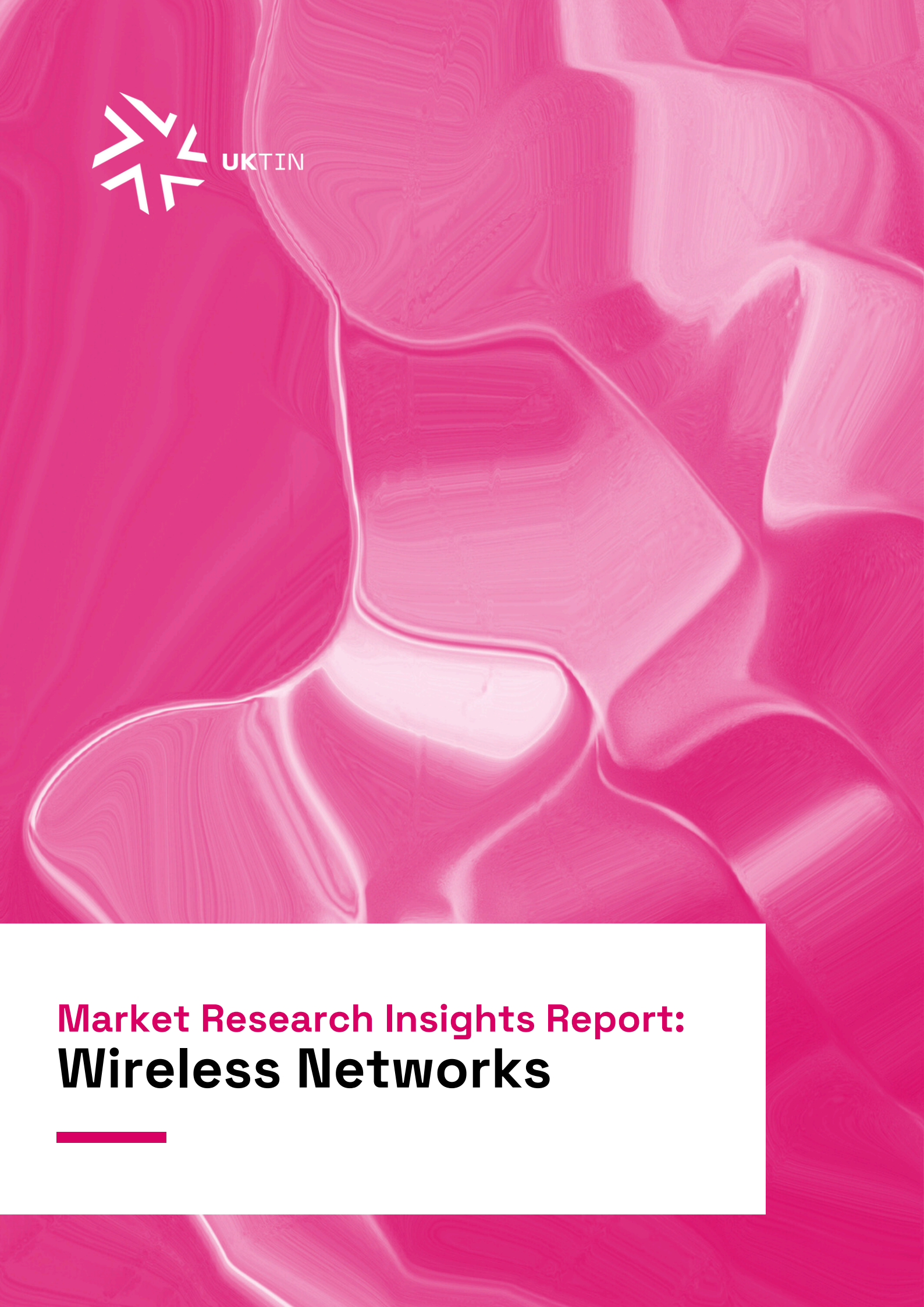
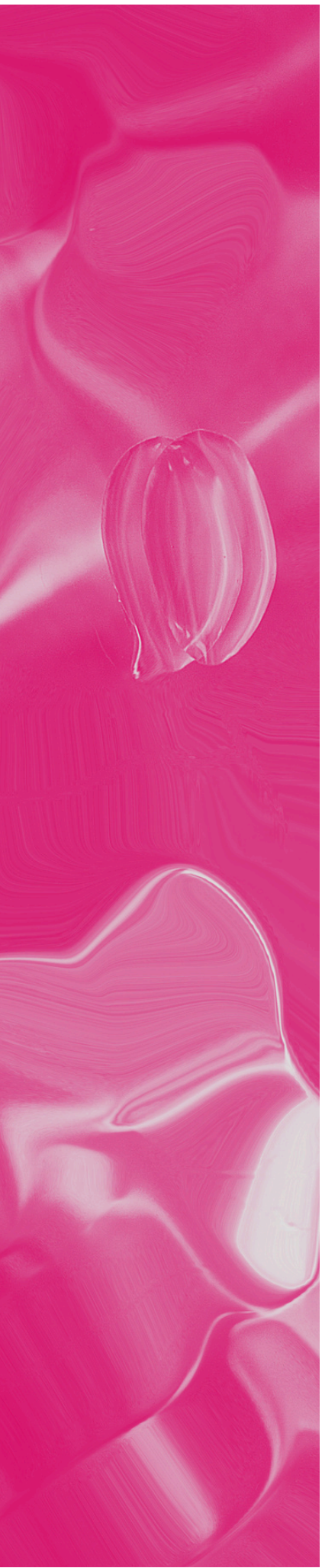


Market Research Insights Report:

Wireless Networks



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Introduction

This report presents insights into research, development and innovation (R&D&I) activities taking place in the UK telecoms sector in the area of wireless networking technology. Wireless networking technology is an established area with over a century of history, with the late 20th century and early 21st century having witnessed a period of rapid technological innovation in wireless networking fields. Advances in wireless mobile cellular connectivity delivering broadband data access in particular have played a key role in most people's professional and personal lives, with 93% of the UK population owning a mobile phone in the year 2021 to 2022.

Part of the UK Telecom Innovation Network (UKTIN) programme, this report is the second in a series intended to provide a high level, non-technical deep dive into pertinent academic and industrial activities relevant to the UK telecoms ecosystem. The data presented in this report seeks to help identify broad trends in the wireless networking technology landscape in terms of presenting areas where funding has been concentrated across a range of funding programmes, and key areas of interest and research among academic experts interviewed for this report. This report may be valuable for a range of stakeholders, including showcasing collaboration and public R&D&I funding trends in wireless networking technologies to industry professionals, but also for academics seeking to map current research trends and projects in their fields, as well as for policymakers seeking to understand overall trends and estimates of funding amounts that have been allocated to particular wireless networking technologies.

Specific focus is placed on quantitative and qualitative data on topics that are of interest to the UK telecoms community, particularly topics that are currently in discussion by the UKTIN Wireless Networking Technologies Expert Working Group, as well as reference to other areas of relevance that are likely to emerge over time, including use cases such as self-driving vehicles, smart systems and the Internet of Things. While non-terrestrial wireless networks also fall under the category of wireless networks, the focus of this report will only be on terrestrial wireless networks. R&D&I activities focused on non-terrestrial networks will be covered in a future insights report. Research related to semiconductors will also be covered in a future report.

Introduction

1.1/ Research Methods

Research for this report involved obtaining publicly available data[1] on UKRI's Gateway to Research database, Horizon 2020's CORDIS database[2] and manual retrieval of data from UK government web pages, all of which detail public R&D&I activity in the telecoms sector, and curating these results to identify R&D&I activities in wireless networking technology. Other research methods included desk research and literature reviews carried out by Digital Catapult, as well as expert interviews with 4 experts from 4 different universities conducted by the University of Bristol. This combined quantitative and qualitative approach was conducted with the intention of providing a high level, non-technical insight into pertinent academic and industrial R&D&I activities in wireless networking technology.

1.2/ Key Areas of Wireless Networking Technology & Definitions

This section provides explanations and definitions of key areas of wireless networking technology that are covered in the report. Terms used later in the report are italicised, relevant industry activity in each area is described, and R&D&I topics from both quantitative and qualitative datasets are highlighted.

Spectrum

Any device that uses wireless media to communicate requires access to spectrum. Examples include smartphones, home central heating valves and satellite service earth stations. While intangible, spectrum can be measured through the energy generated when the device is active and the frequency band(s) in Hertz[3] (Hz) in which it is generating that energy. The following three examples are among the relevant R&D&I objectives of projects identified in our qualitative data.

- Test and measurement (T&M) equipment and tools to make these energy measurements.
- Analyses of the way the energy propagates in the nearby environment to support network planning, e.g. how spectrum can be reused over the planned area, or volume, of coverage, or how the built environment creates shadows and "not-spots".
- Antenna design and implementation - one of the most critical parts of a wireless device. Some may be complex for greater resilience, e.g. spreading the energy across a greater area/volume using multiple receive and transmit antennas - MIMO, or Reconfigurable Intelligent Surfaces - RIS, that extend the coverage between devices and the RAN radio units.

[3] The unit of measurement for frequency is the hertz (Hz), which is equivalent to one cycle per second. Kilohertz (KHz) is a thousand hertz, megahertz (MHz) is a million hertz, gigahertz (GHz) is one billion hertz and terahertz (THz) is one trillion hertz.

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Frequency spectrum ranges and uses – from radio to visible light

The relevant ranges for this report are between 700MHz - 3THz (radio frequency, RF) and 430 - 790THz (visible light, or optical). The most active topics of R&D&I are in the THz range and in visible light bands for optical wireless access technologies.
The International Telecommunication Union Radio Regulations define different categories of uses of radio frequency spectrum up to ~ 60GHz for Radio Communications Services: Fixed; Mobile; Fixed Satellite; Industrial Scientific and Medical (ISM); Space; and Broadcasting among many others. The Radio Regulations apply to spectrum between 9kHz and 300GHz.

In the UK, Ofcom, the regulator, is responsible for managing spectrum assignments within the constraints of the Radio Regulations. As spectrum is used by multiple services, projects such as the Spectrum Sandbox explore innovative ways of sharing it.

There are licence-free (e.g. ISM bands) parts of the spectrum, but the majority of spectrum use, both for profit and for test and research, is allowed only with permission embodied in a licence, which is issued by Ofcom. Spectrum access may be auctioned, for example to Mobile Network Operators (MNOs).

Wireless networking technologies

R&D&I in wireless networking technologies is very diverse, including the radio access component:

- the basic electronics of amplifiers and antennas,
- the transformation of a signal received at an antenna into a stream of bits and vice versa, (signal processing for coding and modulation in the baseband),
- access protocols (Medium Access Control - MAC protocols) that tell individual devices when they can send and receive,
- adapting to the highly variable quality of the wireless propagation environment.

Modern access technology is sufficiently flexible and programmable to be reconfigurable for multiple purposes - known as Software Defined Radio (SDR).

Any specific wireless networking technology deployment must comply with the rules of the technologies it implements and the regulations for using the spectrum assigned to it. R&D&I in this part of wireless communications is related to management of use of the technology and the spectrum available to it to maximise spectrum efficiency, which means that every available Hz is in use as much as possible across the area covered. It is often done in an end-to-end context from the user device that requires orchestration of many different types of resource.

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Platforms integrate wireless networking technologies, core infrastructure, access technologies, and spectrum to deliver services to consumers, industry, critical infrastructure services (e.g. emergency and health, fire and rescue, highways, or aviation), defence, and government.
The following are relevant for this analysis as representative examples:

- Wi-Fi (standardised in the IEEE 802.11 series of MAC protocols) is the most familiar to telecoms industry professionals and the public in its use as a short range Wireless Local Area Network (wireless LAN[4]) with coverage in the range of up to ~50m. It operates in the licence-free ISM bands allocated around 2.4GHz, 5GHz and, recently, 6GHz.
- Bluetooth also operates in the 2.4GHz ISM band, alongside Wi-Fi. Bluetooth is an industry standard that complies with IEEE 802.15.1; it is a Personal Area Network (PAN[5]). LiFi, which operates in the visible light spectrum, is also in the IEEE 802.11 LAN family.
- 4G and 5G, standardised by ETSI, among other major telecommunications Standards Organisations, from Technical Specifications (TS) written by 3GPP, are examples of mobile cellular communications networking technologies. 4G/5G WANs[6] provide wireless connectivity to end user devices through radio cell base stations in the Radio Access Network (RAN) and their associated infrastructure networks. This wireless networking technology is specified and designed to provide a range of small to very large cell coverage areas. As well as providing access on the move to consumers' smartphones, 5G is used to deliver Fixed Wireless Access (FWA) to the home and business premises.
- Low Power Wide Area Network (LPWAN) for Machine Type Communication (MTC): Wireless networking technologies classed as LPWAN aim to achieve large coverage while reducing their power consumption, particularly when transmitting and receiving data. Some, such as LoRaWAN or Sigfox, are suitable for devices with limited power reserves, e.g. batteries or solar cells. They are typically sensors that can only deliver data at low rates and infrequently. Others, such as Wi-Fi Halow, or the 3GPP specifications NB-IoT, LTE-M, or RedCap, can be adapted to higher data rates when more power is available. Devices using 3GPP LTE-M or RedCap technologies can be mobile as well. Although often associated with the Internet of Things, many do not support IP protocols. Satellite systems can also support any of these technologies.

[4] Local area networks (LAN) - usable within a distance of a few 10s of metres, typically for enterprise IT and some industrial applications, in offices and public spaces, or home networks. Wi-Fi is dominant as a wireless access technology.
[5] Personal area networks (PAN) - usable within a range of a few metres of an individual, and implemented in portable devices (e.g. headphones) and fixed devices (e.g. TVs). Bluetooth is used widely.
[6] Wide area networks (WAN) - with a range of up to roughly 10 km for terrestrial networks, such as 4G or 5G mobile communications systems, and from a few 100 km up to approximately 36,000 km for satellite systems.

1.3/ General Outlook for Wireless Networking R&D&I in Telecoms

A McKinsey report on 'Advanced Connectivity' in 2022 estimates that the global GDP impact of wireless networking technology developments such as Wi-Fi 6[7], 5G and 6G and LPWAN networks could be as high as $2 trillion, based on four major industries (automotive and assembly, healthcare systems and services, aerospace and defence, and retail), and driven by operational improvements as a result of advanced connectivity. Generally speaking, these advances in wireless network technology improve access to services such as the Internet and facilitate faster, more secure, reliable and efficient connectivity.

While there is evidence of overall reduced R&D spending by telecoms businesses (from £1.4bn in 2008 to £1.03bn in 2020), there has been targeted R&D&I activity in areas relevant to wireless networking technology, in particular 5G and 6G, as well as Open RAN technology. Certain sections of wireless networking technology receive considerable focus due to their potential economic impact. Wireless networking technologies generally speaking have a wider variety of use cases than voice telephony or consumer Internet access. In a Nokia-Omdia report, for example, the following applications are identified for 5G: Fixed Wireless Access (FWA), video surveillance and analytics, immersive experiences, smart stadiums, cloud robotics and automation, machine remote control, connected vehicles and eHealth.

5G & 6G

5G and 6G are increasingly becoming areas of focus in the private sector. BT reports an R&D expenditure of £604m R&D in FY22, with the Adastral Park R&D facility focusing on a range of areas, including 5G and the Internet of Things. In 2022, Ericsson announced a multi-million pound 6G research programme to take place in the UK over ten years, involving both academia and industry. Samsung also announced in 2022 the establishment of a research group "focussing on developing technologies for 6G networks and devices."

Estimating that 5G technology could "...bring up to £159 billion in productivity benefits by 2035 if adopted widely", wireless networking technologies have been the focus of significant policies and government-aided R&D&I. There have been several UK government R&D initiatives to support 5G, including the 5G Testbeds and Trials Programme (5GTT), 5G Innovation Regions, and the 5G Supply Chain Diversification Strategy. 5G technology underpins the UK's Wireless Infrastructure Strategy, which was published in 2023 with the aim to "invest £40 million to drive take up of innovative 5G-enabled services for businesses and the public sector." The government also set out a plan to invest up to "£100 million in future telecoms research and development, including through the Engineering and Physical Sciences Research Council's (EPSRC) Future Telecoms Research Hubs, putting the UK at the forefront of the diverse 6G research agenda."

[7] Wi-Fi 7 is currently being rolled out.

Open RAN

Open RAN offers an alternative to supply chain models in which currently larger telecom operators use single suppliers across an entire mobile network. Open RAN is an implementation of the Next Generation RAN (NG-RAN) standardised by 3GPP. It is anticipated that Open RAN could facilitate a more diverse supply chain and reduce the UK's reliance on incumbent dominant industry players for mobile access network equipment.

The private sector, both in the UK and internationally, has been exploring Open RAN solutions. In 2021, Vodafone announced that it would open an Open RAN research and testing lab in Newbury, and committed to build 2,500 Open RAN sites across the UK countryside. Vodafone has also built multiple partnerships, including with UK-based companies AccelerComm and Salience Labs, to develop specialised Open RAN chipsets. In a similar line of research, Picocom, a UK-based 5G Open RAN baseband semiconductor and software specialist, announced in November 2023 the launch of a new system-on-chip (SoC) optimised for 5G small cell Open RAN radio units. BT partnered with Nokia to trial an Open RAN solution in Hull. Specifically, this involved BT installing "Nokia's RAN Intelligent Controller (RIC) for Open RAN, across a number of sites, to optimise network performance for customers of its mobile network, EE." BT also has an Open RAN Innovation Centre in the Adastral Park. NEC has a UK-based 5G Open RAN Center of Excellence, "responsible for business and solution development, product development support, project execution and technical support for NEC's global Open RAN business."

In the public sector, Open RAN is a key part of the UK's 5G Supply Chain Diversification strategy as doing so could lead to a more diverse supply chain[8]. In addition, a Memorandum of Understanding (MOU) between DSIT and major UK Mobile Network Operators (MNOs): Virgin Media O2, Three UK, BT/EE and Vodafone, was announced, highlighting the goal of the UK government and MNOs to work "towards an ambition for, in aggregate, 35% of the UK's network traffic to be carried over open and interoperable RAN architectures by 2030." This MOU encourages MNOs to both take part in DSIT R&D programmes, and also undertake their own R&D.

[8] Open RAN principles, UK government.

Government R&D&I

2.1/ Government Funded R&D&I Programmes

The UK government has committed to several R&D&I initiatives and funds relevant to wireless networking technology including 5G, 6G and Open RAN technology, emphasising the value of advanced wireless connectivity to the UK's economy and society. The UK Government has played a key role in contributing towards wireless networks ambitions, ranging from the 5G Testbeds and Trials in 2017, to the Open Networks Ecosystem Competition in 2023. According to the data obtained for this report, the UK government has made approximately £396.52m[9] available for R&D&I relevant to wireless networking technology across 7 different funding programmes.

Table 1: Government Funded R&D&I programmes focused on an aspect of wireless networking technology

Fund/ competition	Subcompetition	Total amount (Sum)
▶ 5G Innovation Regions (5GIR)		£36,637,378
▼ 5G Testbed and Trials Programme (5GTT)	5G Trials in Industry Sectors and Public Services - Create 1 (6 projects)	£10,800,000
	5G Trials in Industry Sectors and Public Services - Create 2 (9 projects)	£16,200,000
	5GUK university test network	£16,000,000
	Industrial (3 projects)	£6,500,000
	Initial portfolio of projects	£27,200,000
	International project (1 project)	£1,000,000
	Other projects/Initiatives (8+)	£10,400,000
	Rural Connected Communities (7 projects)	£24,900,000
	UK5G	£1,700,000
	West-Midlands 5G / Urban Connected Communities (6 projects)	£21,500,000
▶ Digital Connectivity Infrastructure Accelerator (DCIA)		£3,987,406
▼ Open Networks Research and Development Fund	Future Open Networks Research Challenge (FONRC)	£28,789,392
	Future RAN Competition (FRANC)	£36,383,342
	NeutrORAN	£1,600,000
	Open Networks Ecosystem (ONE) Competition	£91,885,585
	SONIC	£20,000,000
	UK & Republic of Korea Open RAN R&D collaboration	£1,211,615
	UK Telecoms Innovation Network (UKTIN)	£10,000,000
	UK Telecoms Lab (UKTL)	£16,000,000
▶ Rural Accelerator		£7,500,000
▶ Smart Infrastructure Pilots Programme (SIPP)		£1,325,965
▶ Spectrum Sandboxes		£5,000,000
Grand Total		**£396,520,683**

This table represents 7 government-funded programmes which include elements of wireless networking technology R&D&I in the UK. Data credit: UK Government

[9] This is an estimate based on public data obtained for this report and analysed in the context of this report. This estimate should be understood as indicative rather than definitive.

This section illustrates the competitions and programmes in the order listed in Table 1.

5G Innovation Regions (2023 - 2025)
Supported by the Wireless Infrastructure Strategy, the 5G Innovation Regions was allocated £40 million to build on the successes of the 5G Testbeds and Trials programme and drive innovative applications powered by 5G and other advanced wireless connectivity from proof of concept to widespread adoption. The programme demonstrates the scalability, replicability, and sustainability of 5G use cases across key sectors of the economy, creating secure connected places across the UK.

5G Testbeds and Trials Programme (2017 - 2023)
The DCMS (now DSIT) 5G Testbeds and Trials Programme (5GTT) was established in 2017 with the aim to maximise the prospective benefits that 5G could bring to the UK economy through timely deployment and effective utilisation of 5G technology. The Programme encouraged and funded the creation of a series of Testbeds and Trials in a range of market segments and was allocated a total of £200 million capital funding.

The Digital Connectivity Infrastructure Accelerator (DCIA) (2021 - 2023)
The Digital Connectivity Infrastructure Accelerator (DCIA) run by DCMS (now DSIT) allocated up to £4 million of funding to pilots which support the implementation of digital asset management solutions for mapping and brokerage of publicly owned assets for use in the rollout of wireless communication networks.

Open Networks Research and Development Fund (2022 - 2025)
In 2022 the Government created and launched the UK Open Networks R&D Fund, driven by the opportunity to build a more diversified telecoms infrastructure, strengthening UK networks' future resilience and security. This £250 million fund aims to build a more diverse and competitive supply market, thereby reducing the UK's reliance on the incumbent dominant industry players for mobile access network equipment.

There are currently multiple projects ongoing under the Open Networks R&D Fund:

1 - Future Open Networks (FONRC) Research Challenge
The Future Open Networks Research Challenge (FONRC) is a £25 million challenge which will enable universities to work with large RAN vendors, and other telecoms organisations, to conduct research and development to drive the openness and interoperability of future network architectures.

2 - Future RAN Competition (FRANC)
Future RAN, a competition run by DCMS, allocated up to £30 million of R&D funding to projects that support the goals of the Government's 5G Supply Chain Diversification Strategy. The competition was aimed at helping to incentivise industry to create new products and services to unlock the full potential of Open RAN.

3 - NeutrORAN (2020)
NeutrORAN was a £1.6 million project designed to explore a new way to build sustainable, accessible and inclusive-as well as cost-effective-rural mobile connectivity, by designing, deploying and testing a rural, shared, neutral host, Open RAN network in Wales.

4 - Open Networks Ecosystem (ONE) Competition
The Open Networks Ecosystem Competition offered up to £80 million[10] of funding to tackle key barriers to the adoption of open mobile networks:

- High Demand Density (HDD) Use Cases/Demonstrations
- Processors, radio frequency and other RAN Hardware
- RAN Intelligent Controller (RIC) and other RAN Software Automation

5 -The SmartRAN Open Networks Interoperability Centre (SONIC Labs)
SONIC Labs is a £20 million commercially-neutral, collaborative, environment for testing interoperability and integration of open, disaggregated and software-centric network solutions and multi-vendor architectures. The key objective is to enable and encourage innovative vendors to participate in the UK telecoms ecosystem and facilitate a more rapid path towards deployment in the UK.

6 -The UK & Republic of Korea Open RAN R&D Collaboration Competition
The UK/ROK competition examined a range of opportunities to improve the power efficiency of 5G Open RAN systems. The successful project Flexi-DAS, which won £1.2 million, developed a highly flexible Distributed Antenna System (DAS) radio heads/units based on field-programmable flexible radio chipsets and Radio Frequency Identification cards.

7 - UK Telecoms Innovation Network (UKTIN)
UKTIN was allocated up to £10 million of funding as the innovation network for the UK telecoms sector, aimed at supporting the telecoms industry to navigate the UK's telecoms R&D ecosystem and drive the development of open networks. It should be noted that UKTIN explores a wide range of technologies and aspects of the UK telecoms ecosystem, and does not focus solely on wireless networking technologies.

[10] While the amount allocated is £80m, tallying the total funding from successful ONE Competition projects amounts to £91.98m.

8 - UK Telecoms Lab (UKTL)
The UKTL is a £80 million state-of-the-art UK Telecoms Lab built in Solihull in the West Midlands. The lab will act as a secure research facility for mobile network operators, suppliers and academics to research and test the security, resilience and performance of their 5G and, in the future, 6G network technology. It should be noted that the focus of UKTL is primarily on telecommunications security.

Rural Connectivity Accelerator (2023 - 2025)
In June 2023, DSIT was awarded £7.3 million funding for the Rural Connectivity Accelerator, as part of a joint Shared Outcomes Fund bid with DEFRA and DCMS. The Rural Connectivity Accelerator tests new ways to bring together satellite, wireless and fixed line internet connectivity to help support agricultural and tourism businesses to access fast, reliable connectivity in remote areas for the first time.

Smart Infrastructure Pilots Programme (2023 - 2025)
The Smart Infrastructure Pilots Programme is a £1.4 million initiative that operates at scale and is empowered to unlock opportunities tailored to specific needs and strengths, to generate value and growth at the local level - working with local industry and public services through the adoption of 5G and other advanced networking technologies.

Spectrum Sandboxes (2023 - 2025)
Facilitated through Ofcom's sandbox framework, this is a £5 million project that will test and demonstrate working with academia and industry to test new spectrum sharing scenarios, with an initial focus on 3.8 – 4.2 GHz band and available parts of the upper 6GHz band.

2.2/ Multi-network projects

The variety of R&D&I funded programmes and projects outlined above sheds light on the multiple components involved in the development of wireless infrastructure. For example, Open RAN provides Mobile Network Operators the flexibility to extend 5G in a cost-effective, secure, and energy-efficient way. Various projects below outline the multiple components of technology that can be involved in wireless networks:

Project TUDOR (Towards Ubiquitous 3D Open Resilient Network) (2023-)
Funding amount: £12,000,000

Project TUDOR focuses on the research and development of open network components and their seamless interoperability in the wider RAN, core, and transport network environment and service platforms, applying them across heterogeneous networks in 5G and beyond. Additionally, it aims to contribute to future standards (5G, 5GAdvanced and 6G), generate essential IPs and contribute to skills enhancements.

Project NAVIGATE (2023-2025)
Funding amount: £3,322,223.97

Project NAVIGATE aims to design, deploy, test, and validate a blueprint for deploying open, shareable, public mobile 5G capacity in High Density Deployment (HDD) environments at scale, with Open RAN (Radio Access Network); the project seeks to validate that the chosen blueprint is technically and operationally viable, demonstrably more cost-effective and energy efficient compared to legacy Single Operator RAN Macrocell approaches.

Best of British RAN Development (2023-)
Funding amount: £4,957,149

The Best of British RAN Development project (BoB) will demonstrate a commercial and technically viable Radio Access Network architecture designed, developed and manufactured in the UK. It is aimed at serving private, local government and industrial owned networks which operate within UK Shared and Local Access Spectrum through the development of an innovative small cell within a disaggregated Open RAN network.

This project will support a range of different application layers, including public network applications and Multi Operator Neutral Host services alongside secure private network services.

UKRI

Composed of Innovate UK, Research England, and seven research councils, the UK Research and Innovation (UKRI) is the UK's national research and innovation body. UKRI funds both academic and industry R&D&I in telecoms.

The funders of the projects identified as relevant for this report are primarily the Engineering and Physical Sciences Research Council (EPSRC), Innovate UK and Horizon Europe Guarantee, with smaller amounts of funding provided by ISCF, FLF and GCRF.

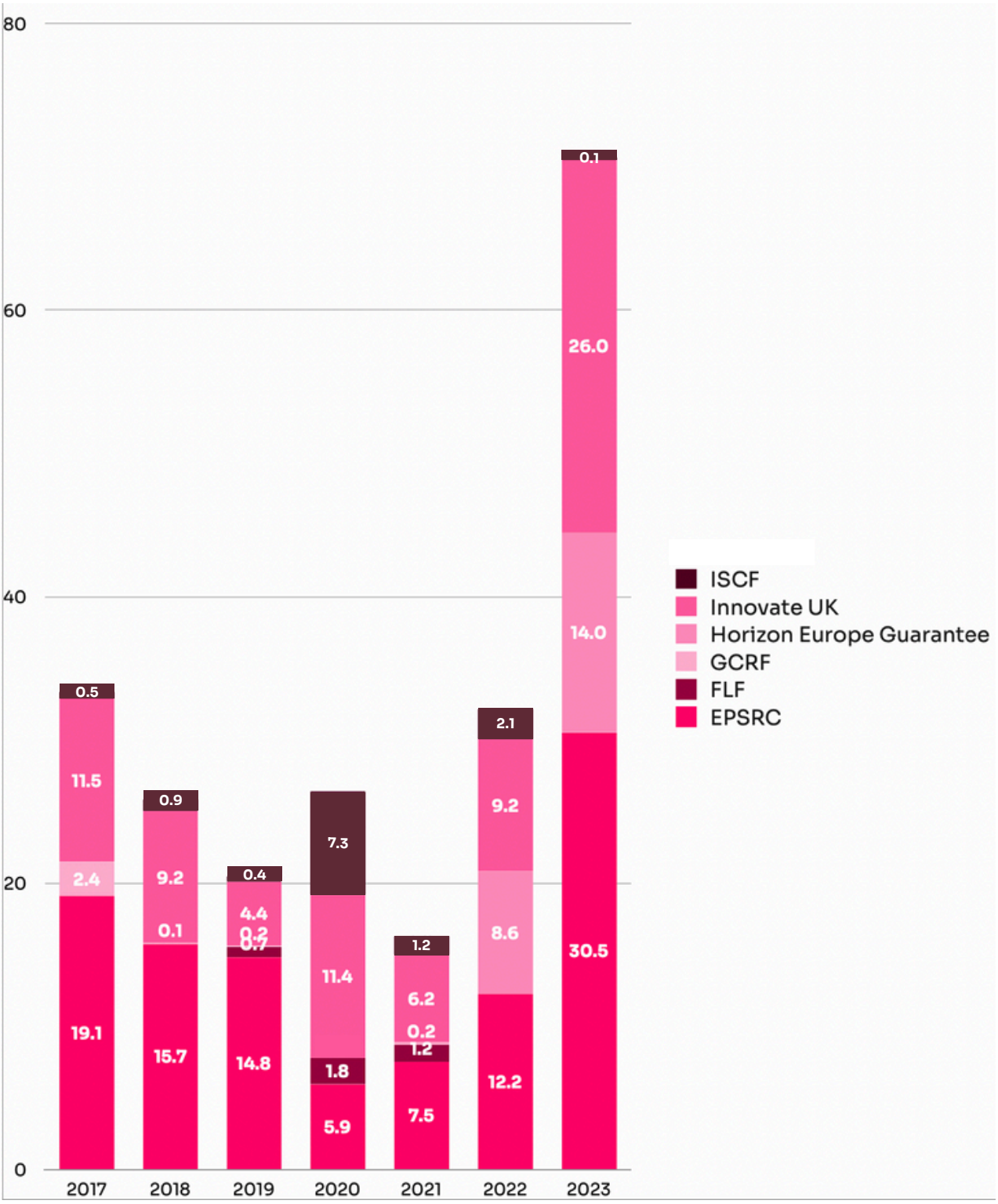
This section comprises a mixed methods approach in which qualitative insights were obtained from academic experts by the University of Bristol, and quantitative insights produced by Digital Catapult. Quantitative methods for this section involved querying the UKRI database with keywords relevant for wireless networking technology. These keywords were selected with the input of experts in wireless networking technology from Digital Catapult and the UKTIN Wireless Networking Technologies Expert Working Group. Of the projects included in this report, 80% were manually curated using a set of rules to eliminate projects that were not relevant to wireless networking technology. The following is a presentation of these quantitative and qualitative findings.

3.1 Research Council-funded Research: EPSRC, Innovate UK, Horizon Europe Guarantee, ISCF, GCRF & FLF

3.1.1/ Funding sources

This report identified 596 UKRI-funded projects that fall into the category of Wireless in telecoms R&D&I, with total funding amounting to £225m in the period between 2017 to 2023. These sources, in order of funding amount allocated, are EPSRC, Innovate UK and Horizon Europe Guarantee and ISCF. FLF and GCRF also provided funding for a small number of projects.

Graphic 1: Funding sources for UKRI-funded Wireless in telecoms research year on year



This graphic represents the total amount of funding granted by UKRI to academic Wireless in telecoms projects, split according to scheme. It considers 596 different projects in total. Data credit: UKRI

Over the period 2017 - 2023, EPSRC funded 188 projects, accounting for £105.8m which represents 47% of the overall total of £225m funded by UKRI. Innovate UK funded 271 projects, accounting for £77.8m or 34.5% of the overall total. Notably, while Innovate UK funds more projects than EPSRC, the overall value of the funding allocated is smaller than EPSRC. Horizon Europe Guarantee funded 91 projects, accounting for £22.6m or 10% of the overall total. ISCF funded 35 projects, accounting for £12.6m or 5.6% of the overall total. FLF and GCRF each funded 1.6% and 1.3% of the total funding amount respectively.

It is clear that funding allocated to projects applications of wireless networking technology increased dramatically in 2023, with £70.7m in funding allocated. Innovate UK and EPSRC represent the bulk of the funding increase, from £9.2m in 2022 to £26m in 2023 and from £12.2m in 2022 to £30.5m in 2023 respectively. The introduction of the Horizon Europe Guarantee programme in 2021 also contributes to the increase in total UKRI funding over said period.

Across seven years, Innovate UK and EPSRC have consistently provided the main proportions of the funding, with an exception in 2020 when ISCF provided £7.3m in funding. Overall, in the 2017-2023 period, in 2020 funding was the lowest, but caution is advised when considering data from 2020, due to the effects of the COVID-19 pandemic.

When asked about their funding sources and general outlook on academic funding for wireless R&D&I, two academic experts interviewed for this report emphasised research councils as funding sources. Three out of four mentioned funding opportunities in the defence sector, or through the Defence Science and Technology Laboratory (DSTL). As one interviewee stated, “a promising avenue for support comes from the defence sector, which is showing a growing interest in civilian telecoms infrastructure and systems. It's noteworthy that many technologies integral to commercial wireless applications often have roots traceable back to military applications.”

The same interviewee noted that, in terms of funding sources and their availability for R&D&I in wireless networking technology, “securing direct industry support for fundamental or low Technology Readiness Level (TRL) research, although feasible, can be somewhat challenging. Industries often prioritise funding for projects addressing acute needs and technologies closer to commercial exploitation.” Another expert mentioned that, in contrast with defence applications, “when it comes to civilian applications, securing funding from industries based in the UK is not as common.”

3.1.2 Projects and R&D&I areas of focus

Table 2: Top Ten UKRI-funded Wireless in Telecoms Research Projects

Project Title	Funding Body	SUM of Amount (£)
Terabit Bidirectional Multi-user Optical Wireless System (TOWS) for 6G LiFi	EPSRC	£10,297,289
Cambridge Connector	Innovate UK	£8,772,218
Terahertz frequency devices and systems for ultrahigh capacity wireless communications	EPSRC	£7,097,283
The Millbrook-Culham Test and Evaluation Environment: A semi-controlled urban CAV Test Bed	Innovate UK	£6,910,294
HyperTerahertz - High precision terahertz spectroscopy and microscopy	EPSRC	£6,517,861
AIRQKD	ISCF	£5,791,324
Signal Processing [sic] in the Information Age	EPSRC	£4,092,206
V-CAL	Innovate UK	£4,032,996
Multi-Area Connected Automated Mobility (MACAM)	Innovate UK	£3,906,934
Multi-Car Collision Avoidance	Innovate UK	£3,054,563

This table represents the ten most highly funded (and multi-partner) projects that fall into the category of research in 'Wireless in telecoms'. Data credit: UKRI

The highest-funded UKRI project is Terabit Bidirectional Multi-user Optical Wireless System (TOWS) for 6G LiFi at £10,297,289. This project explores "...the infrared and visible light spectrum for future terrestrial wireless systems". In particular, the research aims to "develop and experimentally demonstrate multiuser Terabit/s optical wireless systems that offer capacities at least two orders of magnitude higher than the current planned 5G optical and radio wireless systems, with a roadmap to wireless systems that can offer up to four orders of magnitude higher capacity."

The second-highest at £8,772,218 is Cambridge Connector which focuses on automated vehicles, in particular an "at-scale trial of on-demand self-driving vehicles with up to 13 electric vehicles" and using a "5G connected Remote Monitoring and Tele-Operation service to enable a cost-effective deployment that ensures complicated edge cases can be accommodated through temporary override of vehicle automation."

Of the top 30 funded projects, seven focused on autonomous vehicles (with one project also focusing on quantum-secure 5G and one other project focusing on collision avoidance). Four projects focused on antennas specifically, with one project looking specifically at antennas for 6G. Three projects focused on optical wireless, and a further three specifically on terahertz research (terahertz carrier frequencies, spectroscopy and terahertz vector network analyser). Other themes in the top 30 projects included spectrum and security-focused research, research on a network of networks, heterogeneous networks, 6G radio systems and signal and data processing techniques. The range of areas retrieved was broad, including also a rail track monitoring system using LPWAN, atomic clocks, LiFi, research on an autonomous emergency management system, millimetre wave transceiver architecture, dynamic spectrum access and a virtual technology platform.

Academic experts interviewed for this report highlighted several key themes and trends in their own research, and more broadly in wireless networking technology R&D&I. These are:

Wireless Networking Technology, Artificial Intelligence & the Internet of Things
One expert interviewed for this report noted that there is an "...increasing demand of artificial intelligence, machine learning and deep learning techniques to design and control the wireless networks," and that the inverse is also true, that "...wireless networks are also acting as an enabler of artificial intelligence." This linkage is also strong between wireless networking technology and the Internet of Things. The same expert noted, "exploring the interaction between wireless power and sensor design becomes crucial in achieving autonomy for a multitude of IoT devices." Further, the expert noted that "wireless power is closely tied to the Internet of Things (IoT), where numerous low-power devices, such as sensors, require sustained power without frequent battery changes."

Semantic communication and multi-user access techniques
An academic interviewed for this report highlighted that "semantic communication, a new field beyond Shannon's law, is a big topic and explores the physical layer from an information theoretic perspective. System aspects involve multi-user access techniques (MIMO/MMIMO), and cell-free communications to reduce interference by distributing network elements."

Antennas, MIMO, Reconfigurable Intelligent Surfaces (RIS) and Reconfigurable Intelligent Edges (RIE)

Antennas also formed a key part of the research for the experts interviewed, which is linked to massive MIMO. An academic expert in this area described their work in this field as follows: we design and fabricate antennas and antenna arrays, and conduct significant work in signal processing and communication theory. We combine this to deliver technologies such as massive MIMO. XL MIMO represents the latest iteration, focusing on extremely large-scale antenna arrays." A key focus here is optimising energy costs while retaining promised performance benefits. They describe their work as "leading the way in cell-free massive MIMO, a technology often discussed in the context of 6G."

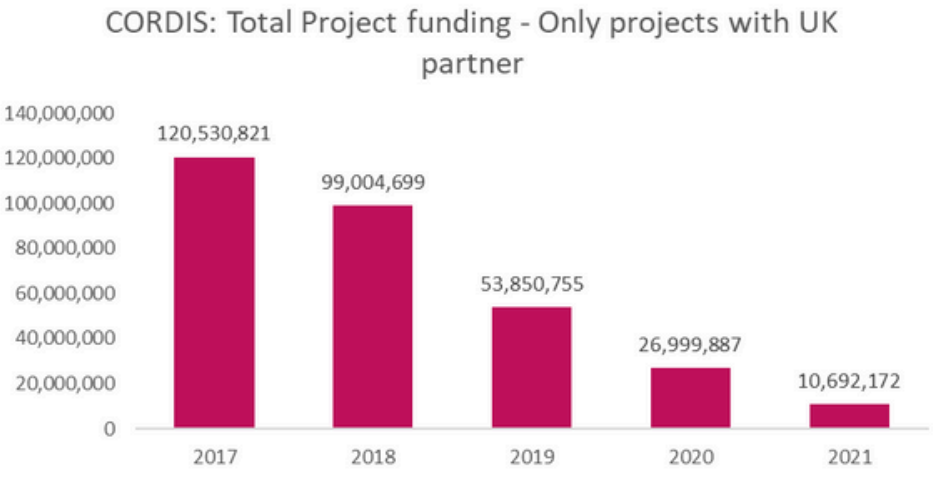
For a second expert, antenna arrays were also a core part of the research they conduct with their broader research group: "Antenna arrays are a key focus, along with signal processing. We engage in FPGA implementation and test bed implementations in the communications context. Within the research group this expert belongs to, some researchers specialise in "FPGA technology and its application to electronic systems beyond communications," while others "focus on applying FPGA technology to sensing, imaging, and computation efficiency."

Research on antennas also overlaps with other aspects of wireless networking technology. Another expert described the focus of their group as spanning "everything from antenna systems to reconfigurable electromagnetic media," including Reconfigurable Intelligent Surfaces (RIS) and Reconfigurable Intelligent Edges (RIE). This involves using new materials to design novel structures that can be strategically positioned (e.g. on the sides of buildings, the edge of buildings or rooftops etc.) to enhance signal propagation, especially in urban environments.

Horizon 2020

Horizon 2020 was a European Union research and innovation funding programme which ran from 2014 to 2020 with a budget of close to €80 billion. This programme has been replaced by Horizon Europe since 2021. The projects funded by this mechanism involved multiple partners across various European and non-European countries. This section focuses specifically on projects that involved at least one UK partner, providing insights into the UK R&D&I in wireless networking technology in the telecoms landscape. It is based on data from CORDIS and covers 43 Horizon 2020 projects that commenced between 2017 and 2021.

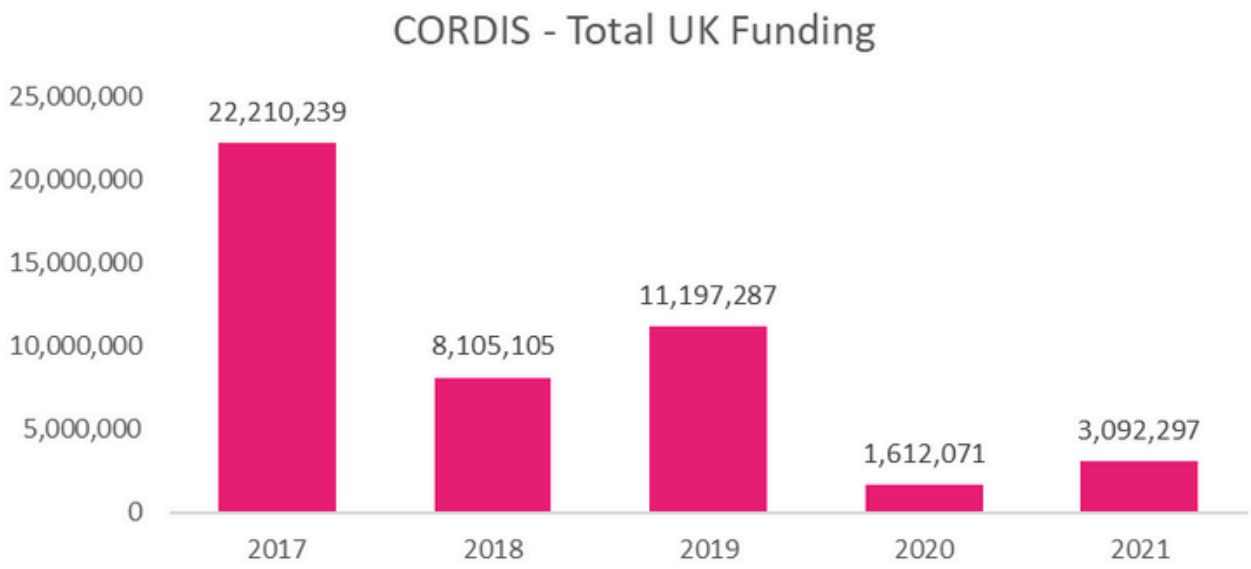
Graphic 2: Total Funding for Horizon 2020 Projects with at Least One UK Partner Involved, by Year



This graphic represents the total amount of funding (in euros) awarded by Horizon 2020 for wireless networking technology projects, involving at least one UK partner. It considers 43 different projects in total. Data credit: CORDIS

Between 2017 and 2018, funding decreased by 18%, followed by decreases of 46%, 50%, and 60% in the subsequent years until 2021. This is mostly due to the decreased number of projects, declining from 22 in 2017 to only 3 in 2021. The graphic displays consistent year-on-year decline, with a compound annual decrease rate of 38%.

Graphic 3: UK Partner's funding per Year by Funding Scheme



Total amount of funding (in euros) dedicated to UK partners awarded by Horizon 2020 for wireless networking technology projects. It considers 43 different projects in total. Data credit: CORDIS

Graphic 3 represents the total funding granted to UK partners in the Horizon 2020 projects related to wireless networking technologies from the previous section. The share of the funding allocated to UK partners over the total project funding varies between years. Across the period 2017 - 2023, Horizon 2020 allocated €46.21m to UK partners. In 2017, out of the €120m allocated to wireless projects within Horizon 2020, the UK received €22m in funding, which accounts for 18.4% of the total funding. However, in 2018, UK funding decreased, accounting for 8.2% of the total funding that year. This was reverted again in 2019, with UK funding representing 20.8% of the total. By 2021, the UK's share of Horizon 2020 funding for wireless networking technologies related projects rose to 29%.

4.1/ Top Wireless networking technology projects funded with UK partners under Horizon 2020

Table 3: Top 10 Projects with Highest Funding and including at least one UK Partner

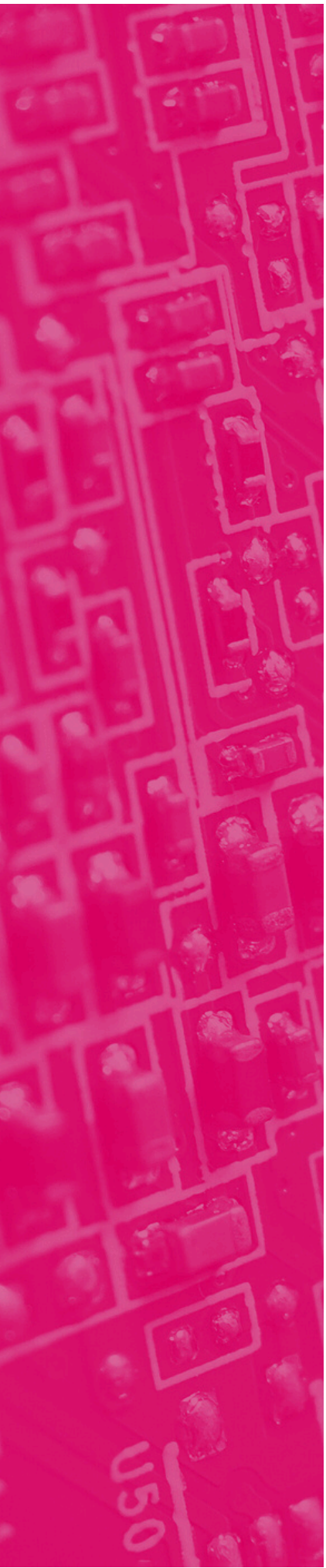
Project Title	SUM of Amount (€)
5G-MOBIX – 5G for cooperative & connected automated MOBility on X-border corridors	€26,795,156
5G-VINNI – 5G Verticals INNovation Infrastructure	€19,997,733
5G-Carmen – 5G for Connected and Automated Road Mobility in the European UnioN	€18,542,016
5GENESIS – 5th Generation End-to-end Network, Experimentation, System Integration, and Showcasing	€15,796,863
5G-TOURS – SmarT mObility, media and e-health for toUrists and citizenS	€14,700,898
5G-VICTORI – Vertical demos over Common large scale field Trials fOr Rail, energy and media Industries	€13,499,491
5GRAIL – 5G for future RAILway mobile communication system	€13,323,105
RESISTO – RESilience enhancement and risk control platform for communication infraSTructure Operators	€10,531,803
5G-TRANSFORMER - 5G TRANSFORMER: 5G Mobile Transport Platform for Verticals	€8,510,582
MATILDA – A HOLISTIC, INNOVATIVE FRAMEWORK FOR THE DESIGN, DEVELOPMENT AND ORCHESTRATION OF 5G-READY APPLICATIONS AND NETWORK SERVICES OVER SLICED PROGRAMMABLE INFRASTRUCTURE	€8,325,083

This table represents the 10 largest wireless networking technology projects funded under Horizon 2020, involving UK partners. Data credit: CORDIS

This table highlights the 10 projects with the highest funding granted involving at least one UK partner within the Horizon 2020 programme. These projects primarily concentrated on improving communication systems for transport, conducting tests on sites and infrastructure to enhance connectivity, safety and resilience of the network. Significant emphasis was placed on developing mobile transport networks and smart mobility solutions, utilising 5G technology to address evolving transportation needs efficiently. Additionally, the projects included large-scale tests on vertical use cases and the implementation of network slicing techniques to meet diverse service requirements. Furthermore, facilities tailored to different use cases were developed to ensure that telecommunications infrastructure could effectively support a wide range of applications and services.

Among these top 10 projects, the first three projects with the highest funding allocations were as follows:

- Starting in 2018 and lasting for 36 months, the 5G MOBIX project focused on enhancing automated vehicle functionalities using 5G. Involving 60 partners, this €26.8m project aimed to test 5G core technologies across two cross-border corridors and six urban trial sites, leveraging 5G for connected and automated mobility (CAM) applications.
- The 5G-VINNI project, which ran from 2018 to 2022, built an end-to-end facility to test 5G use cases. With a budget of €20m, this initiative aimed to validate the performance of new 5G technologies, including tests on network virtualisation techniques and advanced network architectures such as 5G network slicing, core, and radio. It involved three principal UK partners: British Telecommunications PLC, Lime Microsystems, and Samsung Electronics (UK).
- The 5G CARMEN project, a 36-month project starting in 2018, researched, implemented, and demonstrated 5G solutions for Cooperative, Connected, and Automated Mobility. With an €18.5m budget, the project aimed to enable vehicles to exchange information on speed, position, intended trajectories, and manoeuvres by exploring both distributed and centralised approaches for cooperative lane merging.



Commentary

Funding trends in wireless networking technology in the UK

This report has identified that, in the data retrieved across the period 2017 - 2023, a total of approximately £668m has been allocated to R&D&I projects relevant to wireless networking technology. Of this amount, UK government-funded programmes accounted for £396.52m (59.3%), UKRI accounted for £225m (33.6%) with EPSRC and Innovate UK as the main funders within UKRI, and Horizon 2020 accounted for £46.21m (6.9%)[11].

Data from government-funded R&D&I programmes, from UKRI and from Horizon 2020 projects, emphasised utilising advanced wireless networking technologies such as 5G and eventually 6G, for mobility, transport, and rural connectivity. Significant testing efforts have been directed towards ensuring fast and reliable connectivity in remote areas. Additionally, there has been a substantial focus on the application of future networks in industrial settings.

A notable trend in recent years has been the introduction of new funds and competitions aimed at opening the telecoms supply chain to new vendors. This initiative seeks to diversify the range of telecom products and services available in the UK market, with a particular emphasis on Open RAN, to foster a more competitive and innovative telecoms ecosystem.

Key areas of research and applications of interest

R&D&I initiatives in the UK put forward by both UKRI and Horizon 2020 projects encompass a wide range of applications, tools and equipment:

- Projects are focused on developing and integrating optical and radio components for 5G networks.
- A major focus is on connected and automated mobility, with the goal to advance the commercial viability of automated, self-driving vehicles. Projects involve developing 5G-connected remote monitoring systems systems to enhance safety and operational efficiency.
- 5G technology for remote monitoring applications
- Promoting Open RAN development and installations

[11] These figures are based on the data retrieved for this report and a different methodology, in particular the inclusion or exclusion of certain projects and programmes, may yield different results. It should be noted that these figures are to be understood as indicative rather than definitive, and are meant to provide an indication of R&D&I spending in wireless networking technology, rather than definitive figures.

The main areas of focus which have emerged from research for this report are:

- Defining and demonstrating new physical layer techniques, including advanced signal processing methods. A particular emphasis is placed on antennas and massive MIMO with large-scale antenna arrays, especially directed to urban environments. An expert interviewed for this report noted that "...Software Defined Radio plays an important role in defining and demonstrating new physical layer techniques and signal processing."
- Enhancing the UK's capability in 6G radio systems, with research into higher frequency bands, from 6GHz to sub-THz systems, to support the growing demand for data.
- An interviewed expert noted the interconnectedness of wireless networks and artificial intelligence, with there being on the one hand increasing demand for artificial intelligence and machine learning techniques to better design and control wireless networks, and on the other hand wireless networks themselves "...act as an enabler of artificial intelligence."
- The same expert also mentioned the convergence of IoT and sensors with wireless power to achieve greater autonomy.

Challenges & Suggestions from Expert Interviews

Despite ongoing research in wireless networking technologies by both academic and industry players in the UK, experts interviewed for this report highlighted several challenges and put forward some suggestions to address these challenges:

- Access to funding can be a challenge, with research councils representing a key source of funding. One expert expressed that "securing direct industry support" was challenging, particularly at fundamental or low Technology Readiness Level, and suggested that there exists a difference of perspective regarding the priorities of industry and academia, with the former more focused on commercial opportunity and viability.
- Industry presence in the UK and difficulties transferring academic R&D&I to industrial contexts. One expert interviewed suggested how major corporations establishing research labs could help build increased collaboration between industry and academia, while another expert suggested the possibility of addressing this issue by promoting and investing in spinouts, which "...entails creating innovative ideas through university research activities, quickly transitioning them to a commercial environment." One expert also suggested that "...the absence of a UK-based telco vendor poses challenges, as operators are reluctant to engage in UK projects compared to vendors like Ericsson and Nokia, which drive the process and collaborate with universities in mainland Europe rather than the UK." Several experts noted that the defence sector can be an avenue for funding.

Commentary

- Collaboration is identified as a key enabler for further development
  - International collaborations: Experts interviewed highlighted a range of international collaborations integral to advancing wireless networking technology research. One expert mentioned partnerships with institutions and researchers across Germany, Canada, Singapore, China, and Korea.
  - Between different areas of research in wireless networking technologies: an expert advocates for bridging the gap across different sections of wireless research, from the device and physical layer to applications. They note that research tends to be siloed, with specialists often concentrating on "...specific components, such as channel codes, without considering the broader system integration." Interviewed experts further argued that there was value in "multi and cross-disciplinary research, involving mathematicians, physicists, material scientists, and communications engineers", to foster "...integrated research across the entire wireless spectrum, from the device and physical layer to applications".
  - As indicated above, facilitating collaboration between industry and academia is suggested by experts to be an enabler for R&D&I in wireless networking technologies.

Annex

Annex 1: Methodology

For this report, a combined approach was taken to provide detailed insight into some of the key UK R&D&I wireless in telecoms topics, relevant to the UK ecosystem. The approach incorporated quantitative and qualitative analysis from different elements of the R&D&I ecosystem, including desk research, database analysis and web scraping from key datasets, the UKTIN AI discovery toolkit (currently in beta testing), expert interviews by the University of Bristol, and discussions between programme partners and relevant stakeholders. All data incorporated in the report is from publicly available information, and is complemented with primary and secondary research.

In terms of qualitative analysis, the University of Bristol conducted 4 interviews with wireless in telecoms academic experts from 4 leading research Universities working in cluster V on the UKRI KEF2 database.

In terms of quantitative analysis, three approaches were used for the different sections in this report. All methods retrieved projects beginning on or after 1/1/2017. The year 2017 was established as the starting point for data collection to ensure that the data is relevant and recent.

Annex

For Section 2: Government R&D&I, data on the different funding schemes and projects was collected and collated manually from government webpages. This was conducted in May 2024 and the data is accurate to this point. For Section 3: UKRI, in order to identify the relevant projects, a list of keywords was compiled in order to capture the breadth of R&D&I in wireless networking technology, complemented by a list of keywords to exclude to ensure projects were relevant to the telecoms industry (due to low performance or lack of reliability and relevance). These were submitted as a boolean query to the GTR-UKRI API and the results downloaded in XML format. Specific search terms were used to remove irrelevant subject areas, and the data was then manually curated over several iterations to generate a reliable data set with technology experts at Digital Catapult. Results retrieved using this process were obtained in January 2024 and are accurate to this point. Finally, Data for section 4: Horizon 2020, was obtained from the CORDIS database using an early version of the UKTIN Discovery Toolkit. The same set of keywords from UKRI was used to include and exclude projects for this section of the report so as to ensure consistency. The data was subsequently manually curated, cleaned and analysed.

Annex 2: Limitations

This report relies on publicly available data and therefore focuses on public funding for R&D&I. Private company's R&D&I investments are typically commercially sensitive and access is restricted, meaning that web scraping methods are not applicable. The data retrieved for this report is determined by the methods described above, and is presented as an indicative snapshot of information on wireless in telecoms R&D&I, rather than as a definitive and exhaustive list of projects and funding. Different methodologies, specifically different keywords, may yield different results. There may also be inconsistencies in the raw data and the data may change over time.

Annex 3: Data sources list

Dataset	Source
Government-funded programmes	5G Testbeds and Trials Programme
	Open Networks Research and Development Fund
	FONRC
	ONE
	FRANC
	UK-ROK OPEN RAN R&D
	Spectrum Sandboxes
	NeutrORAN
	The Digital Connectivity Infrastructure Accelerator
	5G Innovation Regions
	Rural Connectivity Accelerator
	Smart Infrastructure Pilots Programme
	UK Telecoms Lab (UKTL)
	The SmartRAN Open Networks Interoperability Centre (SONIC Labs)
	UK Telecoms Innovation Network (UKTIN)
UKRI	UKRI Gateway to Research
CORDIS Horizon 2020	data.europa.eu