5G NATION

The UK 5G Ecosystem 2018

5G activities and capabilities in the UK

June 2018

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Digital Catapult is the UK's leading advanced digital technology innovation Centre, driving early adoption of technologies to make UK businesses more competitive and productive to grow the country's economy.

We connect large established companies, startup and scaleup businesses and researchers to discover new ways to solve big challenges in the manufacturing and creative industries. Through this collaboration businesses are supported to develop the right technologies to solve problems, increase productivity and open up new markets faster.

Digital Catapult provides physical and digital facilities for experimentation and testing that would otherwise not be accessible for smaller companies.

As well as breaking down barriers to technology adoption for startups and scaleups, our work de-risks innovation for large enterprises and uncovers new commercial applications in immersive, future networks, and artificial intelligence technologies.

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EXECUTIVE SUMMARY

In late 2017 Digital Catapult was asked by Innovate UK to utilise its impartial position within the digital innovation landscape to provide an ecosystem view of 5G activities in the UK. The aim of this report is to build a picture of the UK 5G ecosystem to drive forward innovation and identify the challenges and opportunities of early adoption of 5G technology in ways that maximise the benefit to the UK economy. Reaching out to a wide ranging representation of the 5G ecosystem, this report presents a snapshot of the current state of 5G-relevant activities, community-contributed insights and views on 5G in the UK, with the aim of informing wider stakeholders including industry, academia and startups.

The UK Government has an ambition to make the UK a leader in 5G. In the UK 5G Strategy, there is a clear recognition that world-class digital infrastructure is the building block for a modern industrial economy, creating new opportunities for growth by enabling new business models, opening up new opportunities for innovation and driving productivity across the economy. This is reflected in the 2017 budget allocation, of £200m for the 5G Testbeds and Trials Programme over the period of 2017-2021. This forms as part of over £1bn of funding into digital infrastructure, including funding from the National Productivity Investment Fund.

This report is not about making the case for 5G in the UK, but to bring together the breadth and depth of the related, and strongly linked, activities in the UK that contribute to the success of 5G development and the early adoption of the technology. Since Autumn 2017, Digital Catapult has conducted targeted surveys, interviews roundtables and workshops, alongside commissioning regional, industry and technology focused reports, to provide a snapshot of current activities and inform further analysis of 5G activities in the UK.

5G offers significant opportunities for the UK as the mobile world and the internet become more closely united, bringing about a reduction in network latency and improved bandwidth, leading to new and imaginative deployment models across the spectrum. 5G deployment will be challenging, requiring new and innovative business models and corresponding regulations to help maximise benefits to the UK economy.

WHAT IS 5G?

5G is a strong and crucial innovation enabler for the digitalisation of economic activities. It combines reduced network delays (ultra-low-latency), increased data transfer capabilities (ultra-high-bandwidth), reliability (ultra-reliable), security (ultra-secure) and speed (ultra-fast). When this is coupled with its purposeful design, allowing for the connection of devices at a large scale, it creates an extremely powerful platform for cross-innovation. This will allow the UK economy to go beyond just mobile broadband applications, and instead enable the deployment of sector specific 5G private networks into new industries, from healthcare, smart cities and education, through to transport and manufacturing.

The flexibility of 5G networks, with improved management and operation support, offers significant opportunities for economic growth through the integration of fixed, cellular and IT infrastructures into one manageable infrastructure, offering flexible industry-specific services. All these drive opportunities for new business models, applications, services and experiences that can utilise reliable real-time accurate data from multiple sources in both B2B and B2C markets.

This study has found that there is a strong and growing 5G ecosystem in the UK, which recognises the accelerating effect of the UK Government's 5G Testbed and Trials Programme. The strength of the UK 5G ecosystem is largely formed from an active research base in academia, supported by the close interconnectivity between industry and academia, with new consortiums being formed and projects undertaken. There is a high awareness of the 5G opportunities and challenges across the UK, including in local government and other industry sectors. However, there is still a need to translate the 5G opportunity into a practical understanding, and in turn convert this into targeted and beneficial delivery activities, projects, programmes and digital strategies that offers stakeholders clear business cases and supports investment decisions. Although no uniform approach to 5G readiness exists across the country, there is a presence of 5G ambition in various local and regional digital strategies.

Today's forecasts are by 2020, a person can generate 1.5GB of data per day, autonomous cars will be 4GB per day, integrated planes will be 40GBs and a Factory would be 1TB per day

WHAT DOES THE 5G ECOSYSTEM IN THE UK LOOK LIKE?

The UK 5G ecosystem has a growing momentum, is highly interconnected, and can be classed as strong. It is composed of a wide and diverse range of players, from private sector companies, academic and research organisations, through to public-sector bodies. This ecosystem is growing around core stakeholders, with testbeds and trials already taking place. This growth has brought the UK largely in line with other leading countries efforts in 5G.

These projects and activities span the entire mobile and wireless infrastructure, from individual mobile technology blocks and software, to end-to-end network system integration and testbeds.

The UK ecosystem has specific strengths in softwareisation, security, development of applications & services and system integration.

ACADEMIA

The funding breakdown for academic 5G projects is: EPSRC 47%, European Commission 38% and Innovate UK and the Department for Digital Culture Media & Sport (DCMS) (combined 9%). The current position of the UK in 5G is influenced directly by its academic activities, with key investments forming pivotal turning points, such as the creation of the 5G Innovation Centre at the University of Surrey.

135
5G - Relevant academic projects

Over 5 yrs

39
Academic Institutions leading or participating

29
Local Authorities

57
Companies

5G in academia: insights from the ecosystem

The establishment of the 5GUK Universities Test Network, between University of Surrey (5GIC), the project leader, University of Bristol and King's College London, has created a very strong capability platform for further 5G development in the UK; their 5GUK Exchange is a leading contribution towards 5G as a network-of-networks system. This has followed the establishment of 5GIC at the University of Surrey in 2013, with initial investment of total £35m from the Higher Education Funding Council for England (HEFCE) and the Centre's industry and regional partners.

UK academic research in wireless and networking systems continues to be strong, as well as broad in its research areas. There is an increased interest, and strength, in applied end-to-end systems research. This compensates to some extent a reduction in UK industrial R&D in mobile communications.

There is significant industry engagement around the active academic centres in this area.

The further success of 5G is reliant on the ability to cross-innovate much more between academia, innovators and industry, where UK-bred R&D in 5G is developed into real world deployment.

The UK would potentially benefit from enabling easier access for Academia to contribute to or affect standards directly, rather than through industry partners. Academia is also contributing through open source solutions for 5G.

Local government

The majority of existing local government projects focus on 5G infrastructure deployment and testbed activity. There is a significant interest from local and regional government to actively explore the 5G opportunities for innovation that addresses local challenges and growth, often in connection with local fibre rollout initiatives. Of further interest for local authorities is the creation of an open environment for innovation that can foster growth across a number of challenges and technology areas.

5G in local government: insights from the ecosystem

Local and regional government's digital strategies, where defined, consider 5G as an important component of their infrastructure plans, often with ambitions to better link the 5G and fibre rollout plans.

There is a recognised need for technical capacity in local authorities to translate the 5G opportunities into a local and regional context, with availability of broad and impartial advice considered crucial.

The UK will benefit from an inclusive 5G rollout with wide coverage and capacity, reflecting on the lessons learned from the rollout of 4G.

Devolved governments have developed (e.g. Scotland) or are developing (e.g. Wales) 5G strategies.

It is very encouraging to see that several of the DCMS 5G Testbeds and Trials Programme Phase 1 projects are led by local authority organisations (Worcestershire 5G Consortium, led by Worcestershire LEP, and 5G Smart Tourism which is led by the West of England Combined Authority), or have a regional focus, such as the Liverpool 5G Testbed.

INDUSTRY ACTIVITIES

Companies are keen to showcase flagship projects that work on the more innovative parts of the 5G stack. Smaller technology specific projects are abundant in the UK, but do not receive as much publicity. These projects are spread across a range of technology areas with mmWave, RAN, NFV and Network Slicing amongst the technology that is most prevalent. 31 projects come under non-specific or "other" technology areas or haven't been made public – this could be due to privacy and competition.

5G in UK industry: insights from the ecosystem

Funding information for industry is not always made public. With high degrees of competition, particularly in London, lack of visibility around innovations between companies can be common. Consortiums and joint ventures are breaking these silos down and there are programmes and initiatives developing.

Industry is already looking at commercial tests and is preparing for launch of the technology, with first 5G contracts already being signed.

There are currently 40 projects funded by H2020 within the 5G-PPP (19 in Phase 1 and 21 in Phase 2) out of which UK stakeholders (academia and industry) are involved in 38, leading four of them and participating with an average of two UK partners in each of them.

MOBILE NETWORK OPERATORS (MNOs)

MNOs remain the primary vehicle for deployment of 5G in the UK, as evidenced by the result of the Ofcom 3.5 GHz spectrum auction (Spring 2018). Their strategy is not yet visible, with a common shared position statement being that 5G deployment is likely to happen with parallel routes, with local authorities and other industry looking to rollout networks in clusters that may then be incorporated into a larger, macro network from Mobile Network Operators continuing their rollout beyond 2020.

66

5G-relevant industry activities

28

UK Based Companies

5G and Mobile Network Operators in the UK: ecosystem insights

UK MNOs expect co-existence of 4G and 5G for a foreseeable future; this is considered a good approach to de-risk the 5G rollout and allow innovation and creation of the business case for 5G at national level.

Mobile operators are all keenly looking to new use cases and revenue streams with the deployment of 5G networks, especially through growth on connected devices, whilst continuing to exploit their significant investment in 4G and its upgrades.

A number of very agile high-technology small companies focused on 5G have been established over the past 10 years, which are leveraging the existence of a very highly skilled workforce being made available due to industry changes in the UK.

The pace of the 5G rollout in the UK by the MNOs will depend on many factors. This includes spectrum allocation, ways to reduce the cost of deployment for densification, and transmission backhaul..

Planning and spectrum allocation require support to make it easier to deploy by enabling/ simplifying the local planning, building, transport regulations and costs by ensuring common access of infrastructure, e.g. common ducting, or re-use of fibre if under-utilised or not lit.

DEMAND AND, FUNDING FOR 5G

Strategy Analytics predicts that by 2022 tens of millions of 5G handsets will have been sold across the globe, and that by 2025 more than 300 million 5G handsets will have been sold. Mobile broadband was the largest cited use case in our survey, followed by transport, healthcare and virtual and augmented reality (VR/AR), with manufacturing further in the future. These latter applications are still very much developing and so there is great scope for the enablement of early adoption of these technology areas as 5G evolves and new and existing testbeds are utilised.

Demand for 5G in the UK: ecosystem insights

Our survey of key players across the value chain in 5G found mobile broadband will be the major opportunity with data consumption constantly on the rise, but with this, technology such as media and VR/AR content (which 40% also saw as an opportunity) can be consumed via mobile broadband with devices readily supporting this.

Industry opportunities such as use cases of 5G in health (35%) and manufacturing (27.5%) were also seen as having potential. However, there were also views that these, at the moment, could be met by existing mobile technology, which points to the need for better awareness of the differences between 4G and 5G capabilities.

Need for 5G comes in the form of a desire to improve latency, coverage and capacity. This would include new innovations that utilise richer levels of data, alongside real time applications and analysis. Considering the key areas where innovation is expected latency is key in delivering the expected performance.

Those surveyed saw the need for 5G in the present and very much near future with 85% of respondents signalling that there is an appetite for the technology to be used by 2022.

FUNDING FOR 5G

Commercial funding could be a key constraint to further progress in developing 5G, including the cost of 5G ready equipment, which is not yet in mass production. The case for 5G will, over the next few years, continue to be developed. In this context, collaborative development of 5G technologies and new business and operation models were highlighted through our research as crucial to the success of the UK's 5G rollout by both commercial and academic stakeholders.

Funding for 5G in the UK

- DCMS Funding – is seen as key to initiating the design research that supports the industry challenges and a driver to many of the activities. It has positively influenced the strength of the project focus and alignment to commercial, academic and government interests.
- DCMS Funding – is key to rebalancing the investment for development aspects of 5G across the UK.
- Shared/Agnostic Infrastructure - A business model providing shared infrastructure lowers cost of ownership of the network. 5G must cover all use cases, not just voice, connectivity and speed, but other areas such as IoT, autonomous cars. These need to share one platform i.e. to allow for any participant, ISP, MNO to engage.
- Higher TRLs – considering the strength of the academic research, a key question is how do we transfer the science results into industry more effectively in this space, pushing towards higher, ready to be taken on by industry or new companies.
- Rural – The applicability of current business models to support rural deployment was questioned, with the release of the 700 MHz spectrum in 2019 seen as a test for the opportunity to consider changed or new business models.

USE CASES, OPPORTUNITIES AND BENEFITS OF 5G

There are a number of areas identified to benefit from the advent of 5G globally. This is a combination of the companies and a strong manufacturing base in the UK, as well as strong investment and a number of pre-5G trials and tests taking place that are expected to scale up to fully deployed solutions.

MANUFACTURING

- Although industrial usage of 4G has been limited, there is potential for much greater scale in Industrial IoT (IIoT) for 5G.
- Manufacturing applications that can benefit from cellular mobility, security and low latency include mobile robots within factories, remote control of factory and supply chain processes, test vehicles for automotive manufacturers, autonomous robots and small-scale vehicles and tracking across a supply chain, both nationally and internationally.
- Many UK manufacturers have looked at or invested in LTE-A and in LPWAN networks and say these provide around 80% of what is expected with 5G.
- Manufacturers are generally reluctant to upgrade legacy systems without a confirmed business case.
- The primary drivers for adoption of 5G and other digital technologies revolve around the ability to reduce operating costs, improve efficiency and increase outputs. Adoption of 5G-enabled technologies is likely to assist under an invest-to-save model for the manufacturing industry.

TRANSPORT

- The opportunity for 5G in public transport (specifically rail) lies largely in delivering low latency applications for vehicles, infotainment and increased automation.
- Successful connectivity to transport routes is dependent on additional spectrum and infrastructure. The key to unlocking 5G access for rail will be the deployment of a neutral host solution with access to either existing or new connectivity along the trackside, something that has already been tested in the Trans-Pennine testbed
- CAV use cases of 5G have great potential, especially in urban areas where road transport is a major challenge. The UK Government wants to become a leader in CAVs and has provided £100M with match funding from the industry until 2021.
- 5G is not the only enabler for CAV technology, and not all of the projects have an element of 5G associated with them, but it is widely accepted that 5G will assist in several CAV services and applications.
- This next generation of vehicles will require low latency, high volume transmission of data, with autonomous vehicles potentially creating terabytes of data every day.
- The growth and expansion of autonomous vehicles in the UK will require reliable provision of cellular data across the UK road networks.

HEALTHCARE

- Remote healthcare applications underpinned by 5G can enable the delivery of healthcare services at a lower cost.
- Assisted living solutions utilising 5G provide further benefits to those patients that could be cared for at home, e.g. dementia sufferers who currently constitute 25% of hospital in-patients.
- A DCMS 5G Testbeds & Trials Programme funded project taking place in Liverpool will look at the use of 5G in health and social care. The project will measure the impact on patient monitoring and support, management of loneliness in older adults, aid to independent living at home and the facilitation of communication between hospitals and the community.
- PillCam trials in the Scotland Broadband project demonstrated the need for high bandwidth connectivity to transfer data from GP surgeries to hospitals.

IMMERSIVE TECHNOLOGIES AND CREATIVE CONTENT

- Better and faster wireless connectivity will help encourage both enterprises and startups to undertake R&D for disruptive products and services in VR/AR.
- Data-driven automation in manufacturing technology is already happening. Together with advanced cloud computing services and ultra HD video technology, VR and AR are likely to disrupt multiple markets from manufacturing and logistics to healthcare and real estate.
- There is an active discussion of 5G/VR convergence when it comes to a mix of stakeholders, e.g. across MNOs, chip and device designers, large VR players like Facebook, and some vertical industries. These see AR/VR as a 'killer app' for 5G.
- Questions that still surround immersive in 5G include how MNOs will deploy ultra-low latency 5G networks and how will these networks be monetised, whether consumers will be willing to pay a premium and will hardware become affordable enough to enable mass consumer uptake.

HARDWARE

- It is worth noting that the UK does not have big chip manufacturer factories in the likes of Samsung, Intel, Qualcomm and Taiwan Semiconductor, but there are known strengths in chip design in the UK, e.g. ARM.
- Ten councils in the Cardiff Capital Region are developing a foundry for technology behind 5G in Newport, which could create about 2,000 high skilled jobs in five years. Funding of nearly £38m has been announced for a facility to make compound semiconductors. The factory will be owned by the councils and is projected to create £375m of private sector investment in the next five years.
- Edinburgh is a hub for semiconductor design giant Xilinx, the first R&D centre outside of North America. A recent investment of £6m from Xilinx and Scottish Enterprise has generated 12 new jobs and secured 30 existing, focusing on developing products for future communications systems.

LAUNCH PLATFORMS FOR 5G IN THE UK

- The UK will host a number of global sporting events in the next five years, including the 2019 Cricket World Cup, the 2019 world cycling championship, seven games of the 2020 UEFA European championship, the 2022 Commonwealth games. Much like the Olympic Winter Games in PyeongChang, where South Korea demonstrated the first steps towards 5G development and potential scenarios, each of the above events represent an opportunity for the UK to demonstrate its capabilities in 5G and could become major launch platforms for 5G in the UK.
- There is a recognised need to coordinate and proactively demonstrate to the world the advances enabled by government intervention in the 5G Testbeds and Trials, as well as the increased commercial activities, with targeted activities for developing both export opportunities, as well as inward investment.

1.

INTRODUCTION TO 5G

5G is the next generation of mobile communication technologies that, for the first time, is being designed purposefully to handle different classes of services, from traditional mobile broadband to large numbers of IoT devices or ultra-reliable low latency services.

5G incorporates new architectures both in radio access, system architectures and protocols that will enable new ways of integrating mobile communication and cloud services together. It aims to offer ultra-low latency and 10+ Gbps bandwidth. 5G is being designed to blend the requirements of previous communication technologies into a new mobile network architecture. This new architecture will be able to operate in multiple spectrum bands and will provide the following key features (although not simultaneously):

- Handle up to 1,000 times higher data volumes than what exists today.
- Support 10-100 times more connected devices than what exists today.
- Enable data rates of 10-100 times higher than current availability.
- Reduce latency by around five times that of 4G technology.
- Enable up to 10 year battery life for low power, machine-type devices.

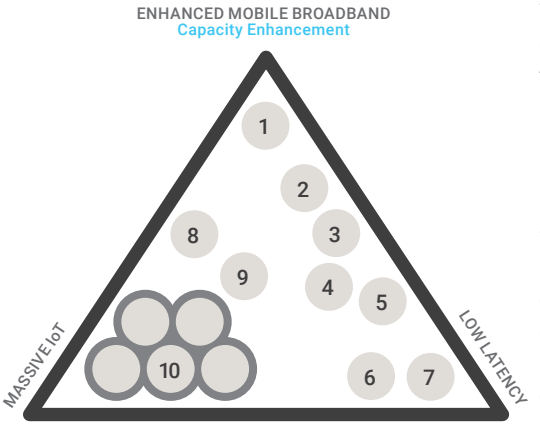
One of the key characteristics of 5G is the drive for more flexible network management through the use of network softwarisation approaches, like Network Function Virtualisation and Software Defined Networking. These ultimately enable a vision of a flexible network that can be modified to deliver on the needs of specific users (e.g. on the factory floor for training or large scale entertainment experiences using immersive technologies).

The use cases for 5G are grouped into three classes:

- Enhanced mobile broadband (eMBB) - Likely to be the first deployments of 5G technology, using 3-6 GHz spectrum, aiming to address the large growth in mobile devices and demand for data. eMBB aims to deliver streaming of 4K video, VR/AR content and immersive gaming.

- Massive machine-type communications (mMTC) - Utilising sub 1 GHz spectrum to deliver large scale machine to machine (M2M) communication and enable large scale IoT deployments and rollouts.

- Ultra-reliable and low latency communications (URLLC) - Driven by new use cases such as robotic surgeons and connected autonomous vehicles, URLLC will deliver ultra-fast mission critical connectivity, utilising the >20 GHz spectrum.



1. Gigabytes in a second
2. 3D Video - 4K Screens
3. Work & play in the cloud
4. Augmented reality
5. Industrial & vehicular automation
6. Mission critical broadband
7. Self Driving Cars
8. Smart city cameras
9. Voice
10. Sensor NW

The vision for 5G goes beyond the mobile communication technology platform, instead taking on an additional role as an innovation platform that provides the ability to bring new business models, products, services, applications and experiences to market faster. 5G also offers a clear opportunity to reconsider the approach we take to digital infrastructure. For instance, it not only enables operators to take advantage of market opportunities and dynamically meet changing consumer and business needs, but also opens up opportunities for existing and new operators to explore new models of delivery that meets specific industry needs. This is due to the fact that 5G offers a wider range of services and system configurations that were not possible through the system architectures of previous generations of mobile networks. In particular, there is a strong expectation that 5G will enable mobile communication services to move from being largely consumer-facing, to supporting digitalisation across the UK economy.

Figure 1
Likely 5G use cases in each class of the technology (source ETRI graphic, from ITU-R IMT 2020 requirements)

KEY FEATURES OF 5G AND THE VALUE ADDED TO WIRELESS SERVICES

Feature	Metric
Higher Throughput	Increases overall capacity to facilitate growth in users, devices and traffic demands.
Reduced latency	VoIP, streaming high quality video and other tasks that are latency critical.
Advanced management and OSS	Reduced operating expenses for operators and carriers.
High motion mobility	Ability to support users and devices on fast moving transport such as high-speed trains.
Improved security	Protection of large amounts of personal data produced with 5G.
New spectrum	Access to mmWave bands.
Enabling new technologies	Massive MIMO, small cells, improved power efficiencies etc.
Universal application support	Ability to provide connectivity for a range of use cases, from low volume, high latency to mission critical systems.

Table 1
Key features of 5G and the value added to wireless services

There are multiple key technology advances that will support delivery of the 5G features. These include:

- New radio air interfaces technology, to support the dense deployment of high-speed low-latency services.
- Improved utilisation of current frequency bands (up to 6 GHz) and exploitation of new frequencies in the centimetre/millimetre wave bands (above 6 GHz), to deliver the necessary capacity and coverage.
- Novel techniques for radio resource control, antennas, protocols and architecture, to improve spectrum utilisation, reduce latency and increase flexibility.
- New network core architectures for management and orchestration of the network services, towards a highly configurable virtualised networks with edge computing

5G will operate across a range of spectrum:

- Under 1 GHz, for rural coverage and deep coverage inside buildings;
- Core frequencies, from around 1 GHz to 6 GHz, for general coverage and capacity, with the higher frequencies used for hot-spots;
- High frequencies (>6 GHz, with plans in the 26-28 GHz or above), for high capacity in areas of dense usage e.g. in high density urban centres, campuses and transport hubs.
- Pioneer bands are specified in 700 Mhz, 3.5 GHz and 26 GHz.

Meeting the targets for 5G networks will require various new techniques to exploit the full potential of existing and new wireless technologies. There are diverse views on what might be needed. However, certain approaches are already appearing in the context of 4G systems and are likely to evolve into 5G over the coming years.

UK POSITION ON 5G

The UK Government is looking to position the country as a world leader in the development and deployment of 5G technology and has put in place a number of funding and research initiatives in order to support this vision. In 2012, the UK Government announced the establishment of a 5G Innovation Centre at the University of Surrey, the world's first research centre set up specifically for 5G mobile research. The centre supports 13 research groups as well as partners across startups, SMEs, universities, research centres and local and national government.

In Autumn Statement 2016, it was announced that £1bn would be invested in full-fibre broadband and trialling 5G networks by 2020-21. The initial investment of £16m from the 5G Testbeds and Trials Programme was made to the 5GUK University Test Network, shared among University of Surrey, University of Bristol and King's College London

The 2017 Autumn Budget announced the allocation of £160m to the 5G Testbeds and Trials Programme. This includes £10m that will be used to create facilities where the security of networks can be tested and proven, working with the National Cyber Security Service. There are plans to improve rail networks to support 5G, by further developing track side infrastructure across mainline routes. These trials will build on learnings from project SWIFT (Superfast Wi-Fi In-carriage for Future Travel), a technical trial delivered by CISCO, Network Rail and Innovate UK, which will provide Wi-Fi on the route between Glasgow and Edinburgh.

The 5G Innovation Network (UK5G) was launched in 2018 with funding from DCMS. The UK5G consortium, led by Cambridge Wireless and in partnership with the Knowledge Transfer Network and TM Forum, works with, but independently from government, to boost the UK 5G ecosystem in a number of ways:

- Facilitate the coordination and engagement of organisations working on 5G activities in the UK.
- Create and maintain an accessible and up-to-date source of information about 5G activities for industry.
- Establish a global marketing brand as part of a strategy to encourage inward investment and participation in 5G activities in the UK.

In October 2017, the UK Government's DCMS announced the 5G Testbed and Trials Programme, to deliver projects in phases, starting with an initial Phase 1 competition for funding of up to £25m, announced on 16 October 2017. The projects that make up this programme will be funded for delivery between April 2018 and April 2019 and will focus on new and innovative aspects of 5G in order to stimulate the development of 5G use cases and business models. The government has published briefing and guidance documents to support potential applicants to this competition, which set out the funding available for individual projects along with eligibility criteria and timings. As with the investment in the UK5G project, the aim of this competition is to support the development of a 5G ecosystem in the UK and contribute towards the delivery of the objectives in the UK's 5G strategy.

Through the 5G Testbeds and Trials Programme, the government aims to establish the conditions under which 5G can be deployed in a timely way to drive efficiency and productivity and foster the development of the UK's 5G ecosystem to ensure that the UK and its businesses are well placed to maximise the efficiency and productivity benefits of 5G. The programme is a fundamental part of the government's 5G strategy. It will stimulate trials involving many different potential 5G use cases, such as those faced in health and social care, and will also fund deployment and technical projects that will help to address some of the practical and economic challenges surrounding 5G network deployment.

At the end of March 2018, the UK Government's DCMS announced an Expression of Interest from public sector authorities who wish to take a key role in the delivery of an Urban Connected Communities (UCC) project based on a large scale city area in the UK. The purpose of the UCC project is to use the latest mobile technologies to meet people's connectivity needs, trialling new 5G services and applications to individuals and businesses - with the aim of improving the quality of urban life and supporting local economic development.

The government has an ambition to extend mobile coverage to 95% of the UK as well as deliver full and uninterrupted mobile communications on all major roads by 2022 and to achieve 5G coverage wherever people live work and travel as soon as possible, and no later than 2025 . Meeting the 5G network targets will require various new techniques to exploit the full potential of existing and new wireless technologies. There are diverse views on what might be needed. However, certain approaches are already appearing in the context of 4G systems and are likely to evolve into 5G over the coming years.

The complexity and the risk are high, however the ability to utilise the network differently will drive new commercial applications and business cases.

Potential applications of 5G

There are a large number of potential use cases that can be enabled with 5G beyond today's existing mobile communication infrastructure.

5G is seen as a crucial innovation enabler. Whilst there are a large number of potential use cases that can be enabled with 5G beyond today's existing mobile communication infrastructure, the most important aspect of 5G as a next generation infrastructure technology is in how it will change things for the better, and increase productivity. Most often these effects will be results of combination of technologies, some of which will not be 5G - but 5G enables the start of that road.

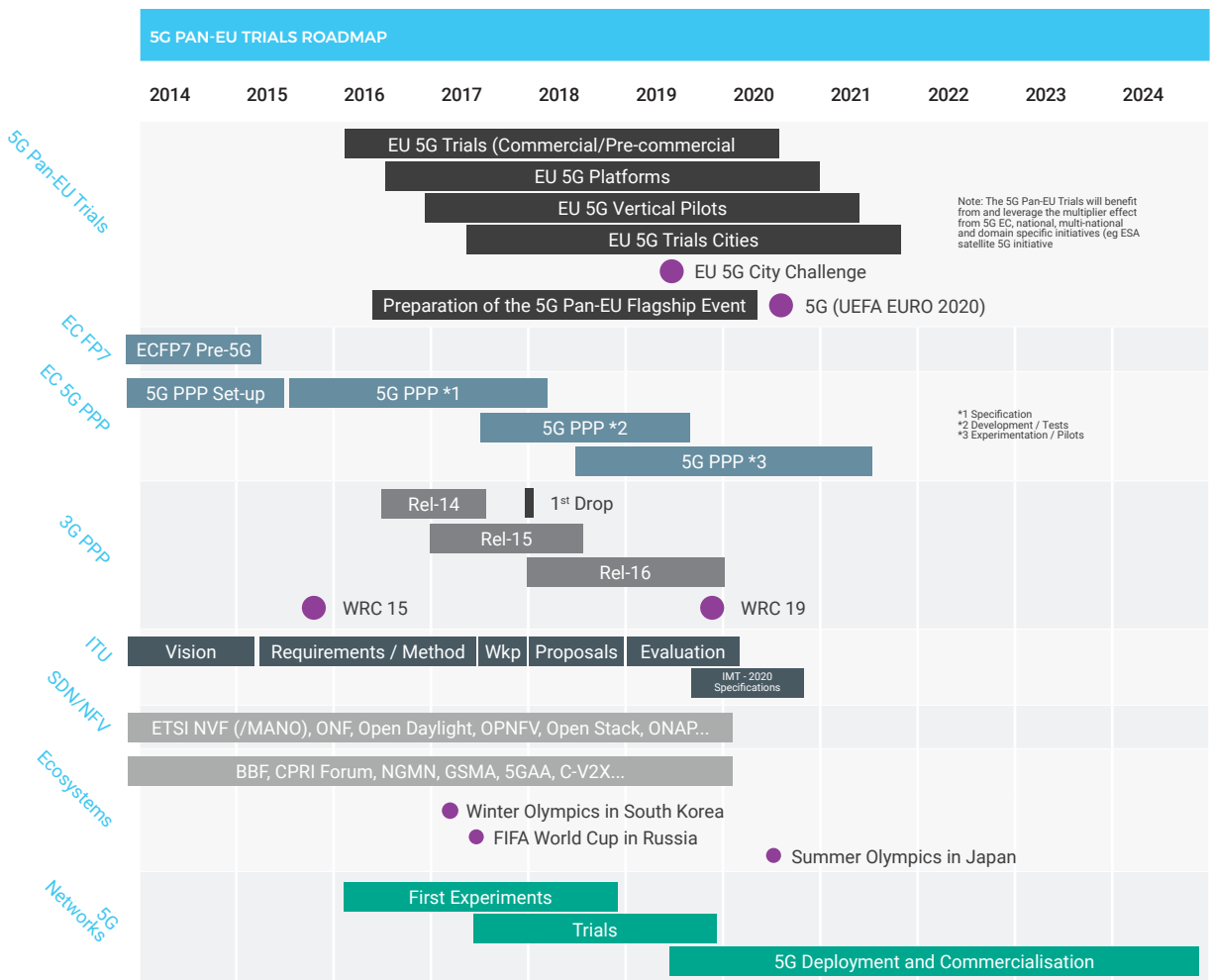
This has led to non-telecom players moving into the 5G space, including Google, Facebook, Apple, Hitachi, Scania and Comau. There are a varied range of use cases and applications for various aspects of 5G.

TIMELINE FOR 5G

The announcement and standardisation of 5G is administered by the 3rd Generation Partnership Project (3GPP), an alliance of more than six thousand member organisations. The standardisation of 5G in 3GPP Releases 15 (December 2017) and 16 (December 2019). In December 2017, 3GPP announced, in Release 15, an initial set of 5G standards, primarily focused on targeted use cases, frequency ranges and architecture configurations.

There are two phases of 5G standardisation:

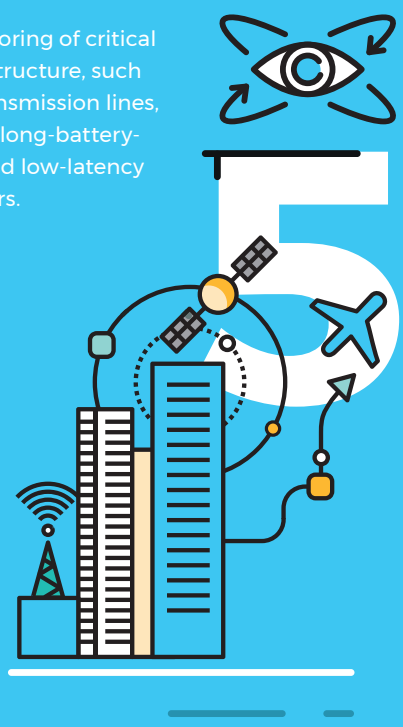
- Phase 1 to be completed by Sep 2018/Rel-15 to address a more urgent subset of the commercial needs (to be agreed).
- Phase 2 to be completed by Mar 2020/Rel-16 for the IMT 2020 submission and to address all identified use cases & requirements.

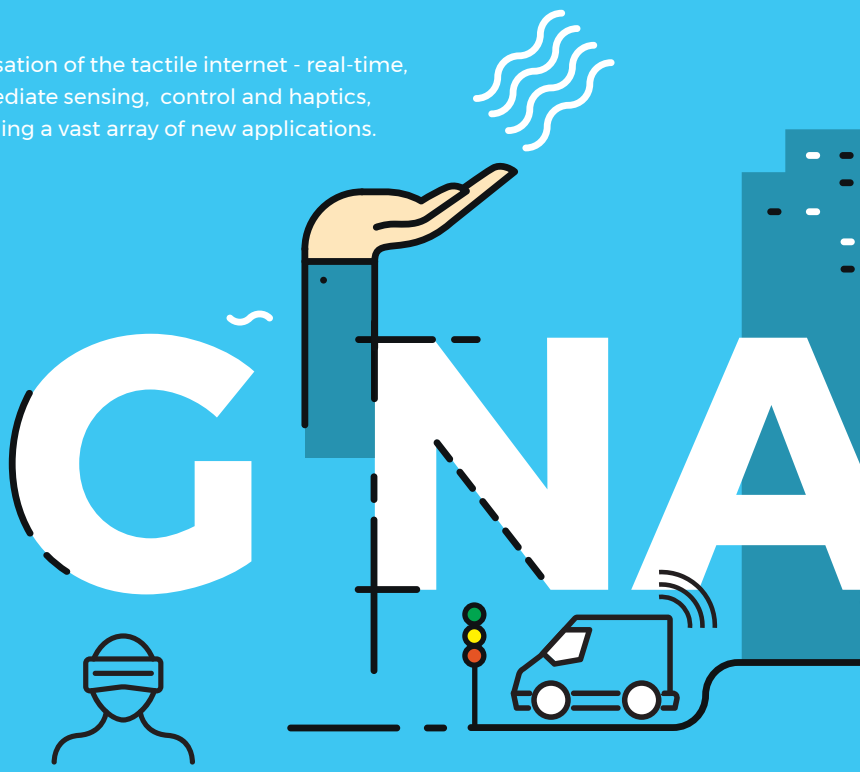


POTENTIAL 5G USE CASES

Realisation of the tactile internet - real-time, immediate sensing, control and haptics, enabling a vast array of new applications.

Monitoring of critical infrastructure, such as transmission lines, using long-battery-life and low-latency sensors.





Augmented and immersive virtual reality. Ultra-high-fidelity virtual reality can consume 50 times the bandwidth of a high-definition video stream.

Smart transportation using data from vehicles, road sensors, and cameras to optimise traffic flow.

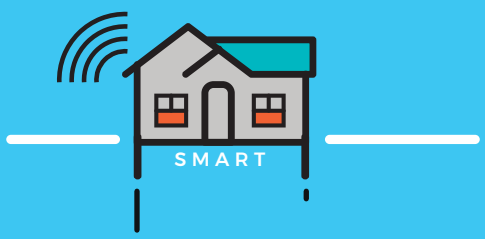
Public safety, including broadband data and mission-critical voice.

Mobile health and telemedicine systems that rely on ready availability of high-resolution and detailed medical records, imaging, and diagnostic video.

Sports and fitness enhancement through biometric sensing, real-time monitoring, and data analysis.

Automotive, including autonomous vehicles, driver-assistance systems, vehicular internet, infotainment, inter-vehicle information exchange, and vehicle pre-crash sensing and mitigation.

Ultra-high-definition video, such as 4K and 8K, and 3D.



SCOPE OF THE REPORT

This report focuses on presenting a summary of the current activities in academia, local government and industry around 5G developments in the UK. Its aim is to provide a snapshot of the current state of the UK 5G ecosystem, activities, views, expectation and capabilities through extensive outreach to companies, academia, local government and other organisations either actively involved in work on development of 5G technology solutions or strategically looking at the opportunities the introduction of 5G represents for their organisations and, more broadly, the UK. More specifically, the report aims:

- To identify and provide a directory of projects and other activities relevant to 5G by academia, industry and local government (including LEPs).
- To outline demand (pull) for 5G technology based on current and future planned projects form the study results that will facilitate 5G adoption and Digital Economic expansion in the UK.
- To provide a summary of insights and views from Academia, Industry and Local government on their experience and expected impact of 5G and its requirements.

As an output, we have brought together a view of the UK 5G Ecosystem which will support innovation activities within it. The map can be used to increase awareness of the specific activities across the UK, to better link opportunities with the existing, or growing, resources and capabilities across the UK.

The study brings out the ecosystem views as to how different consumer groups will likely generate demand (pull) for the technology, as compared to the typical push of previous mobile generations, as the success of 5G will depend to a very large extent on its ability to be usefully adopted by vertical industries. These studies leveraged the cross-Catapult network on 5G, to link the 5G opportunities into all the industrial sectors covered by the group members of the Catapult Network.

Our methodology for the report has been to:

- Leverage existing market research but also undertaking or commissioning new research for ongoing gap analysis.
- Create a capability research landscape view through interviews with key stakeholders in academia and both large and small industry.
- Conduct focused studies in several localities with specific industries of interest, through open consultations and workshops in different UK locations.

Furthermore, the report has been based against evidence extracted from research, studies, workshops and interviews to provide input to Innovate UK and the rest of the government (and DCMS in particular, and directly) on the status of the UK 5G ecosystem. This will enable efficient and effective funding interventions and policy decisions on the 5G-related activities, helping to deliver against the ambitions expressed in the UK 5G Strategy.

METHODOLOGY

This study was completed with a combination of desk and primary research. Consisting of interviews with key players from academia, industry and local governments. Interviews were a mix of face-to-face and telephone conversations detailing key features of 5G and how organisations hoped to deploy or utilise the technology. These interactions built up a view of:

- The opportunity for 5G in the UK.
- The technological readiness of 5G solutions applicable to potential use cases in the UK.
- Barriers to deployment of 5G networks in the UK.

All research was undertaken to capture in an evidence-based manner, key themes affecting the development and opportunity of 5G in the UK.

Six studies were commissioned as part of the UK 5G ecosystem mapping project. As part of each study, an independent, UK based, contractor undertook a study based on either the role of 5G in a particular geographic locality or industry vertical and also undertook a workshop that had a focus on the studies area, inviting stakeholders to discuss the future of 5G in the region or industry.

Over the course of the study, interactions were undertaken with 117 different organisations.

An online survey was distributed to key players across the 5G value chain. The first part of the survey consisted of key questions on the future of 5G and barriers to deployment and adoption. The second part of the survey was dependant on the type of organisation that the reader represented, industrial, academic or local government. The results of the survey analysis are represented across this report.

Table 2
Details of studies conducted as part of the UK 5G mapping report

DETAILS OF STUDIES CONDUCTED AS PART OF THE UK 5G MAPPING REPORT

Study Focus	Organisation	Workshop Date	Workshop Location
Transport	LS Telecom		
AR/VR & Digital Manufacturing	Real Wireless	07/03/18	London
Satellite Applications	Satellite Applications Catapult	08/03/18	Didcot
Greater Manchester	Arup	16/02/18	Manchester
Scotland	Oxido	19/02/18	Glasgow
Wales	Innovation Point	20/02/18	Cardiff

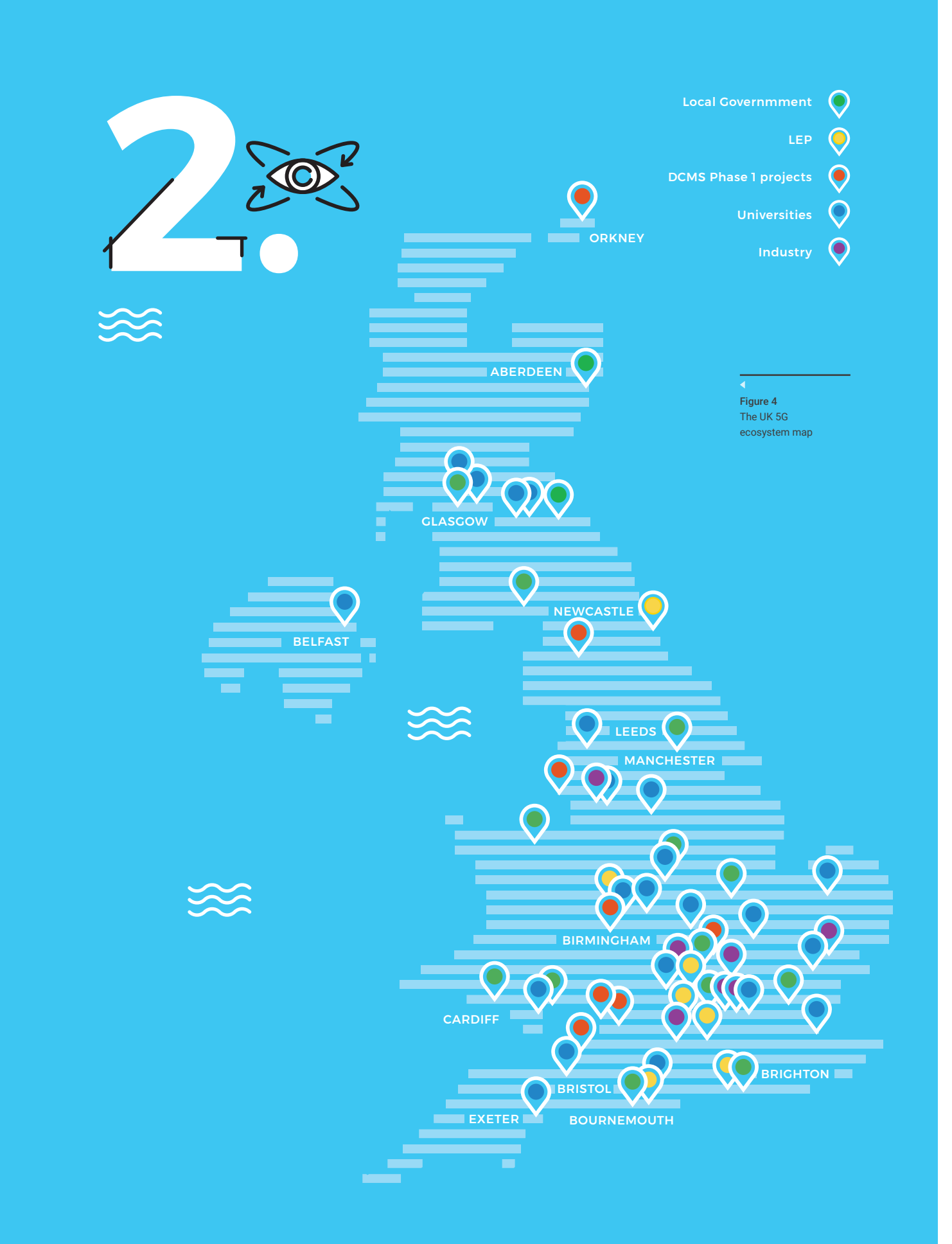


Figure 4
The UK 5G ecosystem map

THE UK 5G ECOSYSTEM

There is no single definition of what constitutes an ecosystem. The Oxford Dictionary defines the ecosystem as "a complex network or interconnected system", and indeed, the UK 5G ecosystem is both complex and interconnected.

It comprises, from one side, the technology providers such as the academia, network operators (mobile, fixed, public), vendors (equipment/software), service providers etc. The other side is represented by the users of that technology, and includes citizens/consumers, private enterprises and the public sector (local and central government). The interconnection is enabled by programmes such as the UK Government's DCMS Testbeds and Trials Programme, public private partnerships such as 3G-PPP and 5G-PPP, industry forums and standards development organisations.

The UK 5G ecosystem is gaining momentum, is highly interconnected, and can be classed as strong. It is composed of a wide and diverse range of entities, from private sector companies, academic/research organisations, and public-sector bodies. This ecosystem is growing around core stakeholders and players, with standalone testbeds and trials taking place, largely in-line with other leading countries' efforts in 5G.

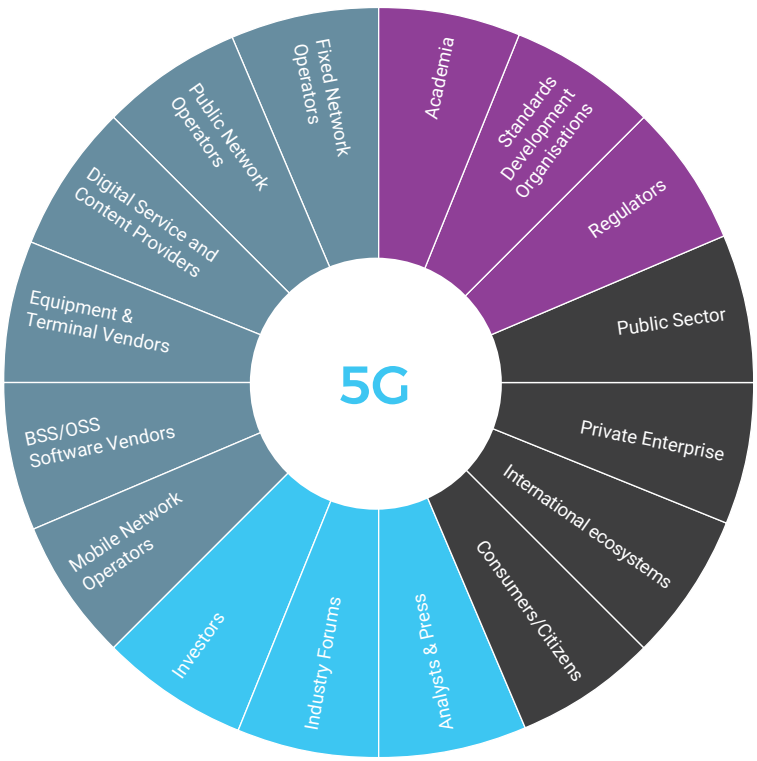


Figure 5
The UK 5G ecosystem (Infographic adapted from DCMS)

The UK's wireless and networking research has been world leading. In establishing the Global System for Mobile Communications (GSM) as the 2G standard for mobile communications, input from UK industry, academia and government has been crucial, with continuing contributions in 3G and 4G. Whilst UK academic research in wireless and networking systems has continued to be strong and broad in its focus, there has been a noticeable reduction in UK industrial R&D. This has been associated and to some extent compensated, by university research groups and institutes being positioned strategically, to take up higher Technology Readiness Levels (TRL) R&D activities and supported by public and industry funding. Some successful examples of this are; the establishment of the 5G Innovation Centre at University of Surrey; the "Bristol Is Open" smart city platform built on advanced networking technology coming out of University of Bristol; or the King's College London Ericsson 5G Lab. At the same time, a number of very small agile high-technology companies have been established over the past 10-15 years, who are leveraging the existence of a highly skilled workforce being made available due to industry changes in the UK.

The DCMS led 5G Test and Trials Programme is working with industry, the public sector, regulators and standards bodies, academia and organisations leading overseas trade to promote the development of a strong pipeline of 5G trials across a range of sectors within the UK. This pipeline will be a key element in driving the 5G ecosystem in the UK and will help to establish the conditions under which 5G can be deployed in a timely way, ultimately developing the UK into a 5G leader.

These projects and activities span the entire mobile ecosystem, including hardware design, backhaul infrastructure and full testbeds and trials.

39

Academic Institutions

29

Local Authorities

57

Companies

Geographical Spread

Figure 4 shows the geographical distribution of projects across the UK. The figure shows (i) academic projects, (ii) local government activities, and (iii) industry activities. A high number of projects take place in London and the South East, with places often related to key players in the ecosystem. London's size, infrastructure and the number of businesses operating in these technology areas make the capital an attractive proposition. With an added benefit of large corporates being based in the city, there are clear opportunities to build partnerships between academia and SMEs looking to innovate and offer 5G solutions.

It is important to note that details around industry specific projects are not always made public, due to commercial sensitivities and time/delivery constraints. As such, funding figures are also often hard to determine. Despite this, it is still possible to identify a number of 5G related activities taking place regionally. As you can see from Figure 4, the strongest concentration of projects are situated in the south and south east, with academic research and the resources offered by these institutions being key factors for the high density of projects and SMEs. This is shown by the volume of projects that have partnered with the University of Surrey, University of Bristol and King's College London. On the other hand, there is a need to leverage existing 5G activities in the north and south west, as these areas have not had as much active engagement between industry partners and academia to the same level as other parts of the country.

5G strategies and activities in England

5G represents a key part of local digital strategies in a number of regions in England. For example, in Greater Manchester, although the 5G work is not divided into or assigned to specific projects (besides Salford University), it has milestones and plans in place to attract companies to innovate and offer solutions, fostering an environment that will offer growth. On the other hand, Leeds

City Council has recognised the opportunity 5G represents through their plans to become a pilot city for 5G and by working with GSMA members to drive new use cases. Through established relationships with the three major universities, the Leeds Teaching Hospital NHS Trust, the Leeds City Centre Data Hub (which was provided by AQL) and the IX Leeds Internet Exchange Point, Leeds is attracting innovation offering solutions around healthcare, transport, air quality healthcare, transport, air quality and assisted living .

5G strategies and activities in Wales

There are fewer projects taking place in Wales compared to England. This can be explained by Welsh projects being tied in with a national strategy and being associated with longer term plans. For example, Swansea's Bay City deal will see £1.3bn of investment in South Wales for the area to ensure for interventions to support economic growth. The local partnership will investigate how investment in 5G technology and applications through the City Deal could support projects within the area, like the Smart Bandage project led by University of Swansea, which uses real-time 5G technology to monitor how a wound is healing and help doctors keep track of patients' activity levels. Testbeds and infrastructure projects take up the majority of the local councils strategy focus in Wales, as a specific technology focus (e.g. VR/AR) would not benefit them as broadly and help the area grow.

Wales is widely considered to be a global leader in compound semiconductor manufacturing. With gallium nitride semi-conductor based chips and modules expected to play a key role in the billions of 5G enabled devices, there is a huge export opportunity for the Welsh economy. Indeed, Cardiff has a national Compound Semiconductor Centre, and South Wales is home to several key manufacturers of the technology including IQE, Newport Wafer Fab and National Instruments. Furthermore, 10 Welsh councils have come together to build a facility in Newport for £38m that develops compound semiconductors .

Testbeds can be created in a number of regions in Wales, as opportunities to apply innovations exist in most major cities. However, through our research it was also highlighted that less well known locations in Wales, despite them also developing innovative products, applications and services, may face barriers in terms of exposure and recognition if Wales' 5G strategy only incorporates larger cities such as Cardiff, Swansea and Newport.

5G strategies and activities in Scotland

There is scope to deploy 5G testbeds in Wales as opportunities to apply innovations also exist outside of major cities, which was highlighted with the local councils in Wales through the regional studies. Through our research it was highlighted that these locations could operate testbeds, but despite them also developing innovative products, applications and services, they may face barriers in terms of exposure and recognition being less well known locations in Wales.

Scottish projects generally come in the form of corporate partnerships with a focus on infrastructure, city wide testbeds and Smart Campus projects. These collaborations are making use of strong relationships with universities in Scotland such as Glasgow and Strathclyde, who also provide an attractive use case and application for testing the technology. This is where the opportunities lie in adding to infrastructure development. Local council initiatives would require a stable infrastructure before any innovation programmes or strategies can commence, unless a focus is given to R&D innovations.

Scotland also has a focus on creating better coverage as there are a number of rural areas that suffer from poor network availability. Projects such as 5G RuralFirst offer the opportunity to build a business case for 5G. Edinburgh has a strategy in place to implement infrastructure that better connects the area with the City Fibre Wi-Fi Network project, which the local council is delivering in partnership with InTechnology, deploying 260 access points around the city, with the technology being 5G ready.

Academic research in 5G

Our universities are a British success story: world-renowned, internationally competitive and a major economic asset, they generate annual output of £73bn for the British economy and contribute 2.8% of UK GDP. Universities generate over 750,000 jobs and around £11bn of export earnings for the UK annually. It is unsurprising then that their contribution to 5G development is a cornerstone of the 5G ecosystem in the UK.

This study has identified 135 5G-relevant active projects in the UK in the past five years, with 39 UK higher education institutions leading or participating. These projects cover over 30 different project classifications focusing on all areas of the 5G ecosystem (full profiles of all projects can be found in appendix B). UK Research and Innovation (UKRI) incorporates research councils that provide grants in six areas and one that that supports facilities (Research England), formerly known as Higher Education Funding Council for England (HEFCE), as well as an innovation agency (Innovate UK). Engineering and Physical Sciences (EPSRC) is the council funding 5G related activities. The largest provider of funding for these projects is the Engineering and Physical Sciences Research Council (EPSRC), which funds 47% of the projects, and the European Commission, which funds 38% of the projects through Horizon 2020's 5G-PPP (21%) and other Horizon 2020 or FP7 funding streams (17%). Other significant providers of funding are Innovate UK and DCMS, which fund a combined 9%. It is important to note that this list of identified projects is not completely exhaustive. Although those identified were verified through the interviews and the surveys we have conducted, we understand that this for now only constitutes a snapshot of the activities and will add to this list in the future.

Figure 6
Funding sources for UK based 5G Academic Projects

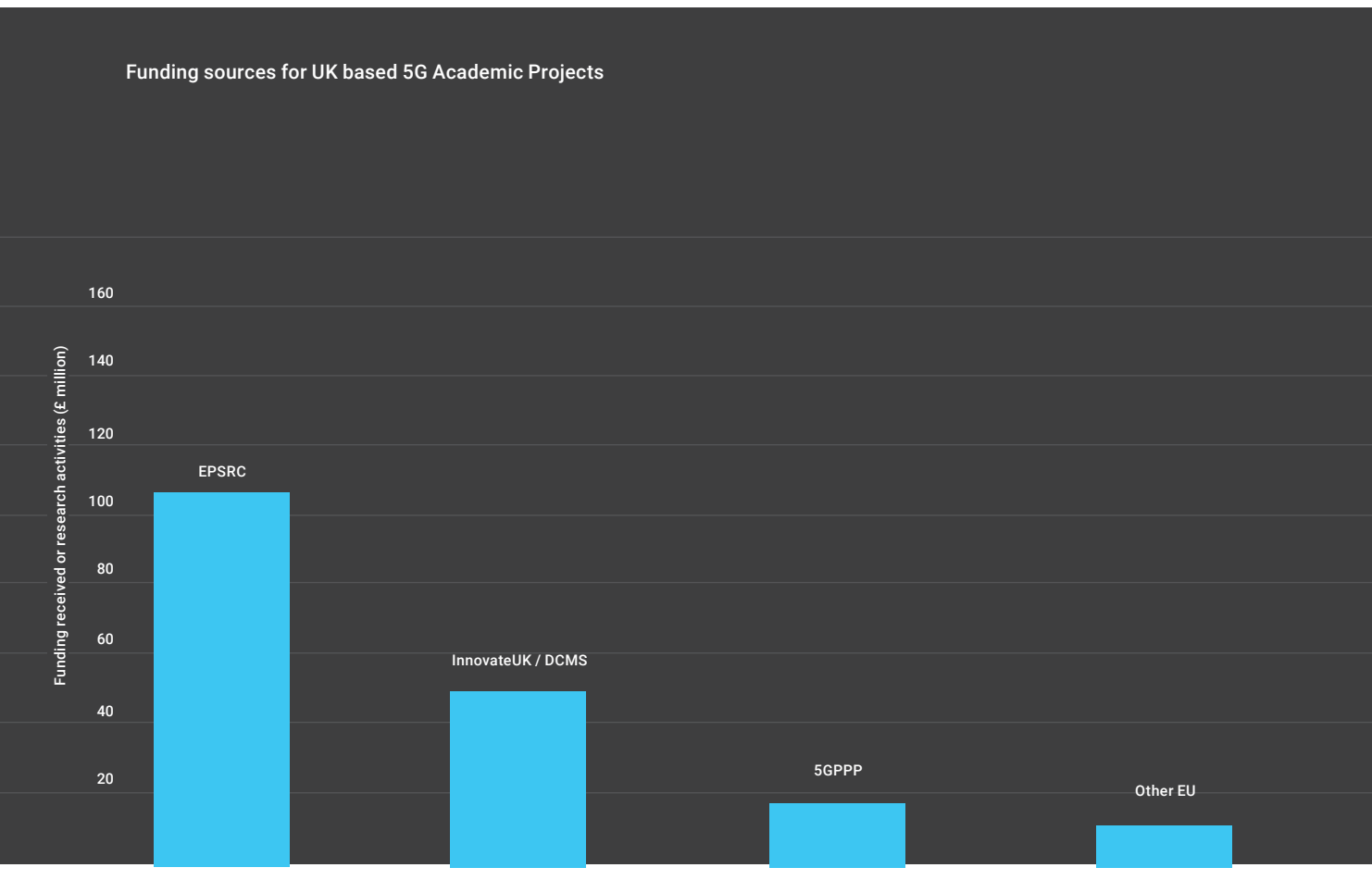


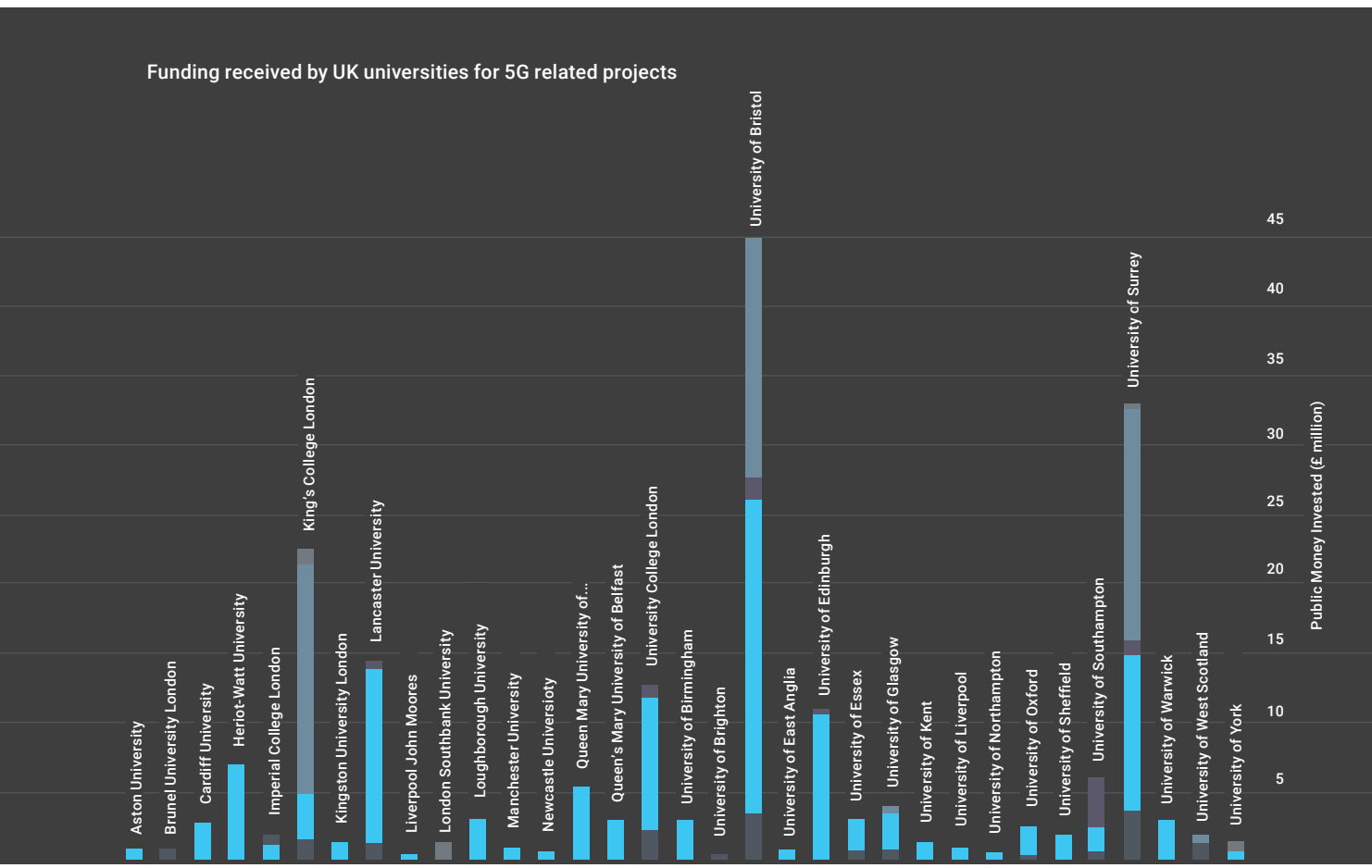
Table 3
Funding for academic research projects provided by the Engineering and Physical Science Research Council (EPSRC)

FUNDING FOR ACADEMIC RESEARCH PROJECTS PROVIDED BY THE ENGINEERING AND PHYSICAL SCIENCE RESEARCH COUNCIL (EPSRC)

Research Area	Total Grants (not only 5G)	Proportional value	% of EPSRC portfolio
Digital Signal Processing	66	£24,537,190	0.5%
ICT Networks & Distributed Systems	122	£47,209,902	0.96%
RF & MW Communications	63	£21,230,319	0.43%
RF & Microwave Devices	61	£18,849,343	0.38%
Pervasive and Ubiquitous Computing	72	£18,995,467	0.38%
Optical Communications	34	£19,557,372	0.4%
Optoelectronic Devices and Circuits	82	£52,975,761	1.07%

EPSRC supports excellent, long-term research and high-quality postgraduate training. At any one-time, EPSRC is supporting a portfolio of research and training valued at between £3bn to £4bn. EPSRC research grants are classified in 111 areas, out of which 28 fall under and total 53 (to a greater or lesser extend) have received funding from the ICT theme. Seven of those areas are closely related to 5G, with a focus on increased collaboration with researchers working in application domains so that others may well benefit from the technology. These seven areas include; Digital Signal Processing, ICT Networks & Distributed Systems, RF & Microwave Communications, RF & Microwave Devices, Pervasive and Ubiquitous Computing, Optical Communications and Optoelectronic Devices and Circuits. The current EPSRC portfolio for these seven areas is reflected in Table 3 below. During this research, we were able to identify 63 grants

Figure 7
Funding received by UK universities for 5G related projects



with a total fund value of over £106m, which have a clear and direct 5G relation. A complete list with descriptions is included in Appendix B.

There are a total of 50 EU-funded projects identified with a clear and direct 5G relation that have raised nearly £25m in funding for UK academia. It is worth noting that out of the 40 5G-PPP projects in phase one and two, the UK has participated in all but two of them, either with academia or industry. The UK Government has confirmed that Horizon 2020 research funding granted before we leave the EU will be guaranteed.

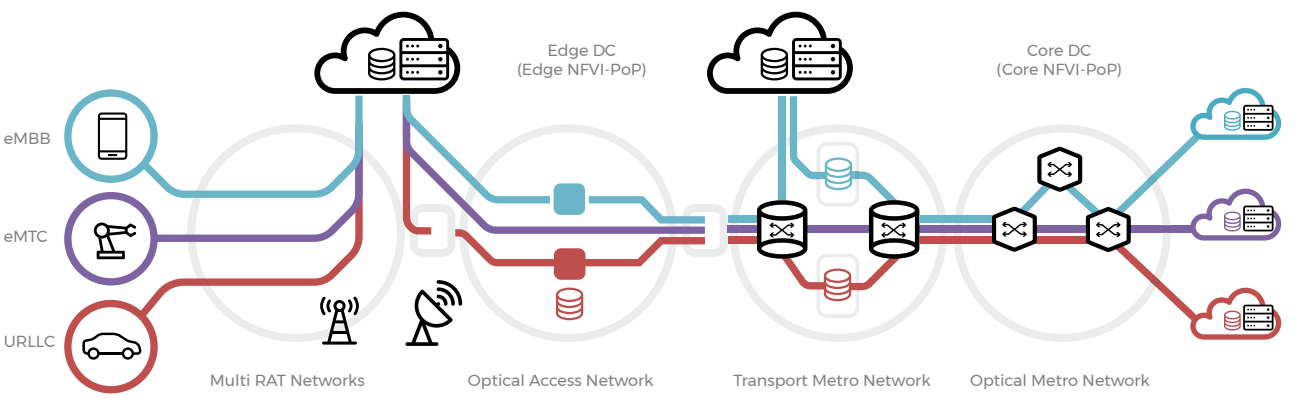
A summary break-down of the funding that academic institutions have received is presented in figure 5. It is evident that the majority of the funding we have identified is related to EPSRC grants, with a strong industrial (including Innovate UK and DCMS funding) aspect.

It is worth noting that both for EPSRC and EU projects, the industrial match funding was not clear and possible to capture. Other significant funding for capital expenditure for facilities and labs, like the HEFCE and industrial funding for the establishment of 5GIC totaling £35m, could not be collected and verified across all institutions, which would change significantly the funding profile in Figure 7.

Looking at 5G as a complete system, different projects and research groups will focus on different areas, from fundamental work underpinning specific technology blocks to end-to-end system architectures, protocols, solutions and their testing. In order to analyse the activities in terms of their focus areas we have devised a classification set comprising more than 30 terms.

The selected terms are collected from key technology enablers associated with 5G networks. e.g. Software Defined Networks (SDN), Network Function Virtualisation (NFV), Multi-access/Mobile Edge Computing (MEC), or components of a mobile network in access and core network. e.g. Antenna, Evolved Packet Core (EPC), system integration/validation, security. We are also capturing the key verticals and use cases where 5G is expected to have impact. e.g. automotive, eHealth, Industry 4.0, media, smart cities (including energy) and the corresponding business models. Colour coding of these terms reflects the area of the mobile network where these terms are more likely to be associated with; i.e. green is the Radio Access Network, orange is the edge and core network, blue is the transport/ backhaul and white is transversal.

Figure 8
5G ecosystem



EPSRC funded projects are investigating more fundamental aspects of the communication stack, generally focusing on the radio side, which aligns with the research areas mentioned above. On the other hand, European projects are looking into more quality of experience, virtualisation and system integration aspects. Interestingly, Software Defined Networking (SDN), which is the link to converged networks (wireless, wired, optical), scores in the top five for both lists.

TOP 5 CLASSIFICATION TERMS USED BY EPSRC AND EU IN RELATION TO 5G

All Projects	EPSRC	EU
SDN	Baseband/ Signal processing	NFV
NFV	Radio Front-end / RF	SDN
Heterogeneous Networks	Antenna	Network Slicing
Baseband/Signal Processing	Massive/ MU-MIMO	QoS/QoE
MEC (Mobile Edge Computing)	SDN	System Integration/ Validation/ Simulation

Table 4
Classification terms used by EPSRC and EU in relation to 5G

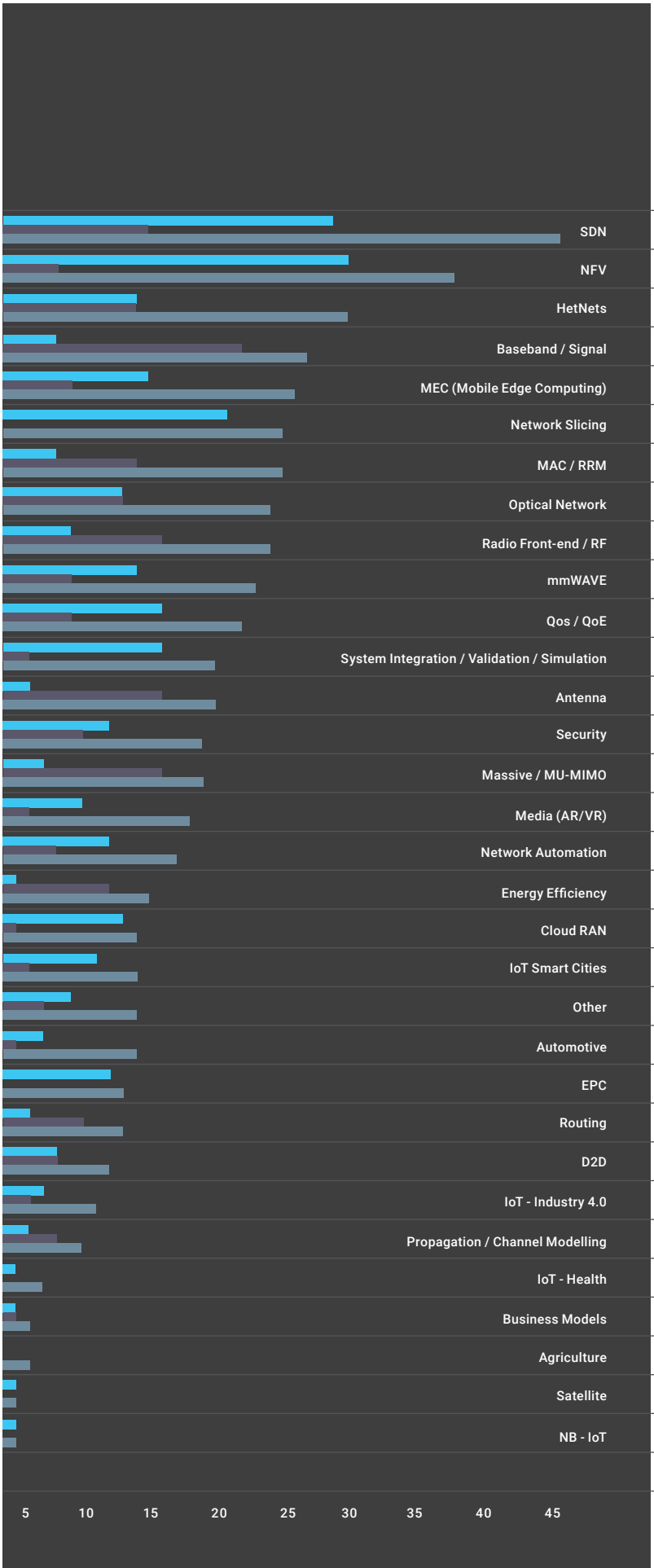
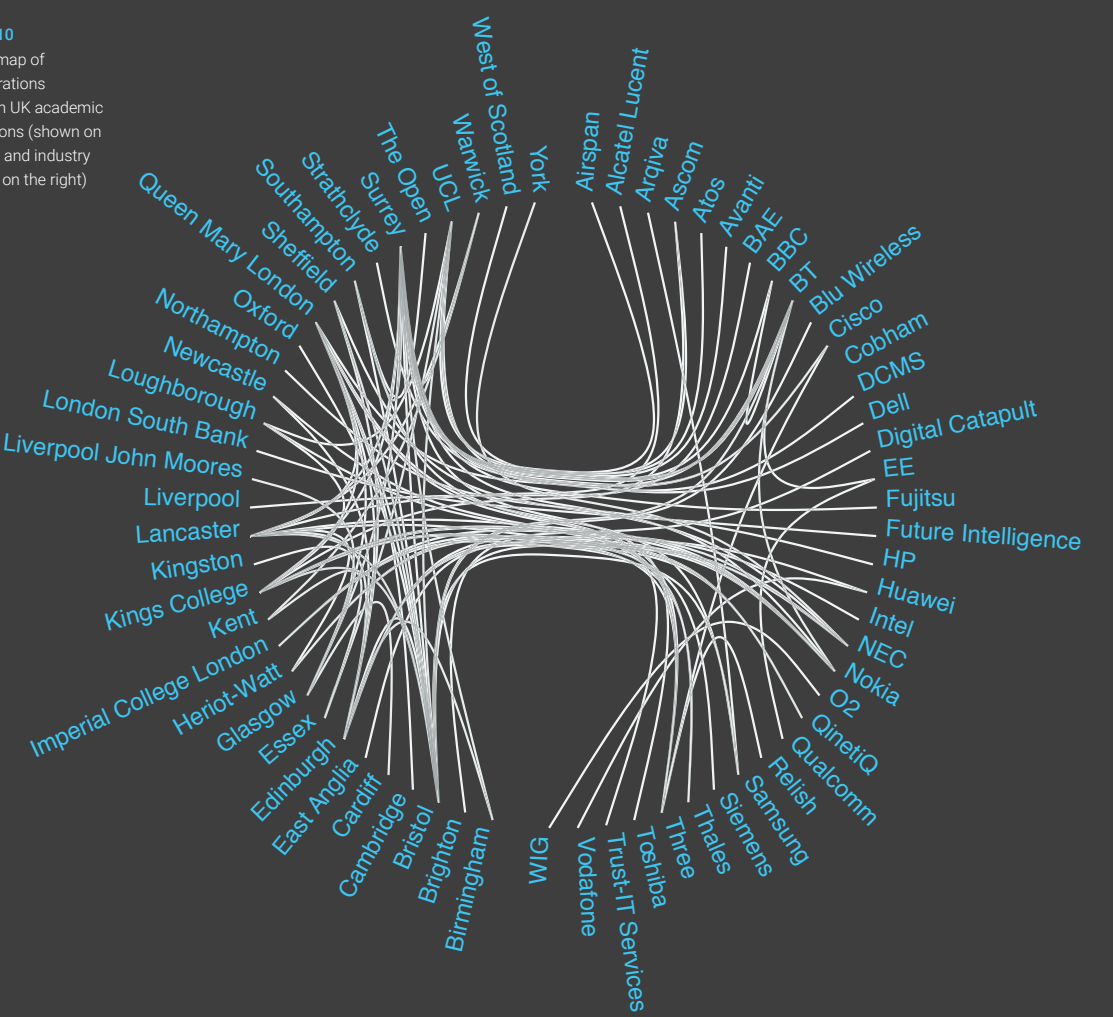


Figure 9
Classification of UK based 5G academic research

The data shows that the 5G UK ecosystem is very connected, both within academia and between industry and academia. There is significant inter-university and industry collaboration across the UK 5G ecosystem with an average of three UK partners per project. The interconnections graph in figure 10 exemplifies this. What is coming out of this are some concentrations of links around key institutions both academic and industrial, like University of Bristol, University of Surrey, King's College London, UCL, University of Oxford, Lancaster and Edinburgh, and on the other side Thales, Interdigital, BT, Samsung, NEC and Nokia.

The current largest and most well-funded single academic project focusing on 5G is the 5GUK project, a collaboration between the University of Surrey with University of Bristol and King's College London. The project received £16m in funding from DCMS for the period April 2017 March 2018, and has developed a unique national asset to be used for testing technical issues and

Figure 10
Spider map of collaborations between UK academic institutions (shown on the left) and industry (shown on the right)



trialling new applications, ensuring that the UK is at the cutting-edge of 5G developments internationally. This asset is available for use by other projects including future trials supported by the 5G Testbeds and Trials Programme. To realise this vision, the project is collectively developing a 5G UK Exchange capability in order to facilitate interoperation and collaboration between these initial test networks and support future 5G projects in the UK to help develop the 5G ecosystem.

Each university brings specialist knowledge and capability. In particular:

- The University of Surrey's 5G Innovation Centre (5GIC) is leading the project and is developing 5G radio technologies (mobile broadband and ultra-low latency) and a fully virtualised, software defined 5G/4G mobile core network with network slicing based on flat distributed cloud architecture.
- University of Bristol's Smart Internet Lab is deploying 5G capability in the extensive Smart City and Smart Campus testbeds in the city of Bristol, with an emphasis on fixed-mobile convergence and Software Defined Network technologies including end-to-end service orchestration and slicing.
- King's College London is focusing on ultra-low latency, ultra-broadband and IoT 5G developments and is also pioneering several important 5G co-design approaches with various industries, including smart cities, smart transport, performing arts and health.

5G Innovation Centre (5GIC)

The 5G Innovation Centre (5GIC) at the University of Surrey is a world leading research centre in 5G development and testing. The 5GIC was opened in 2015 through a combination of public, industry and University of Surrey funding. In addition to the Higher Education Funding Council for England (HEFCE) provided £12m funding for the Centre, with an additional £68m co-investment from the Centre's industry and regional partners, including the EM3 Local Enterprise Partnership. The Centre currently carries out its work within the framework of seven key work areas, each of which is led by a dedicated research team working in partnership with industry partners.

These areas include:

- Content and user
- New air-interface
- Light MAC and RRM
- Multi-cell joint processing
- Antennas and propagation
- System architecture co-existence
- Testbed proof-of-concepts

These research projects are supported by the Centre's live outdoor and indoor testbed, which enables researchers and industry partners to test technologies in a real situation. The 5GIC testbed covers 1km around the University of Surrey campus, consisting of three macro cells and 56 small cells, with a combination of LTE and 5GNR, and a dedicated sliceable and virtualised core network. The Centre is connected to MNO Network Operation Centres (NOCs), and also to the 5GExchange in Slough. The centre has a partner network of 73 organisations formed from government, academia and industry in the UK as well as international partnerships with the South Korean Government's Institute for Information and Communications Technology Promotion. Not all MNOs are working directly with the University of Surrey 5GIC, but they are still inputting into 5GIC.

The University of Bristol 5G Testbed

The University of Bristol 5G Testbed is deployed in Bristol's Millennium Square public precinct, and it is connected to the fibre infrastructure of Bristol is Open (BiO) smart city testbed. It is designed to allow experimental access to a 5G testbed comprising; SDN enabled optical network, SDN enabled packet swtiched network, 3GPP wireless networks including 4G and 5G NR, non 3GPP wireless networks including mm-wave and Wi-Fi, as well as Mobile Edge Computing (MEC) resources at the edge and a data centre to host virtualized network functions.

Each technology domain in the testbed is controlled by its own SDN enabled controller, and orchestrated with an Open Sources MANO (OSM) based orchestrator. The testbed has the capability to support slicing to allow hosting multiple concurrent 5G applications or 5G services. It also supports 5G network function virtualisation (NFV). The testbed NFV platform hosts a repository of essential network functions to support basic end-to-end connectivity services with 5G KPIs (bandwidth and delay). Furthermore, the testbed has the capability to host complex network functions provided by researchers. The testbed is connected to a unique exchange facility i.e. 5GExchange, that enables peering with other test-beds at the transport, control and orchestration levels. The 5G exchange utilise an OSM based orchestrator that enables brokering of network services and resources across multiple experimental testbed for applications and services that require a complex, and multi-domain testbed comprising resources of several testbeds.

The centre for telecommunications research

The Centre for Telecommunications Research at King's College London (KCL) is leading the 5G work for KCL. There are currently more than 100 people working at the centre including academic staff, post-doctoral research associates and PhD students, along with a number of undergraduate students working on a variety of 5G related projects. KCL has received funding from the industry accounting for nearly £1m to date. KCL multidisciplinary research spanning from health, culture/art, cartography (for smart cities) and policy will play a significant role in demonstrating and validating the use of future 5G networks.

KCL's testbed has most of the test networks located in their Strand Campus, in central London. The testbed provides both indoor and outdoor coverage, and has been built with the possibility of being extended to other locations around London, such as the City of London and City of Westminster. The KCL testbed provides testing of different 5G pioneering bands in dense urban environments, with the aim of providing different flavours of the 5G system, which have been widely investigated in the centre for the past years. It has two sites of mmWave access with beamforming capabilities operating in 28 GHz, which allows for high capacity testing, as well as massive MIMO operating in 3.5 GHz, which serves multiple users simultaneously.

The KCL testbed is a non-standalone solution, for which a 4G 1.8 GHz antenna is used to provide control plane operation over LTE. The 5G testbed has a dedicated virtualised core network, which will be upgraded once standardisation is finished in 3GPP SA2. For IoT applications, the testbed includes Narrow Band IoT (NB-IoT) capabilities over 4G LTE-A indoor Small Cell access, connected to an upgraded 4G virtualised core and upgraded to provide NB-IoT features. This indoor testbed operates at 700 MHz and is also enabled to provide 3GPP network slicing for service differentiation at the core.

5G related projects in academia in Scotland

Another academic institution with significant 5G related activities is University of Edinburgh (UoE). The pioneering work on visible light communications (LiFi) has spun out to form PureLiFi that unlocks huge data pipes for the additional data services using new spectrum. LiFi is internationally recognised proven technology and will be a mainstream 5G technology with market products by 2021. UoE's LiFi Research Centre is pioneering the application of indoor high-speed networking to solve the rural divide by allowing backhaul technology to be more affordable through the use of solar panels as data receivers. In addition to these, UoE has significant industrial collaborations with key stakeholders. These include a £5m investment from Xilinx focusing on semiconductor design, supported by £1.01m R&D grant through Scottish Enterprise. This investment has created 12 new jobs and retained 30. Furthermore, Huawei has a recently signed a research partnership with UoE focused on into development of AI robotics systems supported by next-generation wireless networks.

University of Glasgow is working on £1bn worth of investment to expand their campus in the next 10 years. Part of that will include the 5G Smart Campus Development, a living lab which offers a unique opportunity to both test the initial application of 5G research in a real-world scenario, and because it also spans the commercial launch of 5G permits continued learning during the design and build phases of the programme. The scale and mixed physical estate of the University from historic, listed buildings through to brand new construction allows testing of the different deployment challenges. The evaluation of wearables capability allows the testing of lower latency capabilities in leveraging behavioural change and improved wellbeing in a controlled environment.

Key takeaways from research into 5G activities in academia

Academic activities around 5G are largely fundamental and often too narrow and focused to be linked to short term 5G capabilities. For example, research on semiconductors, even through an impact statement will mention 5G as a use case, is unlikely to make a real world practical impact in the next 5 years. Much of the developments in 5G today are a result of academic research carried out a decade ago.

5GIC is recognised as a successful example of industry-academia collaboration, with several interviewees suggesting that it could be a good example to be replicated across the UK, focusing not just on 5G but on next generation internet. Such centres would link academia, innovators and industry, where UK-bred research and development could flourish.

Academia has difficulty contributing to or affecting standards directly. Typically the academic institutions need to have industry links that have delegates on standardisation bodies such as 3GPP or IEEE. However, they are contributing in some of the technical reports that feed into these standards.

Academia is also aiming to contribute through open source solutions, although this is mostly focusing on network software, whilst the wireless/radio side is stated to be more challenging to establish open source community practices.

Funding research in the UK

The case for 5G will, over the next few years, continue to be developed. In this context, funding for collaborative development of 5G technologies and new business and operation models were highlighted through our research as crucial to the success of the UK's 5G rollout by both commercial and academic stakeholders. They raised the continuity of funding as critically important and raised several challenges that could be categorised under timing, values and alignment.
During the engagement, the following general points were made relating to funding and current business models:

- DCMS Funding: Key to initiating the design research that supports the industry challenges and a driver to many of the activities and has positively influenced the strength of the project focus and alignment to commercial, academic and government interests.
- Shared/Agnostic Infrastructure: A business model providing shared infrastructure, lowers the cost of ownership of the network. 5G must cover all use cases, not just voice, connectivity and speed, but other areas such as IoT, autonomous cars, all need to share one platform i.e. allow for any participant, ISP, MNO to engage.
- Higher TRLs: Investment should be used to drive the technology out of universities at higher TRLs, ready to be taken on by industry or new spin out SMEs based in the UK.
- Rural: The suitability of the current business models in rural context is questioned i.e. the necessary levels of investment.

Several stakeholders have referenced funding as the key constraint to further progress, other issues cited in relation to funding are the cost of 5G ready equipment, which is not yet in mass production.

LOCAL GOVERNMENT INITIATIVES IN 5G

Local governments across the UK have identified 5G as key technology for local and regional economic development, but are not yet uniformly clear about what 5G is or how it could be exploited; the level of awareness varies greatly between local councils.

The majority of projects focus on infrastructure, followed by testbed activity. The key objective for local authorities is to address specific local challenges, and in particular to create an open environment for innovation that can foster growth across a number of technology areas. These projects allow for better quality and coverage for populace as well as the innovation opportunities for companies based in the area.

In August 2017 Arqiva agreed a deal to partner with 13 local councils in London to lead a project to fit 5G ready small cells to street furniture around the city. These small cells will be fitted in areas where there is high demand or poor coverage and will boost current mobile capacity plus play a key part of the 5G rollout by 2020. With access to over 16,000 lampposts the contract could last up to 10 years to expand coverage and capacity over these years .

Testbeds highlight Local Councils' attraction strategy for economic growth in their areas. These attraction strategies centre on creating jobs, attracting the right people and becoming innovations hubs.

There is also a feeling of "not being left out" with the advent of 5G. There was a concern that 5G rollout should be delivered in ways that ensure inclusiveness in terms of good coverage and capacity, which reflect on the lessons learned from the rollout of 4G. Taking Bournemouth as an example, the borough's 4G coverage has been below average, despite being awarded digital council of the year in 2015 and hosting a large base of tech startups as part of 'silicon beach'. This has led Bournemouth to become an early leader in 5G in the UK, testing small cell infrastructure and developing a digital twin of the city in partnership with Ordnance Survey.

Figure 11
Categorisation of activities within 29 local governments undertaking active 5G projects

- Testbed 28%
- Infrastructure 52%
- AI 4%
- Research 12%
- AR/VR 4%

This digital twin has enabled planning of antenna deployment, to identify how weather conditions will affect signal and propagation, in line with Bournemouth's ambition to become the UK's first 5G city.

Local Councils benefit through partnerships in 5G

Local councils have also benefitted from partnerships, such as the Digital Greenwich project that brings together the Royal Borough of Greenwich and 5GIC , with a Smart City incubator encouraging 5G applications and innovation in transport, mobility, logistics, energy, healthcare and education. Furthermore, the North East Combined Authority the North East Local Enterprise Partnership, Nexus and Digital Catapult have also developed a proposal to implement a 5G use case on the Metro system to build fibre optic infrastructure in anticipation of future 5G rollout. O2 and the City of Aberdeen and Wireless Infrastructure Group have also partnered to launch the UK's first fibre connected small cell network. Using C-RAN technology, this will be an infrastructure project that includes small cells being attached to street furniture, allowing for future 5G services to offer faster and higher capacity mobile services.

Another example would be the first non-academic 5G testbed in the UK, the 5G Brighton Testbed; which was setup by the Digital Catapult in partnership with the Coast to Capital LEP , while the Basingstoke and Buckinghamshire based LEPs have testbeds in place to create hubs with which SMEs can get a head-start on innovation and create use cases to test out elements of 5G in a variety of scenarios. In addition, the Worcestershire LEP's new testbed will also look to help develop 5G commercial applications and in partnership with 5GIC, provide facilities for innovators to test their new business models, applications, services and experiences via a new incubator at the Malvern Hills Science Park.

INDUSTRY ACTIVITIES IN 5G

This study has identified 66 projects from 28 UK based companies that are a mixture of direct 5G technology classification and projects that are 5G related or will have an established application once 5G is rolled out. It has become evident through this study that while many 5G initiatives are keen

to showcase flagship projects that work on the more innovative parts of the 5G stack, smaller technology specific projects are more abundant but do not receive as much publicity. These projects are spread across a range of technology areas, including; mmWave; Radio Access Network (RAN); Network Functions Virtualisation (NFV); and Network Slicing. 31 projects come under non-specific or "other" technology areas or haven't been made public – which could be due to privacy and competition.

There are opportunities for established players on the telecommunication and network industry to shape the 5G landscape, but also for SMEs to disrupt and look for new applications for the technology. Larger corporations who have a legacy in the industry already have a number of projects on the way, and are a mixture of partnerships with other organisations, large and small as well as academic bodies and local councils. However, it is not only partnerships but strategic actions that drive UK industry's 5G activities. For example, Three's acquisition of broadband provider Relish for £250m, is an example of creating a foundation to succeed when 5G is more widespread.

Industry projects sit under a number of categories. Some are specific to certain parts of the 5G technology stack, while others look more specifically at end-to-end use cases. Companies are aware that the challenges presented are numerous and that the pooling together of knowledge and resources is the best way to tackle them. This can be seen through BT's partnerships with companies who may be considered by their competitors, such as Nokia . When partnering with Local Council projects, industry also has a focus on infrastructure and a desire to align with strategy.

A lack of transparency by industry for commercial reasons, means that creating an accurate and comprehensive map of 5G activities in this area has proved challenging. For example, it is difficult to pin point the direction of a company's 5G strategy, including which technologies are being used in certain projects, what they are focusing on and how they are looking to solve a particular challenge.

Despite this, there have been projects identified in:

- Infrastructure
- Massive MU-MIMI
- Network Slicing
- RAN
- NFV
- mmWave
- Media/AR/VR
- Optical Network
- Innovation Programme
- AI Standardisation
- MAC/RRM
- Security
- Where not explicit - "Other"

Within a number of these identified projects, there have been a series of challenge areas that industry have explored, including:

- Latency
- Capacity
- Reliability
- Consumer applications (including VR and AR)

Examples of industry projects

EE have worked with BT and Huawei engineers to build a complete 5G network in their Hertfordshire testlab, which simulates the real world, end-to-end, from the internet straight to the device. The project includes end-to-end 5G network architecture broadcasting. The core network technologies use programmable software from Huawei on commercially available hardware from HP. A further project working alongside Qualcomm, EE tested a Gigabit LTE network in Wembley stadium which successfully reached a download speed of 698mbps with the technology considered a stepping stone for 5G by delivering more capacity to allow for more efficient connections. This means that devices with a faster 5G network can free up more network resource via faster completion of downloads and uploads.

Demonstrations in controlled environments, such as BT and Nokia's Virtual Reality (VR) demo event at Mobile World Congress in 2017 , look to make use of the low latency and high bandwidth 5G

provides to give consumers a new experience to enjoy live sports. With the potential VR/AR offers and its increasing adoption across industries that are not just consumer centric (such as manufacturing), these tests are the foundation of exploring new applications, products, services and experiences that could have a wide impact across the economy.

Industry projects involving research and innovation organisations across the UK

5GICs presence is seen in a number of industry projects with companies such as Aircom, Rohde & Schwartz, CableLabs, making use of the £75m facility for advance development in core 5G technologies. In addition to 5GIC, there have been numerous interlinking industry and academic collaborations across the 5G ecosystem in the UK. For example, the University of Edinburgh and Huawei's X Labs, whose teams are working on developing use cases for robotics controlled by AI systems that use future networks; or Cobham Wireless' IoRL: Internet of Radio Light project with Brunel, which demonstrates the importance of academic institutions for R&D and expertise around 5G technology.

Industry funding of 5G related projects and activities

The below categorisation of UK based industry projects in 5G demonstrates the aforementioned breakdown of projects that this study has identified or collated information on through primary research conducted through workshops, surveys and interviews. It is important to note that as funding information for industry is not always made public, assigning a definitive classification of technology areas for projects can be difficult. With the large amount of competition in this space, there is often a high degree of secrecy in 5G projects to ensure companies maintain or build a competitive advantage. Despite this, there have been an increasing number of consortiums and joint ventures which have begun to break these silos down.

OTHER 5G RELATED ORGANISATIONS IN THE UK

A number of other organisations are active in the UK 5G ecosystem, some of which are mentioned here.

The UK5G innovation network was launched in December 2017, through a consortium of Cambridge Wireless, the Knowledge Transfer Network and TM Forum. The consortium was chosen by DCMS 5G Testbed and Trials Programme to act as a central point for community sharing of learnings from the 5G activities in the UK, and to support the case for the UK export and inward investment. UK5G is supported by associate partners (Digital Catapult, Real Wireless and Digital Greenwich), as well as the 5GUK Universities Test Network members (Universities of Surrey, Bristol and King's College London).

Cambridge Wireless is a leading international community for companies involved in research, development and application of wireless and mobile, Internet, semiconductor, and software companies, with more than 400 members from major operators and device manufactures to startups and industry. They have led, through several of their Special Interest Groups, workshops and conferences on 5G advances, opportunities, demand and barriers in the UK; for example a workshop on exploring the intersection between digital delivery and media and 5G, titled 'Broadcasting New Media - is 5G a solution or a diversion?' (June 2017).

Knowledge Transfer Network has a significant reach, across the UK, and was established by Innovate UK to help deliver economic growth through linking new ideas and opportunities with expertise, markets and finance and provides tailored innovation insights.

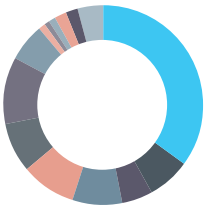


Figure 11
Categorisation of UK based industry projects in 5G

Other	35%
Infrastructure	7%
Massive MUMIMO	5%
Network slicing	8%
RAN	9%
NFV	8%
mmWave	11%
Media/AR/VR	6%
Optical Network	1%
Innovation programme	1%
AI	1%
Standardisation	2%
MAC/RRM	2%
Security	4%

TM Forum is an association of over 850 member companies generating US$2 trillion in revenue and serving five billion customers across 180 countries, helping them to drive collaboration and collective problem solving to maximise the business success of communication and digital service providers and their ecosystem of suppliers around the world. Focus is on supporting members as they navigate their unique digital transformation journeys.

techUK is an association of 950 companies in the UK and works with its members to identify and advance innovation in the key markets representing the most significant opportunities for growth both domestically and internationally. It runs an active members working group structure under Communication Infrastructure Programme, looking at Future Connected Rail, techUK Communication Infrastructure Council, techUK Ofcom Forum and the UK Spectrum Policy Forum.

The Catapult Network, and the Cross-Catapult 5G Working Group in particular, has brought together Digital Catapult, Satellite Applications Catapult, Future Cities Catapult, and Transport Systems Catapult, to discuss the demand, challenges and opportunities around 5G in the UK. They are all looking at collaboratively bridging the gap between 5G infrastructure as an enabling and emerging technology to its applications in specific industry sectors.

Digital Catapult works is to accelerate the development and testing of innovative business models that exploit, and push the boundaries of 5G, as a crucial component of advanced digital infrastructure. Digital Catapult is heavily involved in the future of 5G, as a participant in a DCMS Testbed and Trials project (Smart Tourism) and the lead organisation in the 5G Brighton Testbed, housed at Digital Catapult Centre Brighton. The testbed works with local innovative businesses and the wider 5G UK community to develop a mutual understanding of the work 5G can do. There is a very active and good, group of consulting/special services companies that underpin the UK 5G Ecosystem, from spectrum consulting to techno-economical analysis to bespoke technology solution IP providers in the UK. Some of these companies are providing the necessary technical advice on 5G opportunities, challenges and solutions to the ecosystem – local and central government as well as industry, both mobile and other.

Looking on the standardisation side, the UK organisations are members of the European Telecommunications Standards Institute (ETSI), with the current serving Chair of the General Assembly coming from the Digital Group of the Department of Culture, Media and Sport.

The UK 5G ecosystem has strong international connections. For example, the UK has a very strong participation in the 5G Public Private Partnership (5G-PPP), setup under the scope of the European Union's Horizon 2020 research and innovation framework in 2013. There are currently 40 projects funded by H2020 within the 5G-PPP (19 in Phase 1 and 21 in Phase 2) out of which UK stakeholders (academia and industry) are involved in all but two, leading four of them and participating with an average of two UK partners in each of them. Some of these projects support 5G collaborations with South Korea and China.

UK PRESENCE AT MOBILE WORLD CONGRESS 2018

Mobile World Congress is the world's largest exhibition for the mobile industry and a conference featuring prominent executives representing mobile operators, device manufacturers, technology providers, vendors and content owners from across the world. UK based organisations played a key role in demonstrating world-leading research and development in 5G. More than 150 UK based organisations exhibited at the show across a range of areas relating to 5G including: antennas, aerials, masts & towers, backhaul solutions, cloud RAN, core network equipment, femtocells, NFV, telecoms and certifications.

In Barcelona, the DCMS-funded 5GUK academic project, comprised of the University of Surrey, the University of Bristol and King's College London demonstrated the world's first 5G end-to-end network, controlling a 5G-connected robotic football player across two locations in different halls in the exhibition. Visitors were invited to remotely control a player, by kicking a football on one of the 5GUK stands, the movement of which was replicated by a robotic-foot located on a separate stand in a different exhibition hall, as it kicks another football into a net. Visitors were also able to see a comparison between 4G and 5G in transmission of ultra-high definition video using an intelligent mobile edge computing technique.

UK 5G TESTBED AND TRIALS PHASE 1

DCMS have awarded £23.8m to six consortiums as part of the 5G Testbeds and Trials Programme. This programme has awarded grants of between £2m and £5m to for one year of funding for projects, from 1 April 2018 until 31 March 2019.

The 5G Programme will continue to deliver on the government's commitments set out in the 5G Strategy, which are:

- Accelerating the deployment of 5G networks
- Maximising the productivity and efficiency benefits to the UK from 5G
- Creating new opportunities for UK businesses at home and abroad, and encouraging inward investment

A total of six projects were awarded funding through the 5G Testbed and Trials Programme, these cover a range of opportunities for the UK in 5G and feature a mix of academia, industry and local government players as well as organisations from across the value chain.

5G RURALFIRST:

Rural coverage and dynamic spectrum access testbed and trial

Lead organisation:	Cisco
Other partners:	BBC, University of Surrey, Scottish Future Trust, Agri-Epi, Datavita, Zeetta, Microsoft, Parallel Wireless, Lime Microsystems, pureLifi, University of Edinburgh, Heriot-Watt University, Fairspectrum, Nominet, Telinet, BT, Faose Telecom/SHEFA, Milkalyser, Kingshay, Afimilk, Soil Essentials, Hyperconnections, CENSIS, Stream Technologies, Power Networks Demonstration Centre (PNDC), Cloudnet, Orkney Island Council, Broadway Partners
Location:	Orkney Islands & Shropshire
Grant:	£4.3m

5G RuralFirst, led by Cisco and lead partner University of Strathclyde, will deliver testbeds and trials to exploit 5G benefits for rural communities and industries like agriculture, broadcasting and utilities, to address the challenges of and build the business case for 5G rural deployment. Based primarily on the Orkney Islands, and in the farmlands of Shropshire and Somerset, the project will integrate spectrum sharing strategies for 5G; bringing connectivity to rural communities, enabling smart farming in partnership with Agri-Epi Centre (including drones, autonomous farm vehicles and remote veterinary inspections); innovative methods of delivering broadcast radio over 5G working with the BBC, alongside the delivery of 5G connectivity for IoT in utility and other industries in rural areas.

WORCESTERSHIRE 5G CONSORTIUM

Lead organisation:	Worcestershire Local Enterprise Partnership
Other Partners:	Bosch, BT, O2, Huawei, Yamazaki Mazak, University of Surrey, QinetiQ, AWTG, Worcestershire County Council
Location:	Worcester
Grant:	£4.8m

A team of 5G and Industry 4.0 experts lead this project – working with Worcestershire LEP, the consortium comprises: Worcestershire County Council, 5GIC at University of Surrey, AWTG, Huawei, O2, BT and Malvern Hills Science Park. With local businesses Worcester Bosch and Yamazaki Mazak, it will focus on ways to increase industrial productivity through preventative and assisted maintenance using robotics, big data analytics and AR over 5G, looking to provide sensors for predictive maintenance, with around 1,000 sensors per square km sending around 5Mb/sensor/second. It will also have a cyber security aspect, with QinetiQ providing assurances on the 'security by design' of 5G and IoT technology. Entrepreneurs will have the opportunity to test 5G capabilities in a new commercial tech accelerator located at the Malvern Hills Science Park.

5G SMART TOURISM

Lead organisation:	West of England Combined Authority
Other partners:	University of Bristol, CCS Ltd, BT, Grand Appeal, Mo-Sys, Mativision, Smartify, BBC, Zeeta Networks, Destination Bristol, Digital Catapult, VR Lab, Interdigital, Bristol is Open, Bristol Futures Global, BANES/Roman Baths, 3Sixty, Landmark, IBI
Location:	Bath & Bristol
Grant:	£5.0m

This testbed will focus on delivering enhanced visual experiences for tourists using VR and AR technology in major attractions in Bath and Bristol, including the Roman Baths and Millennium Square. Content and technology developments will be provided by the BBC and Aardman with support from the University of Bristol's Smart Internet Lab. It will demonstrate self-provision of 5G and Wi-Fi and innovative mmWave backhaul and will also address safety issues by providing emergency service capacity through network splicing.

LIVERPOOL 5G TESTBED

Lead organisation:	Sensor City
Other partners:	AIMES, Inventya, DefProc, Digital Creativity in Disability, CGA Simulation, Liverpool City Council, RLBUHT, Liverpool University, and Liverpool John Moore's University, Blu Wireless
Location:	Royal Liverpool and Broadgreen University Hospitals NHS Trust (RLBUHT), Liverpool Adult Social Services
Grant:	£3.5m

Sensor City will lead a consortium made up of public sector health suppliers, the NHS, university researchers, local SMEs and a leading UK 5G technology vendor. Funded for one year in the

first instance, the project will see high value technologies including low-cost open source 5G networks, AI, VR and IoT deployed across deprived communities in the Liverpool City Region testbed. The consortium will use this technology to reduce the digital divide, while measuring the impact on patient monitoring and support, management of loneliness in older adults, aid to independents living in the home and the facilitation of communication between hospitals and the community.

AUTOAIR: 5G TESTBED FOR CONNECTED AND AUTONOMOUS VEHICLES

Lead Organisation:	Airspan Communications
Other Partners:	University of Surrey, Meridian, Blu Wireless, ARM, Celestia Technologies, Cobham, McLaren Applied Technologies, Millbrook, Quortus, and Real Wireless
Location:	Millbrook, Bedford, and 5GIC
Grant:	£4.1

AutoAir will aim to make 5G technologies available for the validation and development of Connected and Autonomous Vehicles (CAVs) at the UK's premiere vehicle proving ground at Millbrook. Fast travel speeds complicate cell-tower handoff and autonomous vehicles will require more network bandwidth than is available currently. It will also investigate how these 5G connectivity solutions could be transferable to both road and r ail transportation.

The project is based on the accelerated development of 5G small cells operating in both licensed Sub 6 GHz and mmWave bands on a shared 'neutral host' platform which allows multiple public and private 5G operators to simultaneously use the same infrastructure through network slicing.

The project will see Millbrook build a fibre backbone and 23 "Small Cell" base station sites. The testbed will allow CAV developer's access to Gigabit/s, low latency, wide-area 5G wireless infrastructure that will work seamlessly across the entire proving ground at Millbrook. This capability is crucial for the validation and testing of level three to level five autonomous vehicles, which require high speed, real-time connectivity to compare the "real world" outcomes with the decision making simulation.

5G RURAL INTEGRATED TESTBED (5GRIT)

Lead Organisation:	Quickline Communications
Other Partners:	Cybermoor 5G Services Ltd, North Pennines AONB Partnership, Broadway Partners Ltd, Blue Bear Systems Research Ltd, Precisions Decisions Ltd, WT InfoTech Private Ltd, King's College London, Lancaster University, Kingston University
Location:	Cumbria, Northumberland, Yorkshire, Lincolnshire, Inverness-shire, Perthshire and Monmouthshire
Grant:	£2.1m

5GRIT will be trialling innovative use of 5G technology across a range of rural applications, such as smart agriculture, tourism and connecting poorly-served communities, using shared spectrum in the TV bands and a mix of local ISPs and self-provision.

The aim is to ultimately make high quality connectivity available across Cumbria, Northumberland, North Yorkshire, Lincolnshire, Inverness-shire, Perthshire and Monmouthshire. Here the consortium will develop 5G-ready AR apps for tourists and investigate how high-bandwidth wireless connectivity can increase

food production in farming, including through use of AR and an unmanned aerial system.

There has been concern that with only one year of funding guaranteed, the 5G Testbed and Trials Programme will create a range of point of concept demonstrators, but once the finding ends in April 2019, many projects will struggle to reach full scale deployment and commercialisation.

JOINT INDUSTRY PROJECTS TAKING PLACE IN THE UK

In July 2017, Arqiva and Samsung Electronics announced that the first field trial of 5G Fixed Wireless Access (FWA) technology in the UK and Europe went live in central London . The trial, powered by Samsung's 5G network solution and customer premises equipment (CPE), used Arqiva's 28 GHz millimetre wave (mmWave) spectrum. The main aim of the trial was to demonstrate the stability of fixed wireless access as a fast to market and costeffective alternative to fibre connectivity to homes and buildings. The system has successfully established a two-way link with downlink speeds of around 1Gbps. This allows for simultaneous streaming of more than 25 UHD 4K TV channels, as a demonstration.

BT and Huawei are undertaking a UK project in network slicing, ring fencing particular slices of a network for specific use cases. This is useful for maintaining operational infrastructure when network demand is high, for example during live sports or music events. BT and Huawei are undertaking this research and these trials into 5G based mobile technology at the Adastral Park Laboratories in Ipswich.

Ordnance Survey, 5GIC and Bournemouth Borough Council who were funded by DCMS and government have come together to create a mapping and planning tool that will create a digital twin of Bournemouth. This will map out all street furniture and indicate the best areas to place radio antennas for 5G. Depending on its success this could then be rolled out to the rest of the country and internationally.

Figure 12
Current ownership of spectrum (4G & 5G) by the four mobile network operators in the UK (Correct as of May 2018)

EE	295 MHz
O_2	166 MHz
Three	150 MHz
Vodafone	226 MHz

Arqiva and Dali Wireless have come together to cover Glasgow City Centre with an updated cellular network. The project will improve mobile coverage and capacity using a next generation digital Distributed Antenna System (DAS) developed by Dali. Arqiva worked with Dali Wireless and Cellular Asset Management to replace ageing analogue equipment which will provide foundations and support for 4G and future 5G services. BT and Nokia are also researching low latency and high bandwidth 5G for the use of VR to broadcast live sports and entertainment. BT trialled this technology using Wi-Fi and 4G to broadcast the 2016 UEFA champions league final from Cardiff, with subscribers getting to watch using distributed cardboard VR headsets. Previous trials have utilised Nokia OZO VR camera.

Vodafone UK selected Ericsson to help evolve the 4G networks in London by utilising Massive MIMO technology, provideing them with 5G Radio technology and have signed a memorandum of understanding that will cover 5G site deployment scenarios, 5G use-cases (including business case studies and proof of concepts) and a 5G Innovation: Technology innovation programme. The partnership involved technology trials, product validation, commercial deployment and professional services.

MOBILE NETWORK OPERATORS ON 5G

A common statement from the 5G community at large is that, while the deployment of 4G from 2012 onwards was largely driven and managed by the four major Mobile Network Operators

(MNOs), it is widely anticipated that with 5G, the deployment will follow parallel routes, with local authorities and other industry possibly gaining more interest in non-eMBB use cases. Despite this statement from many in the 5G ecosystem, research and broad-stakeholder interviews offer little evidence to suggest that the MNOs will not play a major role in the deployment of 5G. Mobile operators are all primarily looking to new use cases and revenue streams with the deployment of 5G networks, whilst continuing to exploit their significant investment in 4G and its upgrades. We have highlighted those that were participating in the Ofcom Auctions, noting there are many other operators (MVNOs) who will look to benefit from 5G as it is deployed.

TELEFONICA (O2)

Telefonica-owned O2 are undertaking a range of 5G activities in the UK, to complement Telefonica's 5G activities across Europe. O2 recently spent £80m installing 1,400 small cell networks across London that are expected to play a vital role in urban 5G networks.

In February 2018, the launch of a 5G testbed at the O2 entertainment venue in Greenwich was announced and will showcase technology to visitors at a number of locations at the venue, primarily focusing on immersive technology and live streaming of content. O2 will use the network to test a variety of equipment and potential use cases for 5G under live conditions.

The testbed is the first of a number of trials across the UK looking at 5G for consumers, businesses and the public sector.

In a statement at the opening of the O2 testbed, CEO Mark Evans said 'the beauty [of 5G] is not just in the cost reduction, it opens up opportunities in adjacent markets such as Smart Cities and remote health monitoring' .

BT (EE)

EE have been the leader in 4G across the UK. As the first operator to offer commercial 4G packages and the most comprehensive 4G coverage in 2018, EE is likely to aim to continue dominating the mobile landscape in the coming years. EE owns 42% of the immediately usable spectrum against Ofcom's declared view that no one operator can own more than 37% of all the mobile spectrum expected to be useable in 2020, which includes not only the spectrum available in the first 5G auction, but also the 700 MHz band. In the current auctions, BT (EE) will not be able to bid for any spectrum in the 2.3 GHz band, because it owns the most, as per Ofcom's note that they have placed a cap of 255 MHz on the "immediately useable" spectrum that any one operator can hold as a result of the auction.

EE is a leading member of the LTE Broadcast Alliance, facilitating key components of future broadcast media and LTE-B, suggesting they see streaming as a key component in the future of mobile broadband.

EE have carried out a number of 5G trails, including one that reached 2.8 Gbps in November 2017 at EE's mobile lab in Hertfordshire. As part of this trial a proof-of-concept Huawei 5G baseband unit was used to link the fully virtualised 5G core network to 100 MHz of 3.5 GHz test spectrum, with EE keen to stress that the 2.8Gbps speed was delivered end-to-end, and not just across the air.

As the title sponsor of Wembley Stadium, EE are carrying out a number of tests at the venue, achieving speeds of 750Mbps, which, while slower than those expected by 5G, is considerably faster than 4G downloads available today.

BT and EE could be the first company in the UK and Europe to launch a live 5G network. Gavin Pattison, CEO of BT, told analysts in a strategy and earnings presentation in May 2018 that the company would launch a live 5G network "within 18 months" indicating that a network would be live by late 2019, ahead of the dates set for commercial launches by European operators including Telefonica and Deutsche Telekom.

THREE

Three is in a unique position in that, despite being the UK's smallest network, it carries 35% of the UK's mobile internet traffic, it has the capacity to meet high data demands, which will be increasingly vital with the move to 5G. It launched Go Binge, an innovative, zero-rated product and open platform offering Three UK customers on selected plans the freedom to stream Netflix, ITV Player, Deezer and SoundCloud, by removing data charges on those services. They completed the acquisition of Relish, a fixed wireless provider operating in central London and Swindon which opened up the home broadband market as a growth area for the business. Three offers 4G broadband and data services to wholesale and channel partners, as well as supplying bespoke campus solutions for enterprises. Relish has 15,000 customers in the UK – most of them in London – which it serves through a mixture of its own 4G mobile spectrum and fibre backhaul. Three have partnered with Cisco Jasper to use the companies IoT management platform and extend their own IoT capabilities as well as announcing in February 2018 that their platform can now support NB-IoT, citing smart energy, connected cars, smart cities and smart buildings as in-demand areas.

Beyond the operator's well documented concerns around its rivals dominating the market, Three has said very little about its work in 5G, given their current push into fixed wireless broadband and IoT, we expect 5G to be a key focus for the company.

In May 2018, Three announced a partnership with SSE Enterprise Telecoms to bring fibre optic connections to Three's 20 core data centres. This multi million pound deal will strengthen the organisation's capacity as 5G launches.

VODAFONE

Vodafone has a large 4G network, with over 95% of the UK population covered. Vodafone is second in terms of UK spectrum ownership, with 28% of the readily available spectrum.

It has begun working towards a 5G network by building 30 massive MIMO sites targeting areas where there are lots of customers in a small area.

The organisation is primarily focused on speed and IoT applications with 5G, but it has partnered with Huawei, Nokia, Qualcomm, Ericsson and Intel to both research 5G and prepare its network for the technology transition. Vodafone is also working towards technologies and services that can be deployed early in the 5G cycle, in 2020.

Vodafone is the first UK operator to complete a standalone pre-standard 5G test, the trial in collaboration with King's College London and Ericsson, independent of any 4G network. The trial took place across a small area at the King's College London campus. They also signed the first UK commercial 5G contract with Ericsson.

It was the first UK mobile network operator to demonstrate communication over the 3.4 GHz spectrum. In April 2018, it tested messages between its offices in Newbury and its Manchester contact centre site, plus tested massive MIMO technology alongside 23.4 GHz spectrum over the core 4G network.
Vodafone is already heavily focused on the IoT space, as a key driver of narrowband IoT (NB-IoT) a protocol focused on low volume, long range data transmission, suitable for a wide range of IoT use cases.

EXAMPLES OF POTENTIAL NEW ENTRANTS IN 5G

AIRSPAN

Airspan has a complete range of LTE and 4G base stations and complementary small cell backhaul solutions using both LTE Relay and proprietary technologies. It also addresses non-mobile carrier and private network deployment including the needs of fixed Internet Service Providers, and a number of vertical market segments including Smart Grids, Public Safety, Transportation and Oil & Gas. The organisation has deep in-house expertise in LTE and LTE-Advanced, OFDMA, Wi-Fi and VoIP. Airspan is able to exploit synergies and develop innovative products and solutions that closely integrate these technologies in the most beneficial ways for customers. Airspan is also looking to the future with the development of solutions that combine small cells with Gbit/s backhaul and Virtualisation, which will be the basis of future 5G products and solutions.

DCMS announced Airspan will take a leading role in the "AutoAir" 5G Testbed consortium, a neutral host based small cell solution for transportation networks in the UK. The AutoAir project will accelerate the development and deployment of two key technologies in the UK, namely 5G and CAVs, as a 5G testbed for connected and autonomous vehicles as part of the DCMS Testbeds and Trials Programme.

The AutoAir project also brings together a large number of industry's leading 5G players and the pioneering research at Surrey Universities 5G Innovation Centre (5GIC). The project consortium includes; 5GIC at Surrey University, Dense Air Limited, McLaren Applied Technologies, Blu Wireless Technology Limited, Quortus Limited, Millbrook, Real Wireless, ARM, Cobham Wireless, and Celestia Technologies.

Airspan were selected to take part in the initial 5G spectrum auction for bands in the 2.3 and 3.4 GHz spectrum however, were unsuccessful in obtaining spectrum in the first round.

CONNEXIN

Connexin are a fixed wireless ISP, providing high power Wi-Fi to cities. Connexin's business model thus far has used investment led by Digital Alpha Advisors, which has a strategic partnership with Cisco Systems, to respond to increasing demand among local authorities for smart city technologies.

The firm is currently scaling up its work with local authorities to provide Wi-Fi as a public service and for connected devices such as road sensors, energy, and security systems.

In addition, its investment partner Digital Alpha will enable the firm to offer local authorities new ways of financing technology upgrades that share the risks and rewards. Digital Alpha will underwrite up to £100m in smart city projects in coordination with investment partners.

Connexin provided Wi-Fi to the City of Hull in a deal believed to be worth around £4m. This free Wi-Fi service covered a large area of the city including Queen Victoria Square, King Edward Street, Jameson Street, parts of the Old Town and Marina, as well as the Interchange and areas within all of the major public parks including East, West, Pickering and Pearson. In addition, there will be a number of sites in 'digital inclusion areas' including North Bransholme, Orchard Park, Longhill and Preston Road with the opportunity to expand coverage even further across the city.

The move by Connexin from fixed Wi-Fi to potentially 5G comes from the companies belief that smart cities will be one of the first movers in 5G and that projects can be completed with funding from capital infrastructure.

Connexin were invited to take part in the initial 5G spectrum auction for bands in the 2.3 and 3.4 GHz spectrum. Its position as a new MNO means that it has the capacity to enable real disruption in the UK 5G ecosystem.

3.

DEMAND AND CHALLENGES FOR 5G IN THE UK

Strategy Analytics predicts that by 2022 tens of millions of 5G handsets will have been sold across the globe, and that by 2025 more than 300 million 5G handsets will have been sold.

DEMAND FOR 5G

Trial handsets are likely to launch in 2018, which will be Test & Management devices, linked to prototype RAN and CN networks, these are likely to still need further development with issues such as software instability, short battery life, unstable connectivity and no handover to 4G networks. By 2022, we expect to see the following capabilities in handheld devices:

- Augmented reality
- Virtual reality
- Massive resolution
- More advanced CPU & memory
- Cloud Computing

While mobile broadband, which is widely commercialised today, was the largest cited use case in our survey, transport, healthcare and VR/AR were also in the most highly identified use cases for 5G, these applications are largely undeveloped and so there is great scope for the adoption of these technology areas as 5G develops. The BBC is active in several of the DCMS testbed and trials project and is working of the development of high quality media through 5G.

Today many international smartphone manufacturers, including Sony, LG, ZTE, Huawei and HTC, have signed up to use the Qualcomm Snapdragon X50 5G NR modem, with expected launches in 2019. As of March 2018, Apple, Samsung and Google are yet to announce their first 5G enabled mobile phones or the modules they will use.

Our survey of key players across the value chain in 5G found mobile broadband to be the major opportunity with consumption of this constantly on the rise, but with this, technology such as media content and VR and AR content (which 40% also saw as an opportunity) can be consumed via mobile broadband with devices readily supporting this. Mobile broadband can be considered an umbrella term such as with applications for VR/AR and consumption of higher quality streamed content.
Industry opportunities such as health (35%) and manufacturing (27.5%) also received a fair share of the responses from our survey. Smart home and IoT devices are becoming increasingly popular - whether their functionality changes with 5G is open to debate as there is evidence from our workshops and interviews that suggested that these devices are currently using other networking options such as Bluetooth, ZigBee or LPWAN, which have been sufficient and more suited in technology and cost than 5G.

There was an overwhelming response from survey respondents as to the need for 5G. The key areas highlighted were: Latency, coverage and capacity. Capacity and latency are the key areas where respondents were interested, with over 50% of respondents stating this. With increasing demand globally for connected devices, increasing the capacity for mobile communications alongside new innovations, points towards a desire for richer levels of data and real-time applications and analysis. Considering the key areas where innovation is expected, latency is key in delivering the expected performance.

Our survey has indicated that there is a wide range of opinions as to what will be the biggest challenge to 5G deployment in the UK (Fig 15), with backhaul infrastructure (linked to 5G-ready fibre) and slow implementation from MNOs (which is related to regulation/legislation and business case) being the largest identified challenges with 17% each.

The timelines of need for 5G indicates an appetite for it to be deployed in the present and near future, with 89% of respondents signalling there is a requirement for the technology by 2022. Consumption of mobile bandwidth is increasingly significant and 5G will contribute to this. The advent of 5G will enable new applications such as the use of autonomous cars, and will help drive policies enabling new business models.

Figure 13
Responses to the question 'Which three use cases do you see as most promising for driving 5G development in the UK?

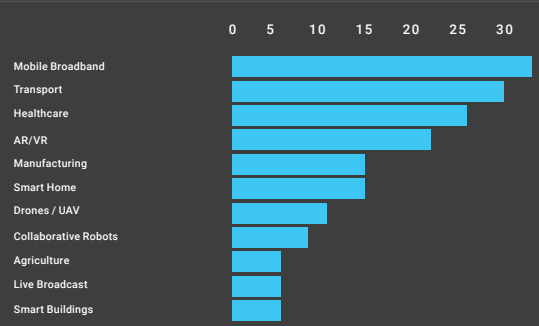


Figure 14
Responses to the question 'For what reason is your organisation interested in 5G?

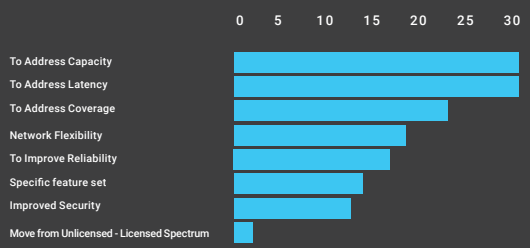


Figure 15
Responses to the question 'What do you see as the biggest challenges for early 5G deployment in the UK?

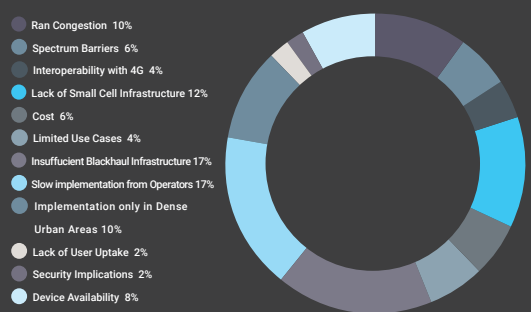
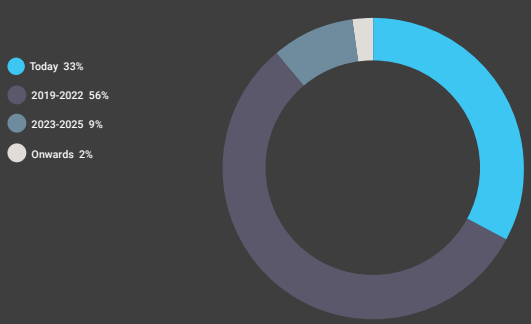


Figure 16
Respondents answer to the question 'When do you seen the need for 5G?



THE REQUIREMENTS FOR 5G

The migration to 5G for UK Mobile Network Operators (MNOs) requires a strong business case. MNOs have a requirement to generate more revenue and/or an increase in UK average revenue per user (ARPU) as in recent years both have become static or have been declining. At the same time, Communication Service Providers (CSPs) such as YouTube, Facebook, WhatsApp and Google are looking to expand into new marketplaces with new service offerings, designed to utilise the capacity that 5G offers.

According to Vodafone, data usage is increasingly driven by the demand for high-definition video, which requires fast download speeds for a better user experience. For example, in 2017 they witnessed data traffic increased by 65% during the year. Ericsson at the same time reports a 60-70% Data Traffic Growth. This data growth is expected to continue exponentially with the consumer video experience expected to become a key driver of 5G adoption. To meet the demand 5G has been designed to allow signalling and data traffic to move in separate bands which enable the MNOs to utilise their licensed and unlicensed spectrum differently. With Ofcom releasing more spectrum around 700 MHz, 2.3 GHz, 3.5 GHz and 26 GHz in the coming months via Ofcom auction, the MNOs have the opportunity to buy more capacity into their networks to meet future demand.

Our survey found that MNOs will not complete a national 5G rollout unless there is an increased incentive to do so and combines with ways to reduce the cost of deployment and transmission backhaul. It is crucial to make it easier to deploy 5G by enabling/simplifying the local planning, building, transport regulations and costs by demanding common access of infrastructure, e.g. common ducting, re-use of fibre if under-utilised or not lit, which will reduce the cost of access enablement.

The industry agreed position is that 4G and 5G will coexist for a long period of time, e.g. different from 3G and 4G, 5G features and capabilities will be deployed in parallel with the existing 4G network, as reflected by the 3GPP Non-Standalone and Stand-Alone (NSA and SA) architectures. As such, eMBB fills the simple business case (more data to be carried, within existing spectrum). It will be deployed initially where the 4G Core Network connects to 5G RAN, using the expanded licensed spectrum to augment 4G, 3G, 2G and Wi-Fi networks.

ENABLING DEMAND

Today's MNO is governed by meeting Ofcom regulations around UK national coverage/capacity marketplace where they traditionally operate in a highly competitive (3-4 MNOs per country across EU) network, with ARPU falling. In their 2017 annual report, Vodafone stated that they have seen 40% average reduction in the price per GB of data over the last three years. Within the marketplace Over The top (OTT) content providers like YouTube, Google, Facebook, Sky, Netflix etc. are able to take a higher value chain approach by servicing the consumer, while MNOs operate at a near zero marginal production cost for the delivery of the valued content.

MNOs realise they have to change their business models, to avoid the risk(s) they face in terms of competition and the new digitalised society we live in. We are witnessing massive changes where companies that depend on fixed-cost business models have been disrupted by digitalisation for example in music, television, publishing, educational media, etc. But new businesses emerged, and not just the major platforms like Facebook, Google, and Amazon. Millions of individuals are producing and selling or sharing virtual goods, at near-zero marginal production cost. All of this content generates data across the networks where the price per Mbs has fallen over the past 3-5 years and the UK marketplace demonstrates declining household spend, despite higher take-up, use and quality of services for the digital communications access. Today, non-telecom players are already active in

the 5G-enabled product space, with pilots in autonomous vehicles, VR based infotainment services and other use cases.

To meet the expected demand base around the eMBB Business case to provide 1Gbps into the home or greater to industry, we see MNOs (Vodafone, EE, TalkTalk) complementing their mobile networks with macro-fibre networks (FTTC/N) with 5G to connect homes with gigabit speeds. The government has recently stepped in to help alternative connectivity and internet service providers via a new £400m digital and infrastructure investment fund (DIFF) REF. This, when supported by private investment, could be worth up to £1.5bn. Over the next four years the DIFF hopes to help an additional two million premises gain access to ultrafast fibre broadband to the home.

Traditionally, 2G and 3G mobile networks often used copper-based Time Division Multiplexing (TDM) circuits, to connect cell sites to a nearby Mobile Switching Centre over the Mobile Backhaul (MBH) network. This MBH architecture has served the industry well for decades, however is not as suitable for 4G and will not work well with 5G. Mobile backhaul upgrades are taking place all over the world converting legacy copper-based MBH serving cell sites to packet-based transport over fibre networks, which enables far higher capacities to future-proof MBH networks. The increased adoption of 4G LTE and LTE-Advanced mobile network technology is accelerating these MBH fibre upgrades, which can and will be leveraged by future 5G networks, given the almost unlimited bandwidth that fibre-based networks offer. Currently in the UK, less than 3% of the UK is served with fibre broadband options and there exists today no map of the UK's fibre deployments. Today there exists no public available dark fibre map of the UK, whereby Enterprises and CSPs can understand what is available as dark fibre to be lit within areas/location. Being able to enter a postcode and discover the fibre asset would enable the marketplace.

Recent announcements will help to alter this as reported:

- EE has predicted there are 580,000 homes with slow or no fixed line access across the UK. This could prove to be a useful opportunity for EE's 90% 4G coverage and announced at MWC 2018 a new 4G Router to enable rural markets in UK to experience 4G in the home.
- TalkTalk and Infracapital have announced plans to build a FTTH network that will cover three million homes and businesses in the UK. The operator and the infrastructure equity investment arm of M&G Prudential said they had agreed "heads of terms" – equivalent to a letter of intent or a memorandum of understanding – on the creation of an independent company to carry out the build. The two companies plan to invest around £500m in the venture themselves, with Infracapital supplying 80 percent and TalkTalk, which intends to raise £200m by selling shares, the remaining 20 percent.
- Vodafone's recent deal with CityFibre , TalkTalk and Infracapital said they planned to focus the new network on mid-sized towns and cities in the UK. The company already has a joint venture with CityFibre in York , where the two companies have been deploying FTTH since 2014.
- Virgin Media committing to add another two million premises by 2019. On top of that KCOM in Hull are aiming to reach 150,000 premises by December 2017 (they've already completed over 100,000).
- BT-owned Openreach has committed to building a FTTH network to three million premises in the eight major UK cities (Birmingham, Bristol, Cardiff, Edinburgh, Leeds, Liverpool, London & Manchester) by 2020 as part of their fibre first programme and said up to ten million premises could be connected by the mid-2020s. This project is expected to cost between £3bn and £6bn.

Alternative network providers (Gigaclear, Hyperoptic, B4RN, GTC etc.) believe they will be able to deliver services similar to BT and Virgin's combined commitment. The fibre deployment, buildout by MNOs will continue using the appropriate long-term funding from government.

As part of the Autumn 2017 Budget the government announced a new £190m Challenge Fund that local areas around the country will bid for to encourage faster rollout of full-fibre networks by industry. Children in 100 schools around the country will be some of the first to benefit, starting with a pilot in the East Midlands in 2018.

Every step above is designed to enable a network to support 5G which will require significantly more infrastructure that has existed for 4G or 3G because of the multiple deployment scenarios and spectrum allocation. In urban areas, densification will require larger numbers of antenna to achieve full coverage. To achieve high densification there is a need to utilise the street furniture, where a neutral host provider or service company can deploy four to eight Points of Presence (POPs) per week. High Densification includes B2B and B2C and it must be flexible to meet the demand loadings.

POPs are deployed at a low level, normally second storey or below in terms of height, currently a progressive City Council has enabled 5,000, while another only five, because they have a pro-active view of the need for POP/Mobility/Digital age. In more rural areas, with a lower population and therefore a smaller return on investment for MNOs in 3G/4G, the objective in 5G (under a Rural-In strategy) will be to address low/no level of service. Through this it will be possible to create a rural environment where 5G is made available and connected to a high capacity EDGE computing platform that will enable local, micro and macro business models to be created, and demonstrate that the availability of those opportunities solves local economic and business issues for users using a shared infrastructure either by carrier-led or independent neutral host models. For example, an autonomous vehicle becoming restricted to areas with good mobile reception is not as desirable as a manually driven vehicle that can travel anywhere in the UK.

Fixed Wireless Access (FWA) is probably the first 5G rollout (outside of Hotspot densification) particularly attractive in areas where there is no existing copper, fibre, or hybrid infrastructure to deliver wired broadband, or when the current fixed infrastructure is unable to provide sufficient service. The business case for FWA only becomes stronger as LTE continues to advance to 5G. One of the 5G use cases currently gaining momentum around the globe is using FWA to provide broadband service for homes and small and medium-sized enterprises (SMEs). It will be the first deployment in USA and other countries. Fixed access deployments are associated with the "last mile" portion of the network that reaches the user premises. Compared with fibre-to-the-home (FTTH) and other wireline solutions, FWA offers a variety of benefits depending on location, including faster service rollout, lower rollout costs and lower OPEX.

In doing this, MNOs can then establish ways to enable industry integration and market segmentation into transport, manufacturing, logistics, healthcare and energy sectors (IIoT, mMTC, uRLLC) as per 5G 's vision and architecture represents a clear opportunity to open such a marketplace with a new software developed architecture that enables connectivity, cloud and storage services with features like mobile edge computing, low latency, ultra-high bandwidth, network slicing and secure access which enables links like Industry 4.0 whereby MNOs can offer services that provide:

- Interoperability - machines, devices, sensors and people that connect and communicate with one another.
- Information transparency — the systems create a virtual copy of the physical world through sensor data in order to contextualise information.

- Technical assistance — both the ability of the systems to support humans in making decisions and solving problems and the ability to assist humans with tasks that are too difficult or unsafe for them.
- Decentralised decision-making — the ability of cyber-physical systems to make simple decisions on their own and become as autonomous as possible.

This requires MNOs to take on Industry expertise, specialist knowledge, commitment, governance, and use their network as the base-line of capabilities because MNOs have already addressed the key concerns in Industry 4.0, as highlighted:

- Data security issues are greatly increased by integrating new systems and more access to those systems. Additionally, proprietary production knowledge becomes an IT security problem. MNOs have a secure Authentication model in 4G/5G that is proven.
- A high degree of reliability and stability are needed for successful cyber-physical communication that can be difficult to achieve and maintain. MNOs have a demonstrable reliability/stability in their networks today.
- Maintaining the integrity of the production process with less human oversight could become a barrier. MNOs have known integrity and validation processes for production.
- Avoiding technical problems that could cause expensive production outages is always a concern. MNOs have been at the forefront of addressing these issues at a national deployment scale.

With a multi-faceted platform, MNOs could offer their network to be able to distribute new products and services beyond the Industry Integration, MNOs have a network that services many millions of devices and subscribers, therefore they have a natural conduit to change access, noting all MNOs now have a fixed and mobile infrastructure in place for businesses. In owning the platforms in the home, industry, etc., MNOs have to change the way they think and so need to provide API-driven, agile and open platforms with strong identity management to offer business partners, software applications, platform integration, common management tools for software and cloud environments. The evolution of 5G will take as long as the deployment of 4G towards mass adoption, but 5G is about "service enablement" via new spectrums, new architectures, reduced operating costs (via use of IP), open access to the network. Where the customer engagement and data application will enable the MNO who owns the data, offers the first point of connection, and defines what a customer will get, when and how and at market price, will have ownership over the whole value chain. There are many lessons to be taken from understanding Amazon's advance from shopping catalogue to a full value chain distribution network, something MNOs need to consider in their strategies. To do this, MNOs need to prioritise to support their businesses with platform and software development skills, service enablement, so they can onboard new products at speed, but maintain consistent experiences in terms of access, bandwidth, latency, etc.

ENABLING MOBILE DEMAND - MORE SPECTRUM RELEASES

Ofcom have so far auctioned two bands of spectrum to enable 5G services. 40 MHz was auctioned in the 2.3 GHz (available for immediate use) and 150 MHz auctioned for use in the 3.4 GHz (earmarked for future use). This auction increases the amount of spectrum available in the UK by around 30%.

Reserve prices have been set at £10m per 10 MHz in the 2,3 GHz band and £1m per 5 MHz in the 3.4 GHz band. Each operator will submit a closed bid, expected to exceed the reserve price.

In recent years restrictions have been placed on the ownership of spectrum, limiting some operators. EE/BT for example has reached a limit of usable spectrum, so were unable to bid on the 2.3 GHz spectrum. They are also only able to

gain access to 85 MHz in the 3.4 GHz spectrum. Vodafone were however able to win up to 160 MHz of total spectrum.

Five companies were approved for participation in the bid:

- BT (EE)
- Hutchinson 3G UK (Three)
- Telefonica UK (O2)
- Vodafone
- Airspan Spectrum - a small cell/backhaul tech leader

Four network operators were awarded spectrum following the auction, with Airspan Spectrum missing out in the auction. The entire 40 MHz of spectrum at 2.3 GHz was awarded to O2, with 40 MHz in the 3.4 GHz spectrum. Of the remaining spectrum in the 3.5 GHz band, Vodafone were awarded 50 MHz, EE were awarded 40 MHz and Three awarded 20 MHz. In total, the initial 5G auction raised £1.36bn.

Spectrum in the 700 MHz band (which will enable massive Machine Type Communication, mMTC) will go to auction in February 2019 and a report detailing the technical conditions and band plan for mmWave spectrum in Europe will be published in an European Communications Committee (ECC) decision and the results of the studies will be presented in the European Conference of Postal and Telecommunications (CEPT) Report. The target for publication of these documents is June 2018.

Ofcom's auction and spectrum release is paramount to enabling 5G where there will be multiple types of deployment scenarios which will be and could be dependent on the operator's available spectrum. However, the primary use cases will be initially around Fixed Wireless Access (FWA), transport deployments in rail & road, eHealth and manufacturing.

Ofcom will look to meet demands in rural areas through the 700 MHz frequencies vacated by Digital Terrestrial Television (DTT) services, which will be put up for auction in late 2019. This band has a significantly larger range than eMBB and uRLLC bands and Ofcom feel it is an opportunity to boost rural mobile coverage. It is proposing that successful bidders would have to deliver "good quality indoor coverage" to 60% of the 200,000 premises it is predicted will lack such coverage at the time of the auction. The 700 MHz band also demonstrates good indoor and underground penetration, opening up a number of use cases not dealt with by other aspects of 5G.

It is important to note that a number of key players interviewed as part of this study believe that a portion of available licensed spectrum in each of the 5G bands should be reserved for innovation and experimental purposes and not sold to network operators for commercial deployments.

Furthermore, rail enablement (Project Swift, etc.) will need alterations in Network Rail regulation around trackside access, rail carriage access to enable 5G.

Licensed shared access (LSA), where Industry bids for PNO models in 3.5 GHz and 26 GHz will allow service offerings outside of MNO capabilities, enabling other opportunities to use spectrum in an agreed licence model. For example, Germany has allocated three blocks to the incumbent MNOs and one block is reserved for Industry (PNO) use under the LSA (Licence Shared Agreement) Model (CBRS in USA is also a known model).

ENABLING NEUTRAL HOST MODEL

The ability to deploy small cells, distributed core networks and integrated network management has become an important part of the fast growing complements to deploying new spectrum and adding additional macro towers as UK mobile operators are focused on densifying their networks in urban areas. Small cells are becoming more common as an attractive option to increase capacity and extend coverage outdoors, and

distributed network solutions are becoming increasingly popular for enterprise buildings and high-traffic indoor venues. This leads to four different models for neutral host as outlined:

- Venue-led deployments, whereby venue owners (e.g. Arsenal FC, Cheltenham Racecourse) have been investing in Radio Access and fibre network deployments to monetise these business opportunities and create new revenues by offering a common network to all mobile carriers.
- Carrier-led deployments, whereby mobile carriers have taken the initiative to deploy and operate a multicarrier RAN solution in other sports stadiums, especially when the stadium carries the operator's brand.
- Tower company neutral host deployments, whereby indoor/external neutral host RAN deployments are a highly complementary opportunity to their primary multitenant tower business.
- Independent neutral host deployments, whereby a company designs, builds, owns and operates networks that support all four nationwide U.K. mobile carriers, and scale to mobile traffic growth.

However, there are challenges within the neutral host model that need to be addressed and supported in Ofcom whereby it addresses the following:

- Spectrum and regulatory issues are very regionally specific and can be daunting where regulators do not, for instance, permit spectrum sharing, but there are many signs of progress round the world as the need for neutral host becomes clearer.
- Management of neutral host solutions emerges as a perceived barrier, but there are many approaches which are already proven, in some cases borrowing ideas from DAS, whose approach will start to converge with small cells in the virtualised environment.
- Inbuilding - small cells Residential and Enterprise is a marketplace heading towards Fixed Wireless Access, it is a known solution for 3G/4G and 5G. However Wi-Fi with Wi-Fi calling is another solution to the coverage issue.
- Access to the right spectrum to enable and offer Smart Energy Services
- Addressing the wider issue of BackHaul/ Transmission and how Neutral Host Connectivity is managed.

5G ARCHITECTURE DEPLOYMENT

Non-Standalone (5G NSA) will be the first deployment method for 5G. It will link 4G Core networks to 5G Radio Access Network, where 5G will be focused on U-Plane alone, while LTE used for control including call origination/termination, location registration, etc. The 5G radio control parameters will be exchanged through LTE, whereby enablement in the CN for those functions should be added to eNB. The UE will monitor the control channels in LTE. Later in 5G SA, whereby 5G Core and 5G RAN are connected, this changes where 5G can work alone in its own network, and local registration is where 5G will be used for both U-Plane and C-Plane, 5G radio control parameters can be exchanged through 5G, and UE monitors paging channels on 5G.

Within the basic scenarios, we have different deployment scenarios, called Fronthaul and C-RAN.

The term Fronthaul is used to describe the connection between the cell tower radio itself (Radio Head or RH) and the mobile network control backbone (the Baseband Unit or BBU). CPRI is a well-known standard for this interconnection. Backhaul on the other hand is the linkage between a base station and the core wired network, is often fibre or coax, and in some cases broadband/proprietary wireless links. Fronthaul, backhaul, and various hybrid architectures will be needed to accommodate cost efficient, backwards compatible, dense deployment of network infrastructure necessary to provide the broadband, low latency demands for 5G systems.

The fusion of fronthaul and backhaul into an integrated 5G Transport Network is a forward-looking concept that targets a flexible, reconfigurable, software defined transport architecture. It envisions a single network that can support a variety of functional splits between the antenna and the packet core. This view aligns with the evolution of Network Function Virtualisation (NFV) and Cloud RAN (CRAN) which points to a data centre that can be configured to support whatever functional split is deployed in the network. At one extreme, a legacy base station and backhaul can be accommodated. At the other extreme, a network of densely distributed radio heads configured for massive MIMO can exchange compressed digitized radio samples for cloud-based processing.

The challenge for Fronthaul will be the cost of dark fibre pricing in UK, as well as access/location to fibre. Then ensuring the developed set of standardised interfaces and a fabric of high-capacity switches that meet the bandwidth, latency, and jitter requirements necessary for all the 5G applications. The interconnection among elements must support fibre, high capacity copper, wireless optics, or millimetre wave wireless links. And, of course, the new network must be backwards compatible with legacy transport systems to enable cost-effective migration.

Ultimately the need is to provide 5G levels of performance in a cost-effective manner, and to limit the ever-increasing growth in OPEX and CAPEX. A crosshaul-type system could provide major gains via software configurability, both for the transport network and by enabling the data centre cost savings promised by NFV and CRAN concepts. Other advantages would be energy efficiency by enabling dynamic activation and de-activation of network components and enabling multi-tenancy and network sharing. The combination of all these benefits may well be a key to the economics of 5G and beyond, and the continuing growth of the mobile wireless technology.

C-RAN architecture is different from FrontHaul, and has the following characteristics that are distinct from other cellular architectures whereby large scale centralised deployments, for example hundreds of thousands of RRHs connect to a centralised BBU pool. This works where you have a maximum distance between RRH and BBU which can be 20 km in fibre link for 4G (LTE/LTE-A) system, even longer distance (40 km~80 km) for 3G (WCDMA/TD-SCDMA) and 2G (GSM/CDMA) systems.

NFV is a key enabler of the coming 5G infrastructure, helping to virtualise all the various appliances in the network. In 5G, NFV will enable network slicing a virtual network architecture aspect that allows multiple virtual networks to be created atop a shared physical infrastructure. Virtual networks can then be customised to meet the needs of applications, services, devices, customers or operators. In 5G, NFV will also enable the distributed cloud, helping to create flexible and programmable networks for the needs of tomorrow.

NFV AND NETWORK SLICING IN 5G

In 5G NFV will permit a physical network to be separated into multiple virtual networks that can support different radio access networks (RANs) or various types of services for specific customers, or customer segments. For the user these network slices will appear as separate networks.

Network slicing will play a crucial role in 5G networks because of the multitude of use cases and new services 5G will support. A primary 5G NFV network slicing use case will be a more powerful mobile broadband with lower latency, but it will also lead to great benefits in bandwidth, mobility, resiliency, security, and availability. Future 5G networks will offer operators the flexibility to allocate speed, capacity, and coverage in logical slices according to the demands of each use case.

MULTI-ACCESS EDGE COMPUTING

Multi-access Edge Computing (MEC) offers application developers and content providers cloud-computing capabilities and an IT service environment at the edge of the network. This environment is characterised by ultra-low latency and high bandwidth as well as real-time access to radio network information that can be leveraged by applications. MEC provides a new ecosystem and value chain. Operators can open their Radio Access Network (RAN) edge to authorised third-parties, allowing them to flexibly and rapidly deploy innovative applications and services towards mobile subscribers, enterprises and vertical segments.

Multi-access Edge Computing will enable new vertical business segments and services for consumers and enterprise customers.
Use cases include:

- Video analytics
- Location services
- Internet-of-Things (IoT)
- Augmented reality
- Optimized local content distribution
- Data caching

It uniquely allows software applications to tap into local content and real-time information about local-access network conditions. By deploying various services and caching content at the network edge, Mobile core networks are alleviated of further congestion and can efficiently serve local purposes.

MEC industry standards and deployment of MEC platforms will act as enablers for new revenue streams to operators, vendors and third-parties. Differentiation will be enabled through the unique applications deployed in the Edge Cloud. Looking at MEC it offers a set of capabilities that can be deployed into the network:

- The Mobile Edge Platform sets the policy and configuration rules for forwarding user plane traffic to MEC applications. It also provides a set of services that expose radio network data and other real-time context information to authorised MEC applications.
- The Mobile Edge Orchestrator maintains an overall view of the deployed MEC Servers to determine the optimum location(s) for instantiating an MEC application.
- The Mobile Edge Platform Manager is responsible for lifecycle management of the MEC applications and management of the MEC Application Platform.
- The Virtualised Infrastructure Manager is responsible for managing the resources of the virtualised infrastructure, which also includes preparing the infrastructure for running a software image.
- Mobile Edge Applications – MEC-enabled services provided independently of the platform are what make MEC valuable. They must use the MEC application programming interfaces (APIs) (definition in progress) and be manageable within the NFV framework.

Today, CSPs are deploying Control and User plane Separation (CUPS) and learning how to do it within their Network, noting Cisco is deploying CUPS with TMO-US. As CSPs understand how they will deploy MEC offers a solution to Fronthaul where connectivity needs a different solution. Thereafter ONAP should move into the RAN so RAN will become OAM Orchestration enabled to address workload. This is where AI will evolve in RAN Network. ONAP (Open Network Automation Platform) is an open source software platform that delivers capabilities for the design, creation, orchestration, monitoring, and life cycle management of Virtual Network Functions.

POTENTIAL FOR THE UK ECONOMY

There are a number of areas where the UK is set to benefit from the advent of 5G globally. This is a combination of the companies present and a strong manufacturing base in the UK as well as strong investment and a number of pre-5G trials and tests taking place that are expected to scale up to fully deployed solutions.

INDUSTRY SPECIFIC USE CASES

The next sections outline the needs of the various industry sectors for telecoms and potentially 5G applications, by using five categories (Coverage, Reliability, New Device Requirements, Latency and Bandwidth) to demonstrate the needs at a high level for any solution deployment.

This chapter represents a set of use cases covered by the studies and workshops run. There are other industry sectors that are not covered here that remain valid candidates for 5G ecosystem building.

HEALTHCARE

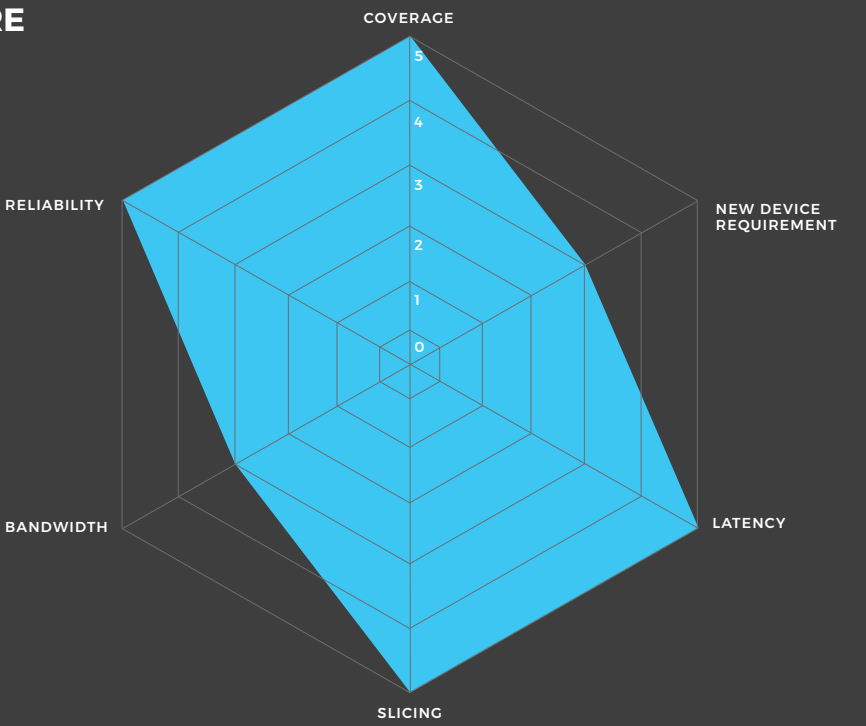


Figure 17
Requirements for 5G in healthcare (where 0 = no change from the existing technologies and 5 = substantial change from existing technologies)

Adopting digital health solutions is a priority for the NHS. At a national level one of the key actions from the NHS Five Year Forward View is to "exploit the information revolution." It is hoped this will achieve greater efficiencies and address the £30bn funding gap anticipated for the NHS by 2020. Within the Digital Catapult survey, 35% of respondents said that Health was a key area for 5G adoption and, as an industry sector, was ranked 4th overall for potential use cases and development of solutions.

According to Deloitte, the UK market size for digital health is expected to grow to £2.9bn in 2018. Digital healthcare services can range from future services like remote and robotic surgery, to current services such as monitoring vulnerable out-patients remotely and improving access to patient records.

The biggest benefits of digital healthcare solutions will be on reducing the strain on the NHS, in particular achieving greater efficiencies and cost savings. Remote healthcare applications that utilise real time data via 5G can enable the delivery of healthcare services at a lower cost. This reduces the strain on physical resources and brings benefits such as reducing the number of missed appointments, currently costing the NHS over £1bn a year. It is predicted that up to 30% less transits to hospital, resulting in a multi-million pound saving per NHS trust, could equate to £10m saving in fuel across the ambulance trust per year and £122m per year saved in bed occupancy across 136 NHS hospital.

Assisted living solutions provide further benefits to those patients that could be cared for at home, e.g. dementia sufferers, who currently constitute 25% of hospital in-patients. This could help reduce the annual national cost of £26bn a year from dementia patients. Preventative health solutions can help address the issue of obesity by allowing people to take better care of their health through a variety of fitness applications. This is expected to lead to reduced use of health case savings and thus decrease costs for treating patients who suffer from various conditions.

A DCMS Testbed and Trials project taking place in Liverpool will look at the use of 5G in health and social care. The project will measure the impact on patient monitoring and support, management of loneliness in older adults, aid to independent living at home and the facilitation of communication between hospitals and the community. The Scotland Broadband project , PillCam trials also demonstrated the need for high bandwidth connectivity to transfer data from GP surgeries to hospitals. Such applications show the potential opportunities for 5G in e-health as data use by healthcare providers increases.

Other potential uses of 5G for health and emergency services were recently demonstrated by King's College London in collaboration with BT, Verizon and Ericsson. Looking into how 5G enabled technologies will deliver so much more than just enhanced mobile broadband, the project demonstrated autonomous control and management of a fleet of drones in central London. The demonstration, which used new pre-commercial 5G radio, was achieved by building a 5G core and creating two network slices with: a low latency breakout for a BT end user and a Verizon low latency breakout. These applications could include advanced disaster recovery services using drones, such as delivery of equipment, medicine, food, water and blood or the rapid deployment of a temporary cellular network using drones to enable vital communications.

PUBLIC TRANSPORT

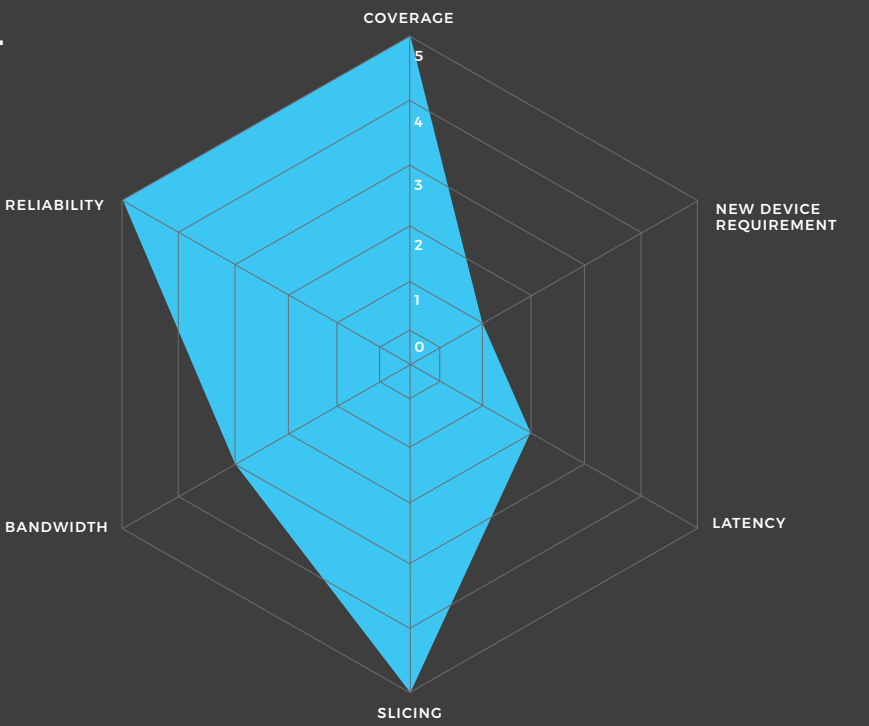


Figure 18
Requirements for 5G in public transport (where 0 = no change from the existing technologies and 5 = substantial change from existing technologies)

Through our study, we contacted 15 organisations to gather evidence of 5G activities in the transport sector, including those who were selected as winners of DCMS's first phase. AutoAir will be a 5G testbed for connected and autonomous vehicles led by Airspan Communications. The surveys primarily highlighted the need to provide wide-area connectivity, minimise deployment cost and a preference for lower spectrum bands versus high bandwidth connectivity with mmWave spectrum deployed on transport routes. It was also mentioned that serving high speed trains and vehicles is an important factor driving spectrum choice.

The survey reflected similar points around the need for reliability, coverage and support for Network Slicing when dealing with different use cases. The opportunity for 5G in public transport (specifically rail) lies largely in delivering low latency applications for vehicles and infotainment, including backhaul connectivity for trains to deliver high bandwidth video on trains for passengers. This points to the fact that rail needs to find the right balance between optimal 5G spectrum balancing on the one hand and the need for high data throughput (which leans towards higher frequencies, such as mmWave) and on the other hand the cost of deploying the infrastructure needed to provide coverage (which leans towards lower bands such as 700 MHz for better coverage).

Automation for trains has also been touted as a potential application, however a number of interoperability dependences were raised, as well as the challenges of new technology being adopted using the correct and relevant technical specifications. These applications will drive network architecture with requirements of mmWave band usage.

The main use cases for 5G adoption in public transportation identified from the interviews included:

- Real-time infotainment in vehicles and trains (enabling wireless on board) (eMBB)
- Real-time passenger information and positioning
- Autonomous trains (URLLC)
- Network slicing provisioning to serve both rail and road from a single infrastructure bearer

Successful connectivity to transport routes is dependent on additional spectrum and infrastructure. As has been noted previously for rural deployments, shared infrastructure and spectrum could unlock significant opportunities for transport routes in the UK. A major barrier however, could be the interoperability across borders and ensuring there is a common approach and transition period towards 5G, so there is minimal disruption to train services in Europe.

The published industrial strategy set out by HM Government in November 2017 highlighted "connectivity for passengers on all mainline routes could be dramatically improved by 2025. Each train could get speeds of around 1 Gbps. This would future proof the connectivity, and in practice could allow several hundred passengers to stream uninterrupted video content at the same time." In order to provide a service of around 100 Mbps per passenger, LS Telecom estimated approximately 8,300 additional sites would be needed for a future network compared to approximately 3,270 for a mobile broadband solution based on today's technology. Additionally, a dedicated trackside fibre access layer would need to be deployed, costing £150-250m.

The government has also issued a call for public input into a series of proposals to enhance mobile connectivity for rail passengers, with the aim of bringing gigabit mobile broadband to trains by 2025. The government hopes to utilise existing trackside fibre, owned by Network Rail, in order to support commercial business opportunities. The key to unlocking 5G access for rail will be the deployment of a neutral host solution with access to either existing or new connectivity along the trackside for the backhaul and connecting to wireless radio equipment mounted on existing or new masts. It is currently possible to test this model at RIDC Melton with Network Rail providing the facilities needed for trackside trials including access to fibre, masts, trains and trackside equipment model and fed small cells.

The trans-Pennine route, connecting York and Manchester is already testing how to use existing infrastructure and Network Rail infrastructure to test track to train systems.

The North East Combined Authority (NECA) plans to open up seven corridors of opportunity by upgrading strategic highway links including Northumberland to Newcastle rail connections, the Leamside line and the Durham coast line, as part of a £60bn transport upgrade. Such upgrades include smart ticketing, improved rail infrastructure as well as direct to consumer connectivity. This long-term improvement programme will make use of 5G connectivity for a range of machine-to-machine and consumer based technologies.

PERSONAL TRANSPORT

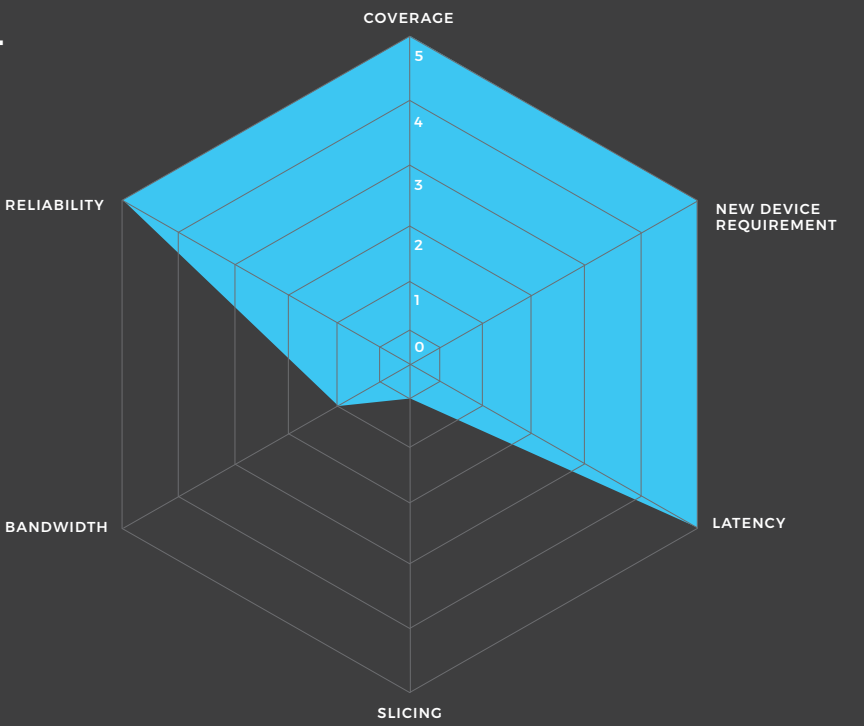


Figure 19
Requirements for 5G in personal transport (where 0 = no change from the existing technologies and 5 = substantial change from existing technologies)

Connected Autonomous Vehicles (CAVs) are seen as the next phase in personal transport. Where 5G aims to address two types of communication that will provide us with enhanced connectivity: vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications.

In October 2017, Millbrook announced that it had successfully bid to become one of the leading testbeds for CAV testing in the UK. It is working in collaboration with the United Kingdom Atomic Energy Authority's centre for Remote Applications for Challenging Environments (RACE), as part of the project co-funded by the Centre for Connected and Autonomous Vehicles (CCAV) through Meridian. With significant further investment in a range of ADAS test capabilities, this most recent announcement reinforces Millbrook's position as the UK's leading test and validation facility for the full range of CAV and ADAS requirements.

The DCMS AutoAir project award (March 2018) is a consortium of partners lead by Airspan Networks and is to be hosted at Millbrook. It is a unique, accelerated development programme for 5G technology and is based on 5G New Radio (NR) small cells that operate on a "Neutral Host" basis. The shared neutral host platform allows multiple public and private 5G operators to simultaneously use the same infrastructure using network slicing, which can radically improve the economics for 5G networks.

Autonomous vehicles are ranked on levels 0-5 by the society for automotive engineers (SAE), with a level 5 autonomous vehicle having no steering wheel or any form of human input. Ford, among other international

OEMs, plan on commercialising level 4 autonomous vehicles in 2021. Throughout our engagement, the stakeholders have named CAV use cases as one with great potential, especially in urban areas where transport systems are a major issue. The government wants to become a leader in CAVs, and has therefore put forward more than £100m with match funding from the industry taking the total spend up to £200m over four years. The University of Warwick and undertaking a CAV trial that will deploy the largest connected testbed be in the UK (around 65 km) and will be deployed using fibre and small cells. It will be open to all MNOs and will be technology agnostic supporting the deployment of 5G when it is ready. Similarly, the UK Smart Mobility Living Lab in central London will support 5G connectivity.

Although 5G is not the only enabler for CAV technology, and not all of these projects have an element of 5G associated with them, it is widely accepted that 5G will assist in several CAV services and applications. This next generation of vehicles will require low latency, high volume transmission of data, with autonomous vehicles potentially creating terabytes of data every day. The growth and expansion of autonomous vehicles in the UK will require reliable coverage of cellular data across the UK road networks. Cellular networks utilising 3G/4G are currently underdeveloped and significant investment is required in order to provide the required connectivity for large scale, high volume data transfer. DCMS has announced a feasibility study to use existing 'Highways England' infrastructure to support 5G connectivity. Similar business models used for track side infrastructure with neutral host and deployment of Mobile Edge Compute (MEC), are also seen as applicable for road infrastructure.

Another use case that stood out from the stakeholder engagement was for improvement in freight operations and connectivity providing for real-time updates and control of haulage vehicles. This potentially has huge business case benefits and cost savings on automating the operations for freight.

Autonomous vehicle pilots in the UK

There exist in the UK a number of autonomous vehicle pilots and demonstrators, at small scale across the UK. Heathrow airport has deployed autonomous vehicles, from British manufacturer Westfield Sportscars, to shuttle customers between Terminal 5 and the terminals car parks, further trials are taking place in Bristol, Coventry (UK CITE) and Milton Keynes. Milton Keynes will be testing the capabilities of a 2 x 3 km 5G network to control 40 autonomous pods. The network is required to transmit large amounts of high quality video data (eight cameras per pod) for security, management and safety. Highways England is working on the M2/A2 connected corridor and is exploring the potentials of 5G connectivity as one of the connectivity options. AutoAir, the DCMS Phase 1 project focusing on CAV, will investigate the capabilities of 'Neutral Host' infrastructure, which can be shared among operators to avoid redundant private network overlap.

E-CAVE is a UK based industry project that focuses on the challenges of creating effective connected environments. The four year project led by Ordnance Survey will look at how CAVs will exchange safety-related messages between themselves and their supporting systems and important geospatial elements. Ordnance Survey are also actively involved with CAV testing across the four recently announced CAV testbed projects overseen by Meridian.

The primary driver for successful rollout of 5G enabled CAVs, will be the adoption of autonomous vehicles by consumers and public transport sectors in the UK. Strong uptake of autonomous vehicles, enabled by 5G, will have significant impact on other parts of the UK economy, including disruption to the insurance, licensing, healthcare, advertising, emergency services and maintenance industry among others.

One of the largest industrial alliances surrounding 5G is the 5G Automotive Alliance (5GAA). The alliance includes several UK business and organisations heavily invested in the UK economy, acts at the interface between key players in the automotive and telecommunications industry. A parallel Europe-centred alliance is the European Automotive-Telecom Alliance (EATA), again with UK presence from the automotive and telecom industry. These organisations provide opportunities for UK industry to affect the standards and policies around both CAVs and 5G.

MANUFACTURING

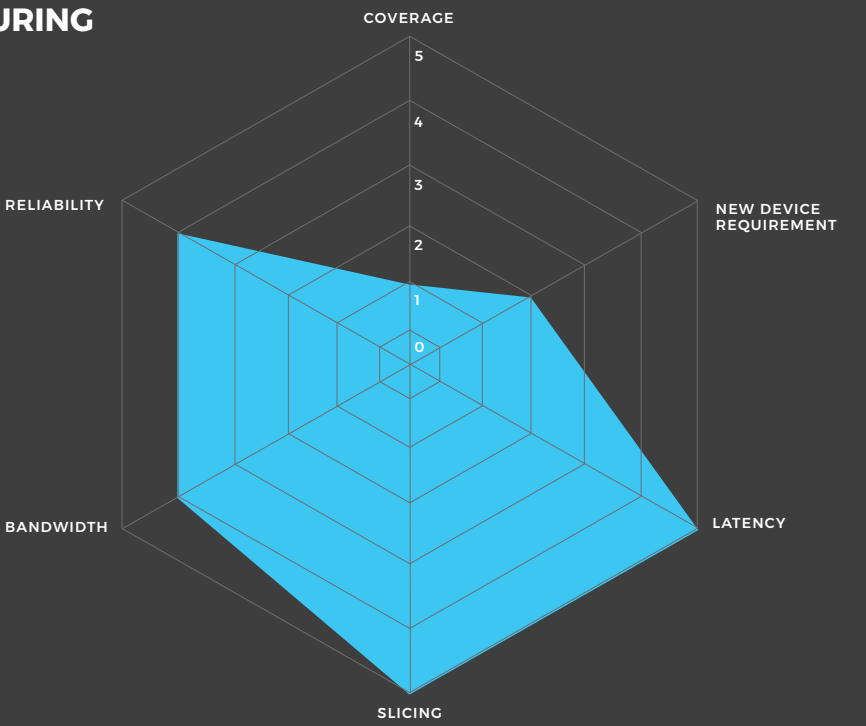


Figure 20
Requirements for 5G in manufacturing (where 0 = no change from the existing technologies and 5 = substantial change from existing technologies)

5G networks offer manufacturers and telecom operators the chance to build smart factories and truly take advantage of technologies such as automation, artificial intelligence, augmented reality and the Internet of Things (IoT).

With 5G, operators can create new revenue streams. Alongside energy and utility, manufacturing represents one of the most significant sectors for new revenue potential for operators addressing industry digitalisation with 5G technologies. According to the Ericsson study, the 5G Business Potential, the expected addressable market in 2026 for manufacturing will be USD 113 billion, a substantial 7% potential revenue growth from current service revenue forecasts.

In particular, the following capabilities of 5G networks could be beneficial:

- Ultra low latency for artificial intelligence or AI-driven wireless robots.
- Always-on connectivity for massive numbers of components and sensors.
- High security and reliability (compared to other wireless options).
- High mobility (e.g. for automatic guided vehicle or AGVs).
- Digital twins – real-time visualisation of data for virtual replicas of production environments and equipment.

These capabilities can be applied to the following manufacturing use cases:

- Smart factory and robotics.
- Testing and producing advanced vehicles such as self-driving cars.
- Smart supply chains.

In our survey, we found that the key attributes for 5G in this sector were: Bandwidth, Latency and Network Slicing as being the important capabilities from 5G, with an additional requirement to use distributed cloud. This enables placing of workloads closer to the edge for better quality of service such as latency.

Often referred to as Industry 4.0, or the fourth industrial revolution, digital manufacturing uses cyber-physical systems for a range of applications including asset tracking, process control and remote management of the factory floor. The UK is currently home to 266,000 manufacturing business as of 2017, making up 10% of GVA and 45% of UK exports. There are 2.7m employees directly associated with manufacturing as of 2017.

Industrial usage of 4G has been very limited, there is however, potential for much greater scale in Industrial IoT (IIoT) for 5G. Manufacturing applications that can benefit from cellular mobility, security and low latency include mobile robots within factories, remote control of factory and supply chain processes, test vehicles for automotive manufacturers, autonomous robots and small-scale vehicles and tracking across a supply chain, both nationally and internationally.

Many UK manufacturers have invested in LTE-A and in low power IoT networks (LPWAN), and believe these already perform around 80% of what is expected with 5G. Manufacturers are generally reluctant to upgrade legacy systems without a confirmed business case, typically systems are upgraded every five years or more, while there is a current lack of uncertainty about spectrum and the timescales needed to achieve critical mass of affordable devices and equipment. However, one of the sectors that more immediately see the benefit of 5G is automotive manufacturing since it has a sophisticated understanding of 5G roadmaps as it develops CAV features in product lines.

The primary drivers for adoption of 5G and other digital technologies by manufacturers is the ability to reduce operating costs, improve efficiency and increase outputs. Adoption of 5G enabled technologies is likely to be adopted under an 'invest to save' model for the manufacturing industry. A prime example of this, even though it does not use 5G equipment, is the bespoke wireless warehousing system for Ocado in collaboration with Cambridge Consultants around automation of the supply chain. Furthermore, Nissan's smart factory in Sunderland produces 500,000 cars with only 6,700 employees, supported by autonomous goods vehicles. 5G connectivity could allow them to roam more freely and support a wider range of tasks, increasing productivity further.

The UK's first Industry 4.0 smart factory incubator opened in 2015 at the Manufacturing Technology Centre in Coventry. This could generate an additional £20bn in revenue for UK manufacturers, although not all related to 5G. Worcestershire LEPs successful DCMS 5G Testbeds and Trials Programme phase 1 bid is focused around the manufacturing industry through their 5G consortium, made of industry, private companies & public-sector players. The testbed programme will seek to connect sensors for predictive maintenance. The consortium predict 5G will enable the connection of up to 1000 sensors connected per km2, with each sensor transmitting around 5Mbps.

IMMERSIVE TECHNOLOGIES

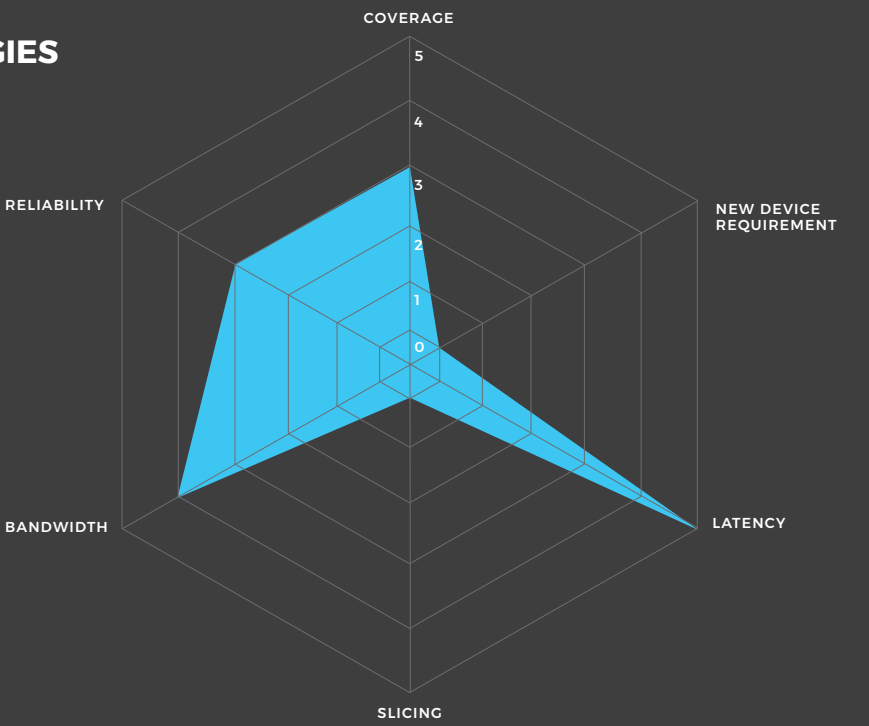


Figure 21
Requirements for 5G in immersive technologies (where 0 = no change from the existing technologies and 5 = substantial change from existing technologies)

The immersive technologies sector is experiencing extremely high growth worldwide. The UK is a recognised centre of excellence for VR/AR technologies and is already benefitting from this high growth rate in terms of emerging new startup companies. From the equipment providers perspective our discussions show that VR/AR is seen as a "killer application" for 5G, due to its need for low latency to enable streaming of data and large scale experiences.

There are three main areas where use cases in this sector will provide benefit for the UK economy.

1. Better and faster wireless connectivity could help encourage both enterprises and startups to undertake R&D for disruptive products and services in this domain. Investment could provide opportunities to industry participants to test new products or services at different scales to bring disruptive solutions to market?
2. Data-driven automation in manufacturing technology is already happening. Together with advanced cloud computing services and ultra HD video technology, VR and AR are likely to disrupt multiple markets from manufacturing and logistics to healthcare and real estate. Investment could help accelerate industry's adoption of Industry 4.0 concepts by enabling both businesses and solution developers to trial disruptive solutions in the real world.

3. Content and software development are critical to emerging mobile media and cloud services, especially to VR/AR, and Ultra HD video. The lack of available content and software could significantly affect product or service adoption or market penetration rate. Investment could be an opportunity to further encourage content and software development for new hardware by enhancing collaborations among key players in the ecosystem.

Immersive technologies are of great importance to the UK economy, with 460 AR/VR companies operating here (65% in producing content, 25% in developing the technology that enables VR experiences to be built and enhanced and the remaining 10% are in the service sector e.g. marketing services, tailored legal and content licensing services) as well as the UK being the largest VR market in the EMEA region. Augmented, virtual and mixed reality content is widely expected to be accelerated with the advent of 5G. The high speed of download will enable content to be streamed in high definition to headsets, especially outdoors where Wi-Fi and wired connections are less prevalent. This growth in immersive technology presents huge opportunities for the UK economy, which is already considered a leader in digital content creation.

There is an active discussion of 5G/VR convergence when it comes to other stakeholders: MNOs, chip and device designers, large VR players (e.g. Facebook), and some vertical industries. By contrast with the specialists, these see VR/AR as a 'killer application' for 5G. Examples of where VR/AR has demonstrated significant opportunities in the UK include the project that Thomas Cook are running, resulting in additional revenues of £12,000, and a 40% ROI, during a limited three-month pilot and will now be scaled up. Additionally, John Lewis has deployed AR for in-store services since 2015, working with Cimagine, John Lewis created a virtual showroom in store. Using Cimagine AR technology they were able to turn any physical space into a virtual showroom filled with high resolution computer generated furniture and appliances. Although these projects do not involved a 5G element, the ability to have mobile VR/AR, could potentially increase the engagement, sale and interactivity of these products, services and experiences. UK retailers could make an extra £1bn a year in revenue from home furnishings alone, if consumers could use mobile VR technology to place products virtually in their own homes, while in-store.

One of the key verticals where VR/AR is employed is the gaming industry. The value of the UK games market, at £4.33bn, was up 1.2% compared to the previous year, while mobile games revenues were up almost 17% to £995m, according to UKIE .

It is widely expected that 5G will enable enhanced AR/VR experiences and be a top use case for 5G by 2023, but many conditions need to be put in place. Mobile network operators are struggling to find the monetisation case for such technologies, while AR/VR specialists largely believe that other enablers are more important to user experience, including; display capabilities, powerful processors, artificial intelligence to work with VR to support fully responsive and context-aware

immersive experiences and edge computing to support low latency communications. The 5G Smart Tourism project, funded by the first phase of DCMS 5G Testbed and Trials Programme, will investigate the aspects of mobile AR/VR and the business case around such use cases. A preview of that was demonstrated at the event "Layered Realities". Furthermore, the Worcestershire testbed will also look into mobile AR from the manufacturing perspective.

Barriers to 5G in VR/AR seem to be high in 2018, with a general lack of standards and interoperability allowing equipment to interact with and content to work across devices. Questions that still surround immersive in 5G include how MNOs will deploy ultra low latency 5G and how these networks will be monetised, (e.g. whether consumers will be willing to pay a premium and where hardware will become sufficiently cheap enough to enable mass consumer uptake).

Immersive content will have a range of connectivity requirements, depending upon the use case itself. Almost all use cases will require ubiquitous mobile broadband connectivity with cell sites deployed across the built environment. The number of cells sites required to cover the city will vary depending on a number of factors including:

- Geographic profile e.g. urban, suburban and rural
- Spectrum band(s) used
- Network capacity required

It is estimated that to deliver the likely coverage and capacity required for the majority of use cases, cell sites will be needed every 0.2–5 km2.

The most important attributes of 5G, according to the stakeholders, which would enable these business changes, are:

- Wireless connectivity of a quality to enable richer and 360-degree content. In these cases, the network must deliver sufficient speed and low latency. Fully immersive 360-degree experiences require at least 25Mbps for streaming and go up to 100Mbps for HDTV. With a global average of 7.2Mbps, only about 12% of global connections satisfy these requirements.
- To be fully realistic and avoid motion sickness, VR requires less than 1ms latency – currently the global average latency is 36ms on fixed and 81ms on mobile.
- Forthcoming video formats will be more data-intensive to support VR/AR – for instance, interactive six degrees of freedom (6DoF) video, which allows users to move around within recorded videos, can require up to 10x the bitrate required for 4K video.

As well as faster, lower latency, more ubiquitous wireless connectivity, that platform will embrace other technology enablers of VR/AR, including:

- AI to work with VR to support fully responsive and context-aware immersive experiences at scale. This needs to be accessible by consumer devices e.g. on an 'as-a-service' basis and at scale (Google's AI core currently supports five device models – greater hardware penetration is required). In the UK, Google and Microsoft have advanced activities in this area.
- Edge computing, to support low latency communications and bring computing resource, for instance for AI and advanced graphical processing, closer to the device. This is a major focus of development in the UK by NVidia and ARM, and in Europe by NXP, for instance.
- New device components including the evolution of video display technology. 4K is a minimum but looks sub-HD when dealing with 360-degree content. To have the best AR/VR experience, devices need to have superior image display (at least 2560x1440 resolution) and audio, powerful processors, large memory space and adequate battery life. Today, fewer than 10% of smartphones worldwide are compatible with popular VR companions like Samsung Gear and Google Daydream. Most screen technology development is led by countries in Korea, Japan and China.

HARDWARE

With the potential for billions of devices to be connected to 5G networks over the next decade, there is huge opportunity in hardware manufacturing for the UK to take advantage of both end devices and component design and manufacture.

The Compound Semiconductor Centre (CSC) was established in Newport, South Wales in 2016. This is a UK Government funded project to develop and nurture this highly specialised area of expertise. The decision to locate this in South Wales was based on an existing cluster of highly advanced businesses operating in this sector. The CSC is now a focal point for this sector and has started to facilitate new sector specific initiatives. One such initiative is the development of a supply chain cluster focused on future 5G technologies. CSC's will be critical to future communication technologies, this knowledge has brought together a strong group including academia, business, manufacturers and local political presence to help develop the supply chain mechanisms required for the cluster to thrive in the future. This 5G supply chain cluster was established in late 2017.

The cluster is formed of the following organisations:

- Compound Semiconductor Centre
- IQE
- National Instruments
- Newport Wafer fab
- Microsemi
- Cardiff University

IQE is ideally positioned to provide components to the emerging 5G ecosystem, from 5G handsets to ubiquitous IoT devices. Currently some 80% of its revenues are being obtained from existing 4G devices.

It is worth noting that although the UK does not have big chip manufacturing factories based in the country, UK councils in the Cardiff Capital Region are set to develop a foundry for technology behind 5G in Newport, which could create about 2,000 high skilled jobs in five years. Funding of nearly £38m has been announced for the facility to make compound semiconductors. The factory will be owned by the councils and is projected to create £375m of private sector investment over the next five years.

Further to this, Edinburgh is a hub for semiconductor design giant Xilinx, its first R&D centre outside of North America. A recent investment of £6m from Xilinx and Scottish Enterprise has generated 12 new jobs and secured 30 existing roles, focusing on developing products for future communications systems .

Other players with a UK presence that are already involved in designs for 5G hardware infrastructure include Teledyne, which is working with a Tier one vendor on E-band fixed wireless access, and Filtronic Broadband, which has designed a 26 GHz 5G front-end module platform in collaboration with Plextek RFI as well as working on high-capacity E-band and W-band backhaul for 5G.

LAUNCH PLATFORMS FOR 5G IN THE UK

The Olympic Winter Games in PyeongChang, South Korea demonstrated the first steps towards 5G development and potential scenarios. The UK will host a number of global sporting events in the next five years, including the 2019 Cricket World Cup, the 2019 world cycling championship, seven games or the 2020 UEFA European championship, the 2022 Commonwealth games, these present an optimal opportunity for the UK to demonstrate its capabilities in 5G. These events could become major launch platforms for 5G in the UK, with major MNOs having already installed fibre networks at many venues as well at EE being a title sponsor of Wembley Stadium.

With large scale networks becoming commercially available from 2020, these events give the opportunity to demonstrate the capabilities of 5G to a wide audience.

5.

CONCLUSIONS

The UK's 5G landscape is active and growing rapidly. This development brin gs the UK to the forefront of the global 5G activities

In preparation and completion of this report Digital Catapult conducted a targeted public survey, more than 75 interviews and seven workshops, whilst commissioning regional, industry and technology focused studies to provide this snapshot of current activities and an informed analysis of 5G activities in the UK.

As a result of this study, Digital Catapult has identified 57 companies, 39 academic institutions and 29 local authorities in the UK actively involved in 5G projects and other activities. In addition to the industry and European funded projects taking place, the first major government funded testbed and trials projects have begun, with six programmes taking place across the UK. Made of consortiums with key players from industry, academia and local governments in a variety of use cases.

There are many benefits to the UK economy arising from the development of this 5G ecosystem, primarily in faster and more capable wireless connectivity, data driven automation and opportunities for content and software development. These benefits generate demand to unlock opportunities for healthcare, transport, manufacturing and the creative industries as well as opportunities to manufacture modules for 5G at the UK's semiconductor design hubs in South Wales and Edinburgh.

With the UK 5G ecosystem moving closer to commercialisation, there is a recognised need for coherent thought leadership, across government, academia and industry, on the priorities for the UK in 5G, from both a development and commercial deployment perspective. This can then lead to a coordinated deployment support strategy that can be delivered through a mixture of immediate business case-supported investment, and a longer term strategic intervention to create the business case and the delivery business models through an innovation programme.

There remain several barriers in the deployment and adoption of 5G in the UK, many similar to other countries. The UK 5G community is working to identify what technology development and solutions will be required over the next five years, (FWA, Fibre Deployments, Small Cells, mMIMO, Network slicing). The 5G architecture is no longer a one size fits all. It is important to build upon the DCMS 5G Testbed and Trials programme to accelerate deployment from 2020 onwards.

Going forward there is a recognised need to coordinate proactive demonstrations both in the UK and abroad, of the advances realised by the UK 5G Ecosystem, in particular those enabled by the government intervention in the 5G Testbed and Trials Programme, but also increased commercial activities, with targeted activities for developing both export opportunities as well as inward investment. With large scale networks becoming commercially available from late 2019/early 2020, the wide range of international sporting events taking place in the UK over the coming years (including EURO 2020 and the 2022 Commonwealth Games) provides the opportunity to demonstrate the capabilities of 5G to a wide audience.

ANNEXES

Digital Catapult has compiled a full list with details of the 236 activities and projects currently ongoing in the UK. This includes 135 academic, 66 industry, 29 local government, and the six 5G Testbeds and Trials funded testbeds.

The full list is provided as a supplementary document. The document can be downloaded from www.digicatapult.org.uk/projects/5g-mapping

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GLOSSARY

3G Partnership Project (3GPP) – unites telecommunications standard development organisations and provides their members with a stable environment to produce the Reports and Specifications that define 3GPP technologies. The project covers cellular telecommunications network technologies, including radio access, the core transport network, and service capabilities - including work on codecs, security, quality of service - and thus provides complete system specifications. The specifications also provide hooks for non-radio access to the core network, and for interworking with Wi-Fi networks.

5G Public Private Partnership (5G-PPP) – is a joint initiative between the European Commission and European ICT industry (ICT manufacturers, telecommunications operators, service providers, SMEs and researcher Institutions).

Average Revenue Per User (ARPU) – One of the metrics used primarily by consumer communications, digital media, and networking companies, defined as the total revenue divided by the number of subscribers.

Cloud Radio Access Network (C-RAN) – is a proposed architecture for future cellular networks, whereby baseband processing of the access network is performed in a centralised datacentre.

Communications Service Provider (CSP) – is a service provider that transports information electronically - for example, a telecommunications service provider. The term encompasses public and private companies in the telecom (landline and wireless), Internet, cable, satellite, and managed services businesses. CSPs include the following categories: Telecommunications carrier, content and applications service provider (CASP), cable service provider, satellite broadcasting operator, and cloud communications service provider.

Customer Premises Equipment (CPE) – is any terminal and associated equipment located at a subscriber's premises and connected with a carrier's telecommunication channel at the demarcation point. CPE generally refers to devices such as telephones, routers, network switches, residential gateways (RG), set-top boxes, fixed mobile convergence products etc.

Enhance Mobile Broadband (eMBB) – One of three classes of 5G use cases providing higher speeds for applications such as streaming, internet access, video conferencing, and virtual reality.

Fixed Wireless Access (FWA) – refers to an established technology means to provide internet connectivity to customer premises (typically homes) using wireless mobile network technology instead of wired lines (fibre or copper). FWA is one of the use cases for 5G rollout.

Industrial, Scientific and Medical (ISM) bands - A group of radio bands or parts of the radio spectrum that are internationally reserved for the use of radio frequency (RF) communications intended for scientific, medical and industrial requirements.

The Internet of Things (IoT) - Refers to a network of physical devices (sensors and actuators) with embedded computation and communication capabilities that allows exchange of data between these devices.

Light Fidelity (LiFi) – is a visible light communications system that is capable of transmitting data at high speeds over the visible light spectrum, ultraviolet and infrared radiation.

Local Enterprise Partnership (LEP) - Non-statutory partnerships between the public sector (mainly local authorities) and the private sector. There are 39 LEPs across England and their aim is to promote economic growth and jobs in their local regions.

Massive Machine Type Communication (mMTC) – is one of three classes of 5G use cases. The term refers specifically to the connectivity services offered by a mobile communication system for IoT devices.

Millimetre Wave Communications (mmWave) – In 5G this term refers to the use of spectrum bands that fall in the millimetre wave communications frequency range (30-300 GHz). The 5G mmWave pilot bands include 26-28 GHz, although these are, strictly speaking, outside the definition of millimetre wave communications...

Multi-Access/Mobile Edge Computing (MEC) – MEC offers application developers and content providers cloud-computing capabilities and an IT service environment at the edge of the (mobile) network.

Mobile Network Operator (MNO) – Also known as a wireless service provider, cellular company, or mobile network carrier, is a provider of wireless communications services that owns or controls all the elements necessary to sell and deliver services to an end user including radio spectrum allocation, wireless network infrastructure, back haul infrastructure, billing, customer care, provisioning computer systems and marketing and repair organizations. In the UK, there are currently 4 MNOs (EE, Vodafone, Telefonica/O2 and Three).

Mobile Virtual Network Operator (MVNO) - A wireless communications services provider that does not own the wireless network infrastructure over which it provides services to its customers. It obtains bulk access to network services from one or multiple MNOs and re-sells that to the customers. In the UK, there are currently 60 active MVNOs.

Multiple Input Multiple Output (MIMO) - A method for multiplying the capacity of a radio link using multiple transmit and receive antennas.

Network Function Virtualisation (NFV) – The abstraction of individual network functions into a virtual layer, thereby separating the needed hardware and software. It allows the network to be built from standard servers rather than dedicated hardware.

Narrow-Band IoT (NB-IoT) – A Low Power Wide Area Network (LPWAN) radio technology standard developed by 3GPP to enable a wide range of IoT devices and services to be connected using cellular telecommunications bands. The NB-IoT technology is deployed "in-band" in spectrum allocated to Long Term Evolution (LTE) system, using resource blocks within a normal LTE carrier (or in the unused resource blocks within a LTE carrier's guard-band) or "standalone" for deployments in dedicated spectrum.

Network Slicing – This refers to technologies that enable a single physical communication network to be split into different multiple virtual networks, which can be used to either provide different services with different requirements, or to allow multiple operators to share the same physical infrastructure. Ability to support network slicing is a key feature of 5G.

Neutral Host – describes a communication infrastructure provider that provides services for a number of operators wishing to deploy infrastructure in a particular location. A common scenario is for the neutral host to provide access to the location, installation, power and/or even backhaul connection.

Point of Presence (PoP) – is an access point from one place to the rest of the Internet. A PoP necessarily has a unique Internet Protocol (IP) address.

Public Network Operator (PNO) – An organisation authorised to offer network services to other organisations, or directly to members of the public. In those countries with a deregulated market in the provision of network services, it is still only appropriately licensed organisations that are allowed to act as PNOs.

Spectrum – Radio spectrum (often simply referred to as spectrum) is the range of radio frequencies over which wireless services are delivered. That includes broadcast television, radar, mobile phones and mobile broadband, GPS, Wi-Fi and any other wireless service. Spectrum is the lifeblood of digital communications and 5G will require spectrum at several different frequencies.

Small Cells - Base stations send and receive mobile voice or data information. They vary in size and cost, but each requires an appropriate site with a power supply and, generally, a fibre connection. Small Cells, or Microcells, provide infill radio coverage and additional capacity where there are high numbers of users within urban and suburban macrocells.

Ultra Reliable and Low Latency Communications (URLLC) – One of three 5G use case classes, it is driven by requirements for high dependability and extremely short network traversal time. This will enable "mission-critical communications such as industrial automation, drone control, autonomous vehicles and new medical applications.

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