integrators does not yet translate into actual partnerships with MNOs. As with ORAN component vendors, MNOs are not yet fully confident in the system integrators' ability to deliver a "full solution". We provide more details on the MNOs' concerns in Section 4.3.3.

4.1.3 Overall value of Open RAN sales (£m)

Only four Open RAN component vendors provided information on their annual value of sales of Open RAN products or services in the UK. The low number of responses is likely for reasons of confidentiality. One vendor indicated that they are currently not selling any products or services to UK customers, and two reported annual sales of up to £1 million. The fourth respondent put their annual sales of Open RAN products/services at between £1 million and £10 million.

4.1.4 Open RAN activity by product type

Our survey asked respondents to state the number of products they have available on offer in the UK, separately for low- and high-capacity sites. These figures, provided below, do not constitute in themselves an indication of the size of the Open RAN market, but they show that vendors are active in the UK in all market segments. Future data collection will enable an assessment of whether the number of items on offer and their distribution across product types is changing over time. This

evidence will need to be interpreted in the round with other sources: based on our assessment, an increase or decrease in the number of products may not in itself indicate greater or lesser market maturity.

Across both low and high-capacity sites, ten out of 12 component vendors provided information on the number of products they offer. Consistent with what we heard from MNOs, there appears to be a significant degree of specialisation as one of the vendors sells only hardware, not software, and four of the vendors provide only software, not hardware. The remaining five vendors sell both.

Out of 12 high-level product types, the mean number offered by the vendors is 4.[19] This is partly driven by two vendors that are more diversified than the other eight. The two highly diversified vendors offer seven and eight product types respectively. Excluding these two, the mean number of product types is 3.1 and the median is 3.

Products on offer for use at low-capacity sites

Products currently on offer

The table below shows the total number of products summed across all responses. It is worth noting that some products may fall into several of the categories mentioned below. For example, when a vendor indicates that they have two software products applicable to small-cell RUs and two to macro-cell RUs, they may have the same items in mind for both categories. Therefore, summing up different cells in the tables below may overestimate the number of products on offer.

Table 4 Number of low-capacity products on offer

	RU: small cell	RU: macro cell	DU	CU	RIC
Hardware: base band	5	1	3	3	0
Hardware: radio frequency	5	7	1	1	0
Software	3	2	6	6	5
Chip sets	5	1	1	0	0

Source: Frontier analysis of Open RAN component vendors' survey responses
Note: Sample size: 10 responses from Open RAN component vendors

[19] The full list of product types is the following: Radio Unit (RU) hardware; Distributed Unit (DU) hardware; Controller Unit (CU) hardware; Radio Intelligence Controller (RIC) hardware; RU chip sets; DU chip sets; CU chip sets; RIC chip sets; RU software; DU software; CU software; RIC software.

New low-capacity products introduced in the last year

Five vendors reported introducing new low-capacity products, distributed as shown in the table below.

Table 5 Number of low-capacity products introduced in the last year

	RU: small cell	RU: macro cell	DU	CU	RIC
Hardware: base band	0	0	1	1	0
Hardware: radio frequency	0	4	0	0	0
Software	0	1	1	1	1
Chip sets	0	0	0	1	0

Source: Frontier analysis of Open RAN component vendors' survey responses
Note: Sample size: 5 responses from Open RAN component vendors

Products on offer for use at high-capacity sites

Seven out of 12 component vendors provided information on the number of high-capacity products they have on offer. It is worth noting that the total is not significantly lower than the number of low-capacity products. This would suggest that the reason MNOs perceive Open RAN solutions to be less suitable for high-density environments is not because of a dearth of existing products, but rather because of the (perceived) performance and cost of these products relative to incumbents' RAN solutions.

Two of the vendors offer only hardware, not software, and one vendor provides only software, not hardware. The other four vendors sell both. The table below shows the number of products on offer, summed across all respondents. The above caveat applies to high-capacity products as well; the same products might fall into several of the categories below and feature on the table multiple times.

Additionally, the products referred to in Table 4 and Table 6 may not be entirely distinct, as high-capacity products may fulfil the requirements of low-capacity environments and also be classed as low-capacity products.

Table 6 Number of high-capacity products on offer

	RU: small cell	RU: macro cell	DU	CU	RIC
Hardware: base band	5	4	4	4	1
Hardware: radio frequency	5	10	2	2	1
Software	1	4	3	3	2
Chip sets	5	1	1	0	0

Source: Frontier analysis of Open RAN component vendors' survey responses
Note: Sample size: 7 responses from Open RAN component vendors

New high-capacity products introduced in the last year

We also asked vendors to tell us whether they had launched new high-capacity products in the last year and, if so, how many. This helps assess the extent of innovation taking place in the market. Six component vendors reported introducing new products, distributed as shown in the table below.

Table 7 Number of high-capacity products introduced in the last year

	RU: small cell	RU: macro cell	DU	CU	RIC
Hardware: base band	0	0	1	1	1
Hardware: radio frequency	0	4	0	0	1
Software	0	1	1	1	2
Chip sets	0	0	0	0	1

Source: Frontier analysis of Open RAN component vendors' survey responses
Note: Sample size: 6 responses from Open RAN component vendors

4.1.5 Private networks

Five Open RAN component vendors and one systems integrator (40% of the 15 respondents currently active in the UK) mentioned that they are supplying Open RAN products to private networks in the UK. Most of these six have provided services to a handful of such networks, but one vendor reported selling to hundreds of them. We also asked vendors what proportion of the addressable size of the

private network market they were serving. The sample size is too small to obtain an estimate of the total value of sales to private networks. However, the results tentatively suggest that Open RAN component vendors are active in this field, which may see relatively quick growth due to the smaller scale of roll-outs and the fact that interoperability with 2G or 3G is not a requirement.

4.1.6 Potential entrants into the UK market

Out of the 12 Open RAN component vendors which responded to the survey, 11 said they are currently selling products or services to customers in the UK. The component vendor not presently operating in the UK reported that they are considering selling products or services in the UK, but have not yet made any plans.

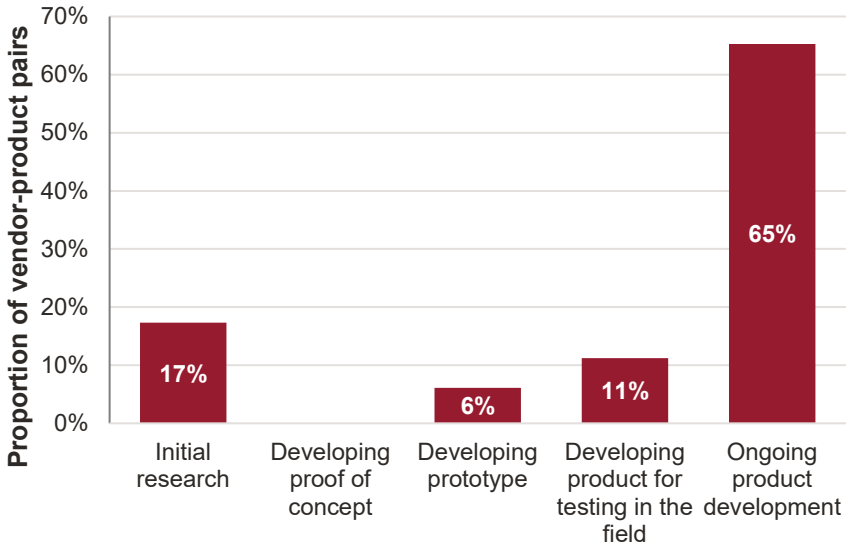
Three out of 12 Open RAN component vendors said they are planning to open new sites in the UK in the near future: two offices and one testing facility.

4.2 Development and testing of Open RAN products by vendors

Average stage of development of technology by vendor and product type

Seven out of 12 component vendors provided an assessment of the stage of development of their technology by product type. Most vendors conduct research on several product types (RU/DU/CU, software and hardware, and chip sets): on average, each vendor reported carrying out R&D for seven product types for low-capacity sites, and six types for high-capacity sites. Figure 7 below shows the stage of development across just over 100 product type-vendor pairs. In around two-thirds of these pairs, vendors said their R&D activity consists of the ongoing development of existing products. The remaining third was split roughly equally between initial research and the development of new prototypes or products to be tested in the field. However, only two of the seven vendors which responded said that they conduct initial research.

Figure 7 Stage of development of technology – vendor assessment



Source: Frontier analysis of Open RAN component vendors' survey respondents
Note: Sample size: 7 Open RAN component vendors, across 98 vendor-product type pairings.

Vendors' testing activities

Twelve respondents said they have testing facilities in the UK. Eight said they have a single site, and one has two sites, for a total of 10. But the actual number must be higher, as three respondents declined to say how many sites they have.[20]

Ten respondents indicated that they are currently testing products in UK labs. Two said that the development of the products that are being tested has benefited from government funding.

Twelve respondents provided their views on whether testing Open RAN equipment is a significantly burdensome or resource-heavy process. Half of them said this was indeed the case, with two Open RAN component vendors reporting instances of abandoning product development due to the high costs of testing.[21] One respondent noted that the process of testing Open RAN involves a different cost calculus from a vertically integrated RAN, where a single vendor tests all the components before putting the product on sale. A disaggregated solution requires that the integration testing of the different components needed to create a RAN is carried out by a vendor, an integrator or the operator.

[20] The questions on testing facilities were asked as part of the extent of the physical presence of organisations in the UK, and so they are assumed to be privately funded.

[21] The remaining 50% of respondents stated that testing is not burdensome.

4.3 Characteristics of and confidence in Open RAN products

4.3.1 Number of products that meet interoperability and security requirements

Vendor assessment

Five vendors of Open RAN components provided information on their products that are interoperable with those offered by other vendors, involving a total of 17 such products. Four vendors also reported that nine products in total have been tested with products from other vendors.

The survey included a question on interoperability between 4G/5G connectivity and 2G/3G in Open RAN products. Four vendors responded. One of them said they have three products that can offer this kind of interoperability, while the others said they do not have any 4G/5G Open RAN products that are interoperable with 2G/3G technologies.

MNO assessment

Only one of the four MNOs reported how many vendors meet their technical specifications, stating that none of them currently meets 85% or more of these standards. However, they explained that they typically do not expect vendors to perfectly match their requirements from the beginning; rather, they assess whether a vendor can confidently implement necessary technical developments to the required standard and quality in an acceptable timeframe. This comment was echoed by another MNO which described taking a very similar approach to procurement.

4.3.2 Confidence of MNOs in Open RAN vendors

One of the four MNOs expressed absolute confidence in using Open RAN in both rural and urban environments. The other three did not:

- One of the three stated that they would be confident if an Open RAN solution met their particular use case needs at the right cost. They also said that they see greater opportunity for using Open RAN in indoor settings,[22] where there is less of a need to consider inter-vendor interworking with surrounding macro cells.
- This was echoed by another MNO, which stated that they are building “some confidence” in Open RAN by working with third parties that use ORAN in Active Neutral Hosting Indoor solutions.
- Finally, one MNO said that their experience of testing Open RAN has been “hard work” and that they would ultimately need to be confident that ORAN vendors can match the performance of incumbent RAN vendors.

[22] However, even in indoor settings, the readiness of ORAN solutions is still an issue. One MNO says: “At the moment, even for our limited indoor use case, many proposed solutions are best fit as a traditional “femto cell” with an evolution to RU/DU/CU split. This is not down to the inability to meet our needs, but the readiness of an RU/DU/CU split capability for the different scale solutions we need from small through medium to large and very large building coverage options.”

We also asked MNOs what they see as the most important technical requirements that Open RAN vendors should fulfil. Three of the four said the requirements would be no different from those of vendors that are not open. Three out of the four MNOs would require support for all spectrum bands/all technologies they operate.

One MNO stated: "*Open RAN vendors should reach the same level of technical requirement fulfilment as traditional vendors; guaranteeing a very good performance in 2G, 4G and 5G technologies is crucial for delivering a good service to our customer.*"

Another MNO, elaborating, said they require Open RAN vendors to commit to being "open" on server platforms, host OS and cloud management stack, and to ensure interoperability across RU/DU/CU split combinations. The MNO also said that in their view, many Open RAN component vendors support specific pre-supported solutions and are not as open to other configurations as would be desired.

4.3.3 Confidence of MNOs and ORAN component vendors in systems integrators

MNOs

None of the MNOs said they are currently working with systems integrators in Open RAN deployments. However:

- One MNO indicated that they would prefer working with systems integration partners rather than self-managing Open RAN solutions;
- One MNO said that they are currently performing systems integration internally. However, they are likely to work with a systems integration partner in the future as volume and scale increase.
- Two of the MNOs said they are working with systems integrators on some R&D activities. One said it prefers working with ORAN consortia, which will perform the system integration role and provide a full "solution" rather than just a set of parts which the MNO would then have to piece together.

In terms of systems integrators' abilities to fulfil MNO's technical requirements:

- One of the MNOs said that systems integrators can meet technical requirements when working in partnership with other organisations;
- One MNO said that many systems integrators can undertake software integration successfully, but they have not identified integrators that can also include hardware.
- Two MNOs said they have not tested whether systems integrators can fulfil their technical requirements.

Three MNOs also offered broader views on the role of systems integrators. Two of them said the availability of systems integrators which could deliver end-to-end working solutions would help achieve wider Open RAN deployment. The third mentioned the ability of the market to provide

systems integration at an acceptable cost to MNOs and without being locked into particular solutions as factors potentially enabling Open RAN deployment.[23]

Vendors of Open RAN components

Open RAN component vendors were asked about their awareness of and confidence in certain systems integrators. Eight vendors responded to the question on awareness of 11 different integrators. The level of recognition was broadly similar, with between one and three vendors indicating that they were aware of each organisation as a systems integrator.

The response level was lower for the set of questions on confidence in existing UK systems integrators, likely due to confidentiality reasons. Two respondents provided information; the average of their responses indicates that they are somewhat confident in working with UK systems integrators.

4.3.4 Number of vendors of Open RAN components invited by MNOs to participate in RFPs

Three of the four MNOs have invited Open RAN component vendors to participate in RAN procurement rounds in the UK, while one has not. One of the three specified that their procurement was for an indoor use. Of the other two MNOs:

- One of the MNOs reported that they had invited three consortia of "major" ORAN component vendors. The consortia were asked to provide an overall solution (i.e. including systems integration).
- One other MNO reported inviting the number of vendors listed in the table below, both for low- and high- capacity sites.

Table 8 Number of Open RAN vendors invited by one MNO

	RU: small cell	RU: macro cell	DU and CU	RIC	All
Hardware: base band	1	9	2	N/A	N/A
Cloud application software	0	0	3	0	N/A
Radio application software	0	0	2	0	N/A

[23] These comments were offered in response to the question "Please list the main issues that need to be resolved before your organisation would be willing to deploy wider Open RAN infrastructure". Further detail on the responses to this question is available in section 5.4.

	RU: small cell	RU: macro cell	DU and CU	RIC	All
Chip sets	N/A	N/A	N/A	N/A	1

Source: Response to baseline questionnaire submitted by one MNO

Note: the MNO indicated that the same component vendors were asked to bid for DU and CU, hence why this table includes one column for both, unlike other tables in this report which report DU and CU separately.

We also asked MNOs whether they are planning to invite Open RAN vendors to take part in their next procurement round. Two MNOs said that they would, while two others provided general information on their approach to procurement but did not specify whether they intend to invite Open RAN vendors.

4.4 Broader views on ORAN market development from MNOs

4.4.1 Testing Open RAN solutions by MNOs

Testing facilities

Three MNOs reported that they are carrying out Open RAN testing in the UK:

- One MNO has outsourced the operation of a testbed to a systems integrator and expects to start testing with an Open RAN vendor in their (the MNO's) main test facility.
- One MNO has a testing facility for Open RAN with a dedicated lab.
- One MNO has been operating a Telecom Infra Project Community Lab that in the future will be used for Open RAN projects, some of which are publicly funded.

Barriers to testing

One of the MNOs that operates a testbed said they had experienced resource challenges in setting up the testbed. This MNO and a second one reported that they had redeployed some of their staff from other activities to Open RAN testing, with associated costs.

One MNO noted that the requirement to test and maintain interoperability over the lifecycle of any Open RAN deployment creates additional costs compared to non-open deployment. This can be excessively burdensome if not done at sufficient scale (so that the cost is spread over larger deployments and offset by the benefits of those deployments).

Other challenges reported by this MNO included a perceived lack of experience of Open RAN providers operating in test environments and the tendency of vendors to focus their deployment efforts on their own capabilities rather than on the MNO's needs.

4.4.2 Broader MNO views on the Open RAN market

Perception of network openness and market diversification

We asked MNOs how they ranked the importance of open networks and market diversification for mobile infrastructure in relation to other challenges for the UK telecoms sector. Their views varied. Two see diversification as a high priority in the medium to long term (5-10 years) while a third MNO regards open networks and diversification as a "necessary long-term objective", albeit not of "critical short-term importance". These MNOs generally do not view openness as a benefit in itself but rather as a potential avenue towards diversification.

One of the MNOs did not consider open networks to be a high priority but said they would be willing to invest in solutions provided at scale by new vendors should these emerge, as long as the products are competitive from a price and technology perspective.

Issues that may be limiting the adoption of Open RAN

When we asked MNOs what problems need to be resolved before they would be willing to deploy wider Open RAN infrastructure, the following themes emerged:

- As described in section 4.3.3, three MNOs mentioned the availability, comprehensiveness and cost of systems integration solutions;
- All MNOs referred to costs and performance relative to incumbent RAN systems. Open RAN to cost the same as or be cheaper than RAN equipment. Some MNOs also expressed concern whether existing Open RAN component vendors can deliver their solutions at the required scale;
- Two MNOs specifically mentioned performance in high-density/high-traffic environments, i.e. whether Open RAN-compliant equipment can work in these settings;
- One MNO cited the risk of using new component vendors. The possibility that some vendors may not exist in their current form five years from now is a particular worry when deploying software. In other words, if a vendor is bought up or ceases trading, some of the hardware purchased from that vendor would be reusable but its software might not be.
- One MNO said the Huawei ban is leading to long-term volume commitments being made now; the deals are being struck with incumbent suppliers as they are the only ones that can fill the gap.

Views on government support for Open RAN

We also asked MNOs how the government could best support the development and adoption of Open RAN.

Two MNOs described how Government supporting the Open RAN supply chain to achieve greater scale would be useful. Their comments link back to the need for Open RAN to match incumbent solutions in cost and performance and also to concerns about the long-term sustainability of Open RAN vendors. These two MNOs did not specify what form of support they had in mind (e.g. R&D funding vs other types of funding). A third MNO said using publicly funded R&D to bring solutions to maturity is helpful. However, a fourth MNO suggested a greater focus on measures accelerating adoption and deployment rather than funding for "labs and trials" and encouraging new start-ups. The

same MNO also said Open RAN government programmes should “work in practice for MNOs” and be “worth it financially for operators”.

Other issues signalled by individual MNOs included the following:

- Regulation: one MNO described that they could be faced with the risk of failing to meet regulatory requirements due to the inability of new vendors to deliver on time or to a complete specification. A solution to this problem could be for MNOs and Ofcom and/or government to discuss key regulatory risks early in a deployment cycle; alternatively, deadlines for compliance could be extended when a deployment involves a new vendor, or forms of forbearance could be considered when needed.
- Skills: an MNO said that installing and operating Open RAN requires different skill sets from those needed for incumbent products, and people with the relevant skills are in short supply. The push towards Open RAN in countries outside the UK means these skills are in high demand.
- Risk: one MNO suggested that government intervention to mitigate the risk (to MNOs) of new vendors exiting the market could be useful.
- Investment in cheap last-mile fibre to allow for the high data rate connectivity needed between RU and DU/CU, and also rack space in the exchanges to which the fibre is routed, was mentioned by one MNO as important to enable the transition to fundamentally different network architectures.

5 Lessons learnt and recommendations for future evidence collection

While our online survey received a high response rate of 82% (18 out of 22 recipients of the questionnaire), most respondents did not report financial information on their investment in R&D or revenues from Open RAN activities in the UK. Although respondents were reassured that their data would be used only to form an aggregate picture of the market, this was likely on confidentiality grounds. Indeed, this was the reason that some respondents explicitly gave for not disclosing the information we sought. To overcome this reticence, we would recommend exploring with a selected number of market participants how to allay their concerns before market surveys are rolled out. Moreover, it may be useful to ask participants whether they have generated any revenues in the UK or invested in R&D, before asking for the amount. It will also be helpful to engage with industry bodies (e.g. techUK) at an early stage of the evaluation process to get their input and contact details in relevant organisations if possible.

Engagement with MNOs revealed that other Open RAN component vendors and systems integrators are active in the UK, in addition to those we surveyed. Future data collection should seek to include these market participants. This was not possible within the timeline of this study because data collection from Open RAN component vendors and MNOs took place in parallel. Future monitoring and evaluation may benefit from a staged approach - engaging with MNOs before embarking on wider surveys - to ensure that all the vendors that MNOs are aware of are invited to participate in the data collection.

This baseline study involved collecting evidence on how the UK's Open RAN research ecosystem compares to other countries' (e.g. the proportion of academic papers published by researchers at UK institutions; qualitative views from academics on the UK research ecosystem compared to international benchmarks).[24] Future evaluation of the ONF may want to consider whether there are other measures that could be gathered internationally. While collecting primary evidence directly from vendors on activities elsewhere could be quite resource-intensive, it may be possible to draw on new data generated by other research projects that was not available for this study.

[24] We also asked ORAN component vendors and systems integrators what proportion of their global ORAN R&D investment took place in the UK, but very few organisations responded to this question.

Glossary

Key terms used in this report include:

Radio Unit (RU). The RU processes, transmits, and amplifies radio signals. The RU connects wireless devices with wireless base stations.

Distributed Unit (DU). The DU processes signals received from the RU and undertakes lower-layer processing functions. The DU is generally located close to a RU, either on site or in an Edge Cloud/data centre.[25]

Centralised Unit (CU). The CU is responsible for performing higher layer processing functions. The CU however can be either located in the Regional Cloud/data centre (e.g. C-RAN), or with the DU (e.g. D-RAN). The DU and the CU are the computation parts of the base station.

RAN Intelligent Controller (RIC). The RIC is a primarily software-based component of the Open RAN architecture that is responsible for controlling and optimising baseband communication functions on the RAN.

[25] https://uk5g.org/discover/supply-chain-diversification-UK-telecom/uk-open-networks-ecosystem-technology/open-ran-research-development-UK/distributed-and-centralised-units-openRAN-UK-telecom/

Annex A – Further detail on primary data collection

A.1 Questionnaire design and dissemination

- We developed an initial draft of the questionnaire based on the list of success measures and data sources agreed with DCMS as part of Phase 1 of the project. We then adapted the questionnaire for various types of stakeholders: Open RAN component vendors, incumbent vendors, MNOs and system integrators.
- We tested the initial draft on two Open RAN vendors by asking them to review it and holding interviews to get their input. Their feedback was mainly on the breakdown of Open RAN products and the stages of development of technology in Open RAN product areas.
- We also incorporated feedback from two MNOs on the MNO questionnaire. Their feedback similarly touched upon the different Open RAN product areas as well as questions on general security and interoperability requirements.
- After finalising the content, we scripted the survey questionnaires through an online platform (SurveyMonkey) and tested it within our team.
- The survey was first disseminated on 23 November 2022. The recipients were asked to complete the survey by 7 December. We contacted those who did not complete the survey on time and extended the deadline to 16 December.
- To further boost response rates, we offered organisations that had not yet filled in the survey by mid-December the possibility of returning responses via email or a document. We received two further replies in writing and collected a further response by telephone. These three responses were then aggregated with the data gathered through the online survey.

A.2 Data analysis

- We made adjustments to some responses we received via email. This was mainly to transform the inputs into the same form as those received on SurveyMonkey. For example, some email replies had detailed responses to 'Yes/No' questions. We coded these accordingly as a Yes or No and added the extra comments to the free text answers received in the survey.
- On the question of Open RAN products introduced in the last year, the response of Open RAN component vendor was adjusted because it was not broken down by product type. Using the unadjusted response led to a finding of more Open RAN products being launched in the last year than are currently offered in the market.
- The questions on market size estimation, level of investment and annual sales elicited a particularly poor response, likely for confidentiality reasons. In the email replies, some Open RAN vendors said that due to company policy they could not provide any sales data beyond that already published in annual statements and filed with Companies House.

Annex B Further detail on secondary data collection

B.1 Data on university rankings

We identified four possible sources of data: Edurank.org, QS World University Rankings, Times Higher Education World University Rankings and Shanghai Ranking's Global Ranking of Academic Subjects.

Times Higher Education and QS do not compile university rankings based on telecommunications as a subject; as such, they were excluded as viable data sources. Shanghai Ranking grades the top 300 universities in telecommunications engineering and gives details of its underlying methodology. The ranking is available only on a global basis, but a league table for UK universities in Europe can be constructed from the available data.

EduRank, which DCMS had identified as a potential data source, also offers university rankings in telecommunications, both in Europe and globally.

We collected data from both EduRank and Shanghai Ranking and used the mean of the two. Gathering data from these sources is not time or resource intensive, and using them both can increase the resilience of the baseline estimation in case either of the rankings is discontinued in the future.

The results are similar across the two rankings. For example EduRank puts seven UK universities in the global top 100 and Shanghai Rankings lists 11. Moreover, both rankings include several UK universities among the top 10 in Europe:

- According to Shanghai Rankings, six of the top nine[26] European universities are in the UK, and UK universities are the five highest ranked in Europe;[27]
- According to EduRank, five of the top 10 European universities are in the UK.[28]

At the global level, Shanghai Rankings rates the UK more highly than EduRank does. Shanghai Rankings names four UK universities in the global top 20, but the highest-ranked UK university on EduRank is Cambridge, at number 27.

26 Shanghai Rankings does not compile a Europe-specific top 10 and provides only a group ranking after the top 50 globally. This means it is not possible to derive a European top 10 but only to rank the nine UK universities included in the global top 50.

27 From higher to lower ranked: University of Southampton, Queen Mary University of London, Imperial College London, University College London, Lancaster University, Queen's University Belfast.

28 From higher to lower ranked: University of Cambridge, University of Edinburgh, University of Southampton, University of Surrey, University College London.

B.2 Data on patents

The Open RAN patents were identified through the following process:

1. Running a keyword search on all telecoms patents filed in the UK in the period under review (using “Open RAN”, “ORAN”, and “Open Radio Access Network”) did not yield any patents directly related to Open RAN.[29]
2. As an alternative measure of Open RAN patents, we searched for telecoms patents filed by known Open RAN component vendors (as listed in section 3).

B.3 Data on academic publications

As the first step in our approach, we collected information on the abstracts and authors of **papers in four relevant high-impact journals published by the Institute of Electrical and Electronics Engineers**: IEEE Communications Magazine, IEEE Wireless Communications Magazine, IEEE Journal on Selected Areas in Communications, and IEEE Transactions on Wireless Communications. We selected these journals as they are generally regarded as the most important and the ones with the highest impact. We collected data covering 24 months from December 2020 to November 2022.

We identified 405 academic papers authored or co-authored by UK-based academics, defined as those who are affiliated with academic institutions in the UK. We included papers if at least one co-author is affiliated with a UK academic institution.

However, while many of the papers covered items that apply across many wireless communications systems, including ORAN, none were specific to ORAN or more relevant for ORAN than for other technologies.

The next step was to run a keyword search (under “Open RAN”, “ORAN” and “Open Radio Access Network”) using standard IEEE index words on **the IEEE Xplore digital library**. IEEE Xplore contains the scientific and technical content published by the IEEE and its publishing partners.

[29] Relying on the definition of telecoms patents as “H04W: Wireless Communication Networks” on the Cooperative Patent Classification scheme.

Annex C Full list of success measures

ONF Objectives:

1- Develop an internationally recognised ecosystem

2- Accelerate open-interface products and solutions

3- Incentivise and derisk accelerated deployment in the UK

Success measure	Notes on definition (if relevant)	Value	Source/Collection Method	ONF Objectives
UK University ranking for telecommunications globally and in Europe	N/A	Global: 9 UK universities in top 100 Europe: 29 UK universities in top 100	**EduRank and Shanghai Ranking**	1
Number of Open RAN patents filed in the UK	Relevant period: 2018-2022	24 patents	**UK IPO Patent Journal**	1
Number of telecoms patents filed in the UK	Relevant period: 2018-2022	2,048 patents	**European Patent Office Espacenet database**	1
Number of privately funded testing facilities		10 testing facilities identified in the industry survey	**Secondary data / Industry survey**	1

Success measure	Notes on definition (if relevant)	Value	Source/Collection Method	ONF Objectives
% of survey respondents who consider that information and knowledge are readily transferred within the telecoms ecosystem more widely	N/A	Average level of consideration of knowledge sharing: 3.22, corresponding to '3 – to some extent' on a scale of 1 to 5	**Industry survey**	1
Number of UK-acceptable scale system integrators	Number of system integrators that other market participants are aware of	21 distinct system integrators	**Industry survey**	1
	Total UK sales of systems integrators	N/A - Insufficient data on sales provided by survey respondents		
Level of confidence in existing UK systems integrators		Average level of confidence in system integrators: 3.00, corresponding to '3 – to some extent' on a scale of 1 to 5	**Industry survey**	1

Success measure	Notes on definition (if relevant)	Value	Source/Collection Method	ONF Objectives
% of survey respondents who consider that information and knowledge are readily transferred within the Open RAN ecosystem		Average level of consideration of knowledge sharing: 3.20, corresponding to '3 – to some extent' on a scale of 1 to 5	**Industry survey**	1
% of respondents (Open RAN vendors) who consider the UK to be a viable market for entry	Defined as % who are considering entering in the UK	100% (2 out of 2 respondents who are not currently active in the UK)	**Industry survey**	1
% of respondents (Open RAN vendors) who are actively considering entering the UK market	Defined as % who are planning to bid for UK contracts and/or % who are planning to open sites (offices, manufacturing facilities, testing facilities) in the UK	0%, calculated as those planning to bid for UK contracts out of those who do not operate in the UK – sample size is 1 Open RAN vendor 25% planning to open new sites in the UK	**Industry survey**	1
Size of UK Open RAN market (£m)	Defined as sales to UK customers	N/A – insufficient information on sales provided by survey respondents	**Industry survey**	1

Success measure	Notes on definition (if relevant)	Value	Source/Collection Method	ONF Objectives
Number of private networks using Open RAN		208 (based on 5 responses)	**Industry survey**	1
% of private networks using Open RAN		12.5% (based on 3 responses)	**Industry survey**	1
Perceptions of market participants on role of UK in international Open RAN ecosystem		Please see qualitative input in sections 3 and 4	**Interviews/industry survey**	1
Number of UK Open RAN research papers published in international high-impact journals	Relevant period: 2018-2022	0	**Secondary data**	1
Capital raised by Open RAN-focused university spin-outs	Relevant period: 2018-2022	0	**Secondary data / Industry survey**	2
Number of relevant academic papers authored or co-authored by UK-based academics	Relevant period: 2018-2022	10	**Secondary data**	2
Number of Open RAN-focused university spin-outs		0	**Secondary data / Industry survey**	2

Success measure	Notes on definition (if relevant)	Value	Source/Collection Method	ONF Objectives
Number of low-capacity macro O-RU and O-DU products available		Please see Table 4 for a breakdown of low-capacity products	**Industry survey**	2
Number of high-capacity macro O-RU and O-DU products available		Please see Table 6 for a breakdown of high-capacity products	**Industry survey**	2
% products in labs that originate from DCMS R&D funding		1 product being developed with support from ONF; 2 out of 10 respondents testing products in UK facilities (20%) are benefiting from UK government funding	**Project monitoring /Industry survey**	2
Total number of Open RAN products on offer that meet interoperability requirements		17 products classified as 'interoperable' by vendors	**Industry survey**	2

Success measure	Notes on definition (if relevant)	Value	Source/Collection Method	ONF Objectives
	A vendor's product will be considered interoperable if: it has been tested with products from other vendors; and, for products that can be used with 4G/5G, if the product is interoperable with 2G/3G.	9 products tested with products from other vendors 3 products that can be used with 4G/5G that are also interoperable with 2G/3G technologies		
Total number of Open RAN products on offer that meet security requirements		4 products currently offered that meet UK MNO security requirements	**Industry survey**	2
Number of viable Open RAN products* developed which are suitable for dense urban areas (via R&D programmes and otherwise)		Please see Table 6 and Table 7 for a breakdown of high-capacity products introduced in the last year	**Project monitoring for R&D programmes, industry survey for rest**	2

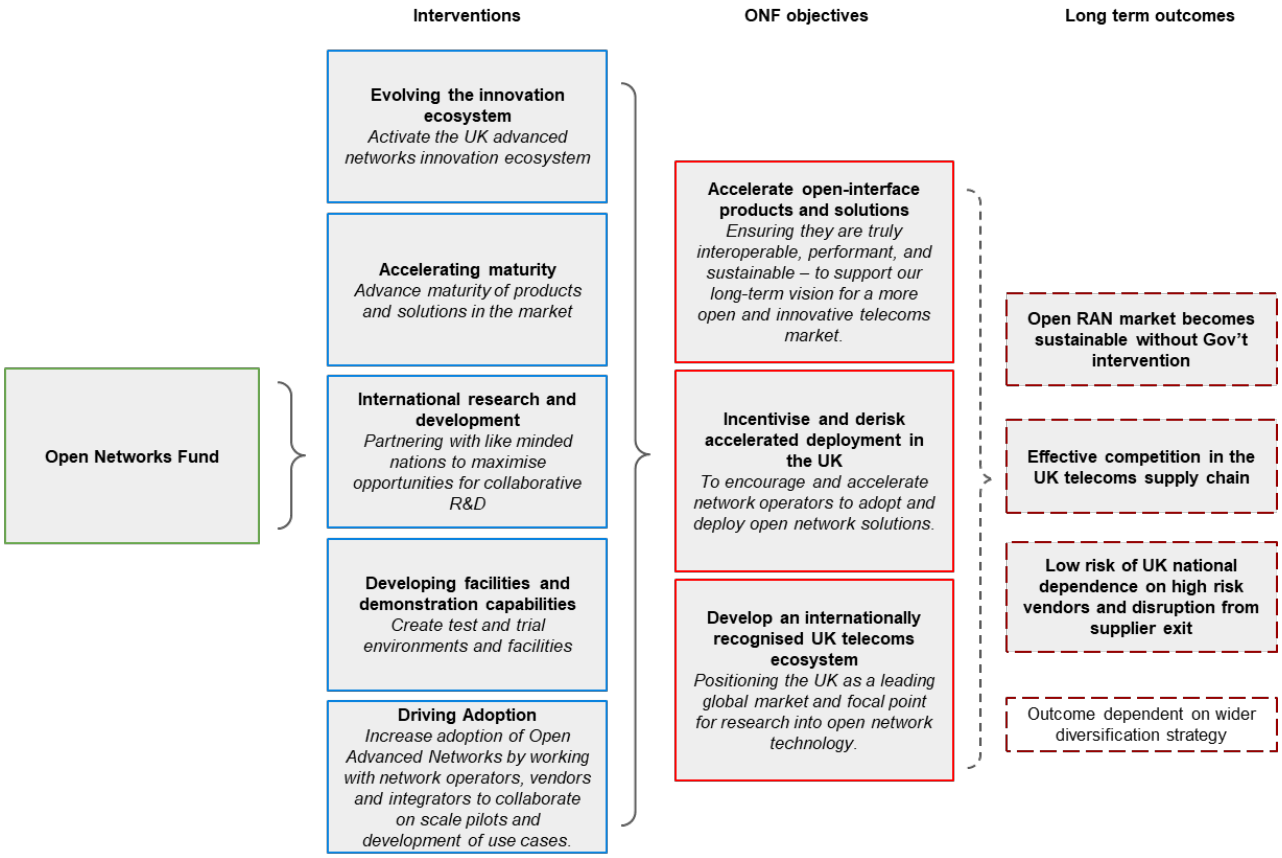
Success measure	Notes on definition (if relevant)	Value	Source/Collection Method	ONF Objectives
Number of Open RAN R&D projects launched by incumbents not directly linked to government funding		0 identified in the industry survey. Based on publicly available information, Ericsson launched the Ericsson Open Lab in March 2021 to collaborate with Cloud RAN customers and partners to drive virtualised 5G RAN technologies. Open RAN is among the technologies that this initiative will explore further. [30]	**Industry survey**	2
% of respondents who see testing Open RAN equipment as significantly burdensome / resource heavy		50%	**Industry survey**	2
Number of vendors (at the RU/CU/DU/RIC level or above (gNB)) in the UK market		38 component vendors	**Industry survey**	2

[30] Source: https://www.ericsson.com/en/press-releases/2021/3/new-ericsson-open-lab-to-drive-network-virtualization-technologies

Success measure	Notes on definition (if relevant)	Value	Source/Collection Method	ONF Objectives
Private sector investment in R&D on Open RAN		N/A – information provided by survey respondents insufficient to estimate total. Average response: Over £1 million - up to £10 million (based on 3 responses)	**Industry survey**	2
Percentage change in private sector investment in R&D on Open RAN since previous year		Average response: Increased by 10-30% (based on 4 responses)	**Industry survey**	2
Average stage of development of technology by vendor and by product type		Average stage of 'developing new products to be tested in the field' for all product types for both high and low-capacity sites	**Industry survey**	2
Level of confidence of MNOs in using Open RAN vendors		High: 1 MNO Low-medium: other MNOs	**Interviews**	3
% of MNO respondents who are planning to invite Open RAN vendors to participate in next procurement round		75%	**Interviews**	3

Success measure	Notes on definition (if relevant)	Value	Source/Collection Method	ONF Objectives
Number of Open RAN vendors invited by MNOs to participate in RFPs/ ITTs		N/A	**Interviews**	3
Number of UK factories dedicated to manufacturing or assembling RAN components	We expect there will be relatively little manufacturing in UK at baseline, but some assembly of components may be taking place (and this may be a higher value-added activity)	2 production/assembly facilities	**Industry survey**	3

Annex D Summary logic model



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