

# Industrial 5G

A Toolkit for Business  
in a Digital Future

April 2022

In collaboration with

**CATAPULT**  
Digital

  
Department for  
Digital, Culture  
Media & Sport

## Summary

This following document contains the component parts of the Innovation Toolkit for the DCMS funded industrial 5G Testbeds and Trials Programme.

The toolkit is intended to act as one of the main vehicles through which dissemination of learnings from the projects, along with useful and accessible information regarding 5G in manufacturing and logistics for those at different stages of understanding and deployment in their 5G journey.

This interactive toolkit is structured to encapsulate a full range of resources necessary to promote the adoption of 5G in manufacturing and logistics industries and reach a wide audience in a digital age, whilst also understanding the traditionalities within the sector.

Toolkit resources include a report entitled 'What is Industrial 5G?', a 5G glossary, ecosystem mapping, a summary of lessons learnt so far, blog posts, webinar recordings and infographics.

## Contents:

Select one of the links opposite to jump to each section of the report.

Throughout the document, there are navigation tabs at the top of the page and subsection navigation at the start of each section. You'll be able to navigate through the sections in the same way.

**WHAT IS INDUSTRIAL 5G?**

**4**

**ECOSYSTEM MAPPING**

**53**

**WEBINARS**

**103**

**GLOSSARY**

**105**

# What is industrial 5G?

CLICK TO JUMP TO A SUBSECTION

WHAT IS INDUSTRIAL 5G? 6

WHAT PROBLEMS WILL INDUSTRIAL 5G SOLVE? 8

WHY 5G? 9

CAPABILITIES 11

DIGITAL CATAPULT AND INDUSTRIAL 5G 12

CHALLENGES AND BARRIERS 13

RETURN ON INVESTMENT 16

CASE STUDIES 19

LESSONS LEARNED 43

NEXT STEPS FOR INDUSTRIAL 5G 51

To fully realise the value of 5G, collaboration between the mobile industry and other industry sectors is crucial.

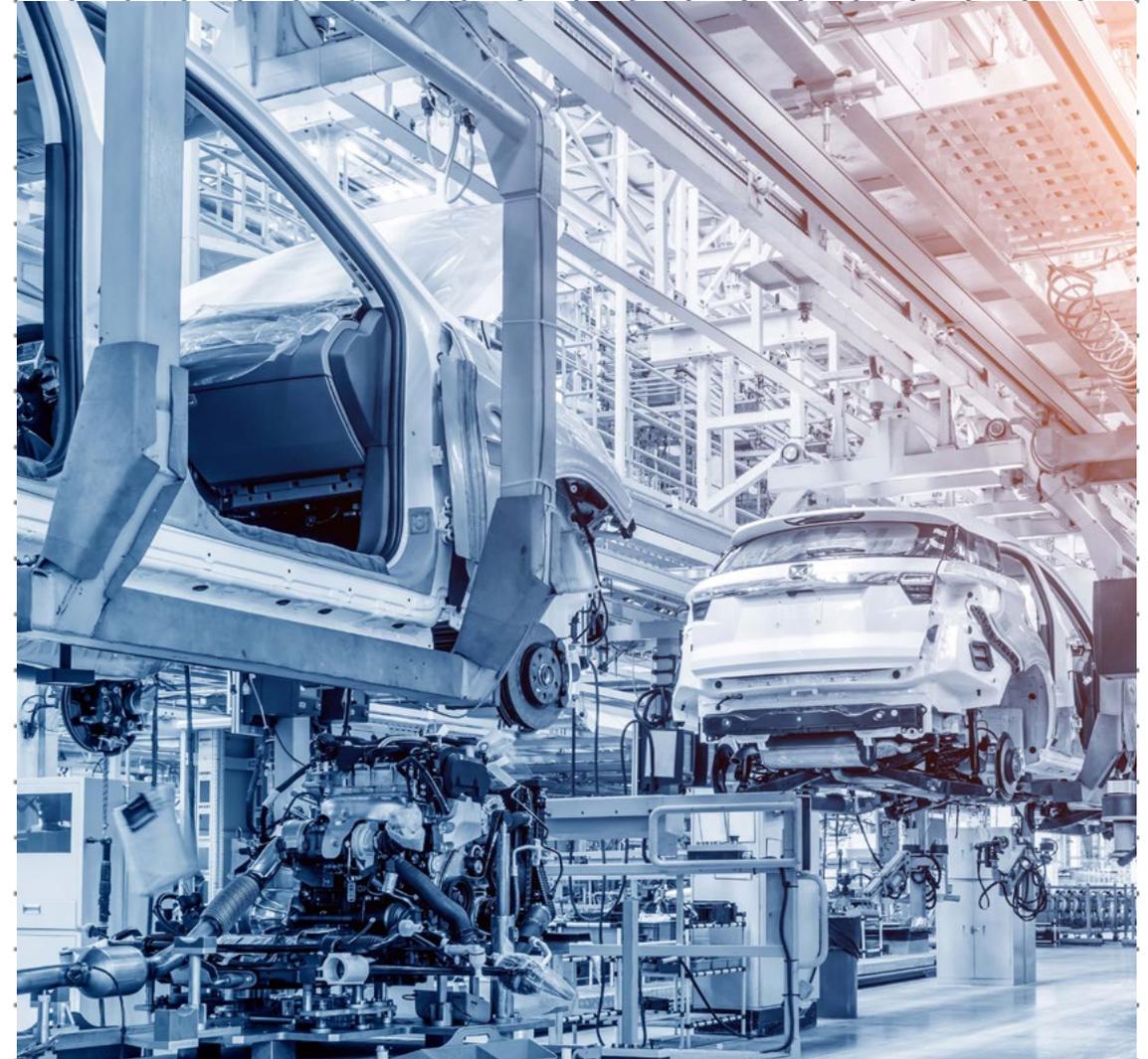
## What is industrial 5G?

Industrial 5G is the term used to capture the conceptual framework, architectures, principles and best practices guiding 5G deployment and integration with specific industries' processes and systems.

When looking at the industry that the term Industrial 5G applies to, simply put, manufacturing creates products and assets, logistics manages them.

Inputs used to manufacture a product include raw materials, prefabricated components, and the materials that are used to assemble the components; the output asset is a product, which may be complete and final or which may require the addition of other components at a later stage.

Logistics covers the whole lifecycle of all these products. It includes the supply chains, transport and tracking in the wide area, status monitoring, local movement and tracking through the processing stages, and waste management.



## What is industrial 5G?

5G is the first mobile technology system that has been designed with the deliberate intention to meet the advanced digital communication and connectivity requirements of industrial environments (e.g. manufacturing, transport, logistics, energy, construction, etc.), in addition to the consumer-focused mobile internet. There is significant interest in how 5G can be deployed and used in these environments, as well as the benefits that adoption of 5G can provide to the digitalisation of industrial activities. To meet this growing demand and fully realise the value of 5G, collaboration between the mobile industry and other industry sectors is crucial.

This close-working relationship will deepen and broaden the exploration of what is possible, learning together how existing and new systems can be integrated and deployed in real-world environments and what new business models will evolve over the coming months and years. 5G is also an extensive, global, mobile technology standard. Originally targeting consumer communications, the specifications, standards, products and best practice system integration guides and expertise are largely for that domain.

**The UK Government's 5G Strategy rightly sees 5G as a significant innovation opportunity. The key questions and focus should be both:**

1. How can 5G technology help enable the digital transformation of industries?
2. How can 5G technology be developed to meet these requirements purposefully?

In addressing these ambitions, there is a clear opportunity in the next two to four years for the UK to establish leadership in scoping what the specific 5G solutions for industries will look like. This opportunity is driven by the promised efficiencies of Industry 4.0 digital transformation enabled by 5G, which in turn requires mature standards, a reliable supply chain of trustworthy devices and regulatory support for operating 5G services in an industrial setting.

As the 5G standards mature over this timeframe and consumer mobile broadband is deployed across the country, specific tailored 5G solutions for individual industries will need to emerge that have a clear business case and are deployable and manageable at scale.

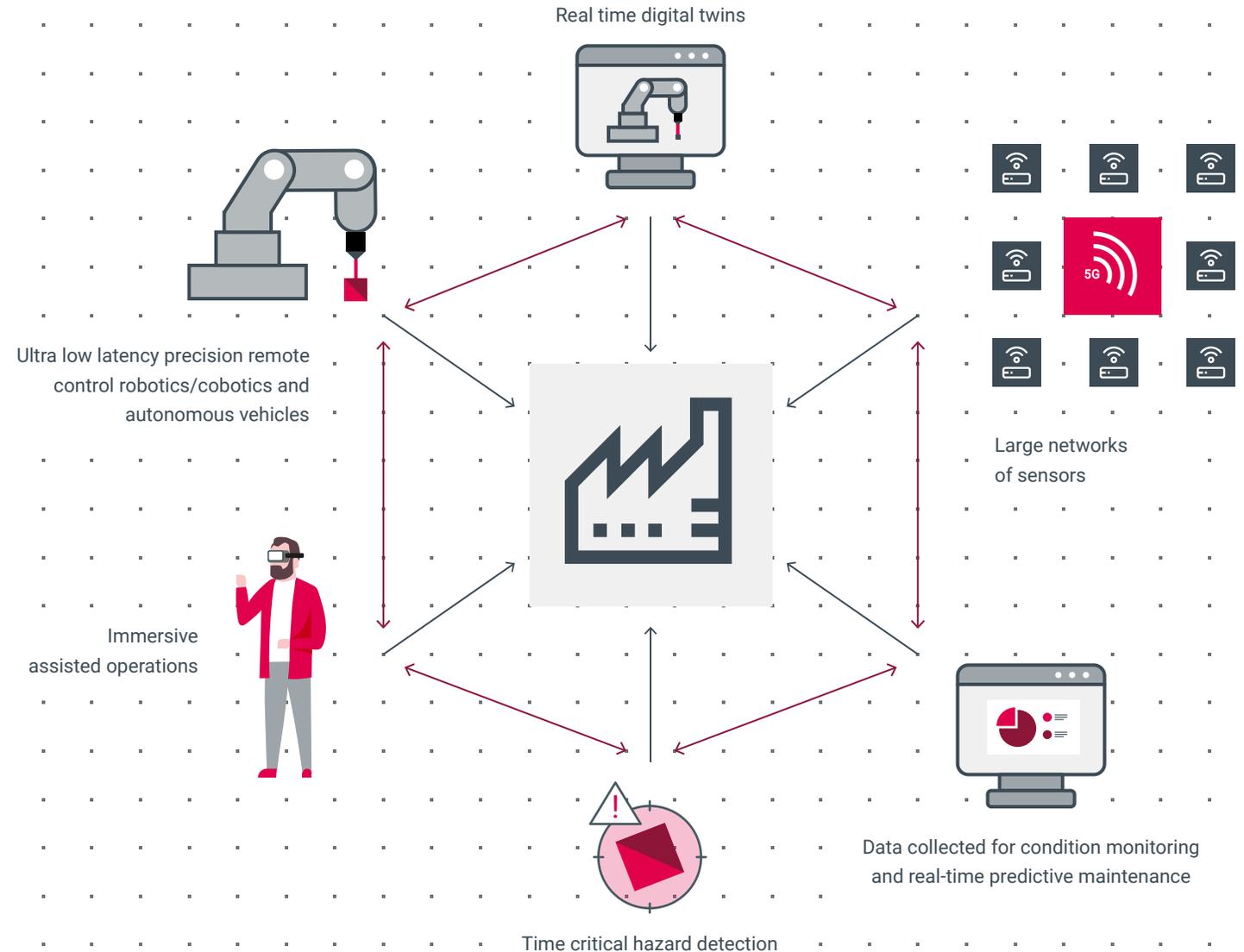
We expect industrial 5G to be further refined both in the UK and globally over the course of the next few years. To ensure the UK takes a leading global role in establishing and developing the concept into maturity, Digital Catapult's ambition and role is to help coordinate and bring together the key ingredients and players to maximise collaboration and demonstrate the potential it can offer all parts of the value chain.

## What problems will industrial 5G solve?

Industrial 5G will provide a common framework that will inform industrial sectors and sub-sectors, the supply side of innovative technology companies and the telecommunications sector on:

1. How to deploy 5G in industrial environments. In particular how to exploit 5G characteristics towards an integrated advanced digital infrastructure fit for digitalised processes in industries.
2. How to achieve interoperability and coherence within and between 5G systems. In particular, looking at how legacy systems can be integrated within the 5G service architecture or operate on top of it and across regulatory domains.

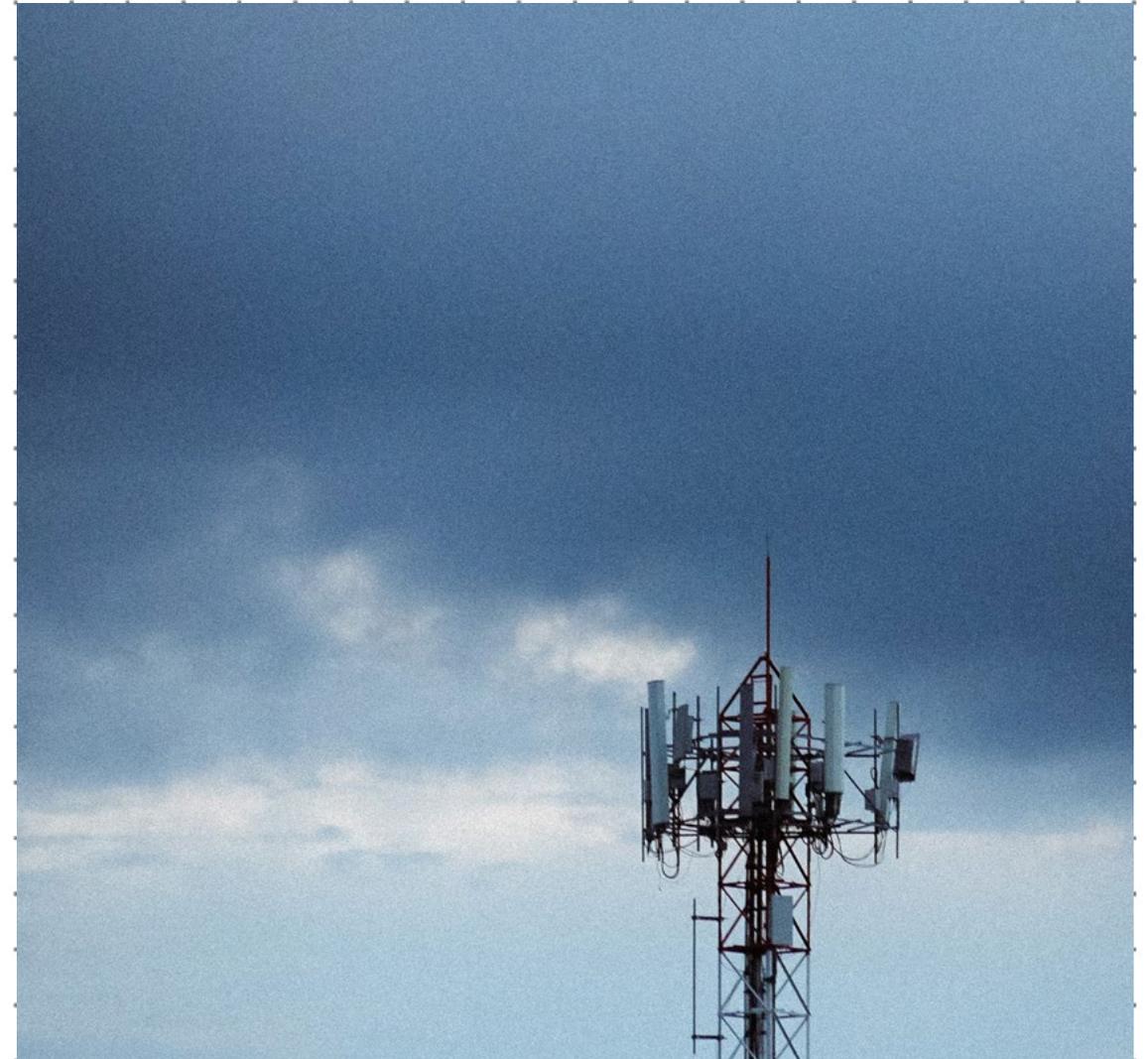
It is also a means to other specific practical ends, particularly the provision of a standardised, affordable, scalable, resilient, future-proofed, high-performing advanced digital infrastructure platform that can be adapted to many other industrial applications.



## Why 5G?

**There are obvious questions to ask:** What problems does 5G, as a key part of the advanced digital infrastructure, solve for industry? What new problems does it create? What is it going to make easier, or more complex? What is missing?

A historical perspective is important. 3G (UMTS) was conceived as a universal mobile service platform but did not fulfil expectations of the wide range of services it could deliver. Nevertheless, it kick-started the integration of mobile broadband with Internet services and led to 4G, which delivered the consumer mobile internet services that later transformed our social lives. 4G achieved the architectural and physical layer step changes to make these services a success in the consumer domain and in certain enterprises. Meanwhile, many 3G and 4G capabilities that could be of interest for industrial 5G remain unexploited.



## Why 5G?

5G is a very significant update, as well as an evolution, of 4G. It is designed to be operated in different ways from 4G and also to provide services that 4G cannot deliver. However, we will need to tackle an important challenge facing this evolution, namely: how can we ensure that 5G will represent the ideal level of simplicity that masks unavoidable complexity? One way to prevent such complexity is to establish a minimum subset of 5G specifications to the minimum sub-set that delivers on the requirements for specific industries – i.e. defining industrial 5G. Will 5G networks and systems applied into industry live up to expectations? In order to find positive answers to this question we need to collectively understand if it is:

**Standardised:** Is it at the right level for industry? Does it enable digital innovation? What are the gaps – system integration, technology blocks, interoperability?

**Scalable:** Can a local small standalone network suitable for a startup be scaled up to serve a large enterprise spread across multiple sites? At what size will it transition to a non-standalone network that would be better supported by a mobile network operator's shared platform?

**Safe:** Given that some industrial processes and the products they deliver have safety-critical considerations, what new safety hazards could arise?

**Secure:** Are new vulnerabilities created that compromise safety and operational integrity? Does the 5G solution make it easier or harder to secure the system(s)?

**Resilient:** Can availability, continuity, integrity, latency and responsiveness be maintained at required levels for the services to be implemented?

**Future-proofed:** Can new services supporting new functions be introduced easily? Can different industry sectors be supported?

**High-performing:** What is the extent of compromises to achieve eMBB, mMTC and URLLC? What do applications really need? Are there inherent potential inefficiencies in balancing the demands by applications, e.g. can spectrum utilisation be optimised?

**Affordable:** What is the entry cost? Does it offer value for money? Do capital and operational costs exceed revenues as the network grows? What are the business models?

**Mobile:** Like earlier generations, 5G will provide seamless network mobility, which is a problem that the Internet architecture does not address. Will this be scalable for large numbers of simple devices such as sensors or actuators? Will there be seamless operation indoors and outdoors?

**Effective for industry:** Looking closely at the 5G network as an integrated advanced digital infrastructure, does the 5G system architecture (combined with edge computing, network softwarisation and orchestration) facilitate the allocation of resources to support industry's network functions and the services they provide? Is multi-tenancy possible while maintaining the control that industry typically requires?

**Able to withstand regulatory challenges:** Can 5G networks operate effectively in an evolving landscape for the right skills required to make use of the high speed networks?

The above list acts as a starting point, and is expected to grow as discussion and activities around industrial 5G build momentum. These questions are also linked by trade-offs that may give different answers when the working assumptions and requirements are taken into account.

## Capabilities

5G offers three main platform enhancements:

- Improved radio communications performance - 10 times that of 4G. The performance indicators for so-called Ultra-high Reliable (99.999% delivery) and Low Latency (< 1ms) Communications (URLLC) are important for time-critical manufacturing processes. Similarly, increased capacity and support for very large numbers of devices is supported, an important aspect for logistics.
- Virtualisation of the infrastructure and the radio access network from dedicated hardware components of the core, infrastructure and communications to programmable software components. This allows computing and functionality to be located wherever it is needed, and communications capacity to be managed to deliver quality of service. Both can be dynamic over short timescales to respond to demand.
- Disaggregation of core functions into micro-services. This enables full support for 5G by cloud platforms. 5G core functions can be mixed with and connected to application functions directly, and new 5G cores can be set up quickly. The NG-RAN functions can also be disaggregated down to the base-station level to support dense small cell deployments, e.g. in a factory or industrial campus.

Alongside these, telecoms standards umbrella body 3GPP has developed specific advanced capabilities for vertical industries, including:

- End-to-end management of quality of service using network slicing.
  - Synchronisation, which allows time sensitive networking (TSN) to ensure timely delivery and deterministic networking that is predictable and repeatable.
  - Direct device-to-device communications. This will reduce latency further and allow more ad-hoc interactions between connected devices, e.g. for emergency stops.
  - Local area network integration. Many industrial automation systems use derivatives of Ethernet, and 5G can act as a transparent wireless switch between LAN connected devices, supporting broadcast and multicast with enhanced security.
- Positioning, 3GPP Rel.16, provides a positioning capability “for commercial use cases” the following the starting-point performance targets:
    - Horizontal positioning accuracy greater than three metres (indoors) and 10 metres (outdoors) for 80% of the UEs.
    - Vertical positioning accuracy greater than three metres (indoors and outdoors) for 80% of the UEs.
    - End-to-end latency less than one second.

## Digital Catapult and industrial 5G

Industrial 5G accelerates the digitalisation of industrial activities through 5G adoption.

It is also the national initiative that brings together activities from the UK Government's Department for Digital Culture Media and Sport (DCMS) 'Industrial 5G Testbeds and Trials' projects. This national programme will help define the approaches, standards, best practices and use case examples of 5G in an industrial setting that will strengthen the concept globally, make it tangible and place the UK at the heart of global leadership in this space.

The programme draws upon our world class 5G ecosystem, research institutions and supply side of innovative technology startups and scaleups – bringing them together with industry to solve real-world challenges, seizing the significant opportunity of the 4th Industrial Revolution for the UK. The industrial 5G term was adopted by Digital Catapult during its wide-reaching engagement with UK manufacturing, logistics, telecommunication and IT industries in preparation of the Industrial 5G Testbeds and Trials Programme competition.

More information about the programme can be found [here](#).

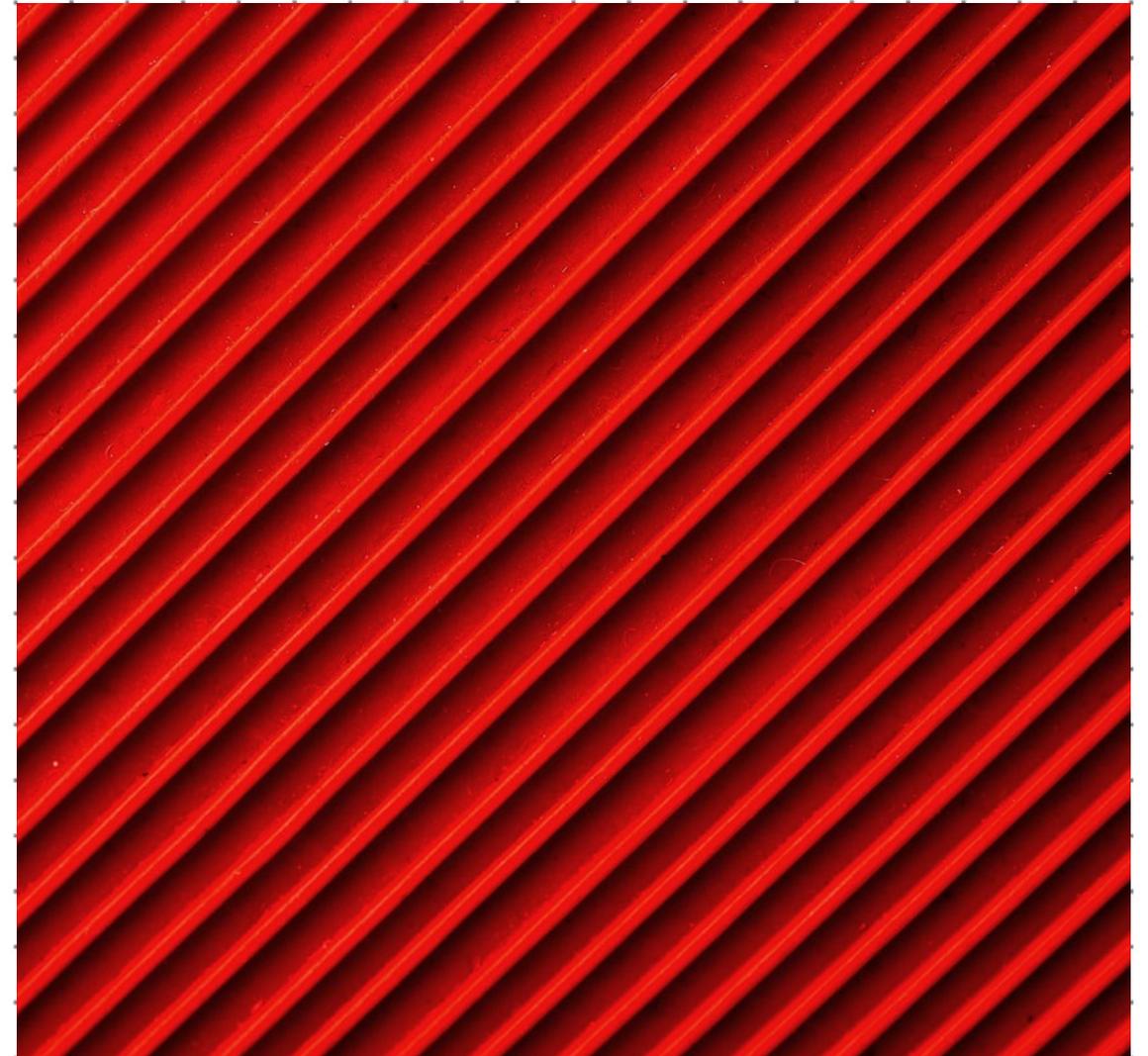


## Challenges and barriers

While enterprises and commercial bodies across all sectors are discovering how to transform their organisations with 5G, the manufacturing and logistics sectors could stand to benefit significantly from adoption.

However, Digital Catapult's partners in the 5G Encode and 5GEM-UK projects\* in the Industrial 5G Testbeds and Trials Programme have identified several potential barriers that currently stand in the way of adoption.

\*Whilst other projects exist in the Industrial 5G Testbeds and Trials Programme, 5G Encode and 5GEM started early, providing early pertinent insight into the challenges and barriers that others can learn from and overcome.



## Challenges and barriers

### Lack of understanding of 5G capabilities

As one of the newest forms of communication, there is often misunderstanding around what 5G is, its capabilities and potential use cases. Whilst an issue across sectors, early adopters of 5G in manufacturing have reported a lack of understanding within their organisations preventing complete buy-in from the necessary actors, therefore stalling adoption. This lack of understanding may be throughout the company or solely within particular departments. For example, an organisation's IT team may struggle to understand 5G's key benefits and differences in comparison with traditional WiFi. This also extends to those working in the 5G community; even amongst 5G professionals, there is often a discrepancy as to the overall understanding of 5G technology. Digital Catapult through its programmes and projects, such as Industrial 5G Testbeds and Trials Programme and 5G Create, is helping to increase understanding of 5G and its capabilities. To help inform those in industry, as well as throughout the wider technology and cultural sectors, Digital Catapult is developing glossaries, blog posts and webinars, along with other valuable resources and information.

### Lack of a robust ROI business case

Both projects have identified the need to support early adopters in making an informed decision on the use of 5G technology as an area of key significance. As there is often a requirement to present a robust business case at early stages of the 5G implementation process, Digital Catapult held a workshop session to better enable early adopters to build a business case. Examples from other projects have been beneficial in proving ROI in industrial settings – in the Worcestershire 5G project, initial findings from the augmented reality trials at Yamazaki Mazak suggested the potential for productivity improvements. Proven and demonstrable improvements by others in the industry are often more likely to help to strengthen the business case. Digital Catapult will continue working with partners to communicate industry successes and learnings from industry. The potential ROI of 5G is looked at in more detail later in this paper.

### Fostering a culture of digitalisation

Related to this is a widely-cited practice in many manufacturing organisations, particularly in ones that may be family owned or have long histories. In companies where digitalisation and adoption of new technological practices are not intrinsic to company development, there may be a fear of 5G, which may prevent company owners from investigating ways in which it can help their business. By working with manufacturers of various sizes and disseminating key benefits and learnings of industrial 5G, Digital Catapult intends to ensure that all manufacturers understand how it can benefit their core needs.

### Accessing 5G-ready devices

In instances where organisations are ready to engage with and implement 5G into their business activities, they may be hindered by the current market for 5G-ready hardware. While the market is beginning to see both 5G-ready smartphones and home broadband devices for commercial sale, industrial-ready products are not readily available. As a result, business owners can only choose from commercial products, with many aspects such as functionality, affordability and availability leaving them unsuitable for mass industrial use.

## Challenges and barriers

### Safety

There are two topics for 5G adopters to consider: the safety of the industrial 5G system as a whole and safety of the radio environment of the installed 5G equipment, both of which may affect willingness to adopt 5G. As such, it is necessary to do a comprehensive safety and security analysis to identify the specific measures needed for any given use case. This analysis includes understanding what is to be secured and the asset base, hazards it will suffer for the use case's concept of operations and a risk assessment of the consequences when those hazards become real following successful attacks. The results will lead to security requirements and objectives, followed by actions to mitigate the consequences of an attack on system integrity and safety and verify the measures for effectiveness and plans to maintain security.

There has been much speculation about potential harm to human health from radio frequency (RF) emissions since cellular communications were introduced to a mass consumer market in the 1990s. None of the claims has proved to be more than just speculation.

Inevitably, magnified by social media mis-information about a link between 5G and the coronavirus, the same claims have been made about 5G. Ofcom has published the results of its investigation of these claims<sup>1</sup> and Digital Catapult is working with partners to alleviate myths and misconceptions around 5G, as well as to ensure the safety of industrial 5G environments.

### Technological needs and skills

Central to the adoption of 5G in industrial settings are the necessary technological skills and capabilities required by certain job functions. Without the necessary technical skills and understanding, companies may have difficulty determining the necessary equipment, operating systems and long-term processes required to fully deploy and harness the benefits of 5G. Reports suggest that whilst the UK currently has access to 5G savvy professionals that have the skills required to deploy the technology effectively at this early stage, the demand is still high. As more and more companies adopt 5G there will be a surge in demand for skills, which the UK may not be able to meet straight away.<sup>2</sup>

### Understanding what to invest in

As part of Digital Catapult's innovation coordination in the discovery phase of the Industrial 5G Testbeds and Trials Programme, an innovation survey was conducted, which revealed that a significant percentage of manufacturers in the early stages of 5G discovery did not have a strong understanding on the hardware, software and services they need to invest in. With existing discussions around 5G being particularly relevant to commercial and not industrial use, those seeking to deploy 5G in manufacturing and logistics settings may not discover the relevant insights, either from peers or external resources, that will aid them in this understanding. As such, it can be hard to estimate what budget should be allocated to 5G adoption and which aspects of adoption should be prioritised.

<sup>1</sup> <https://www.ofcom.org.uk/about-ofcom/latest/features-and-news/clearing-up-myths-5g-and-coronavirus>

<sup>2</sup> [https://uk5g.org/media/uploads/resource\\_files/Worcestershire-5G-Skills-Report.pdf](https://uk5g.org/media/uploads/resource_files/Worcestershire-5G-Skills-Report.pdf)

## Return on Investment

With 4G centred on speed and capability, the advent of 5G focusses on latency and large scale capability, aspects that will become increasingly important as manufacturing organisations embrace data-centric processes and technologies commonly associated with Industry 4.0.

However, whilst 5G can be transformative in enabling the adoption of these processes, manufacturers often hesitate around the return on investment that will be received from initial investment in 5G capabilities. As such, many manufacturers are held back from realising their 5G potential. In 2019, Digital Catapult and UK5G conducted a large piece of research around the applications and barriers to entry for 5G in the UK manufacturing sector.



## Return on Investment

However, whilst 5G can be transformative in enabling the adoption of these processes, manufacturers often hesitate around the return on investment that will be received from initial investment in 5G capabilities. As such, many manufacturers are held back from realising their 5G potential.

In 2019, Digital Catapult and UK5G conducted a large piece of research around the applications and barriers to entry for 5G in the UK manufacturing sector.

After a thorough technological and business consultation with a working group of companies including Ericsson, BAE Systems and Jaguar Land Rover<sup>3</sup>, the three prominent use cases recognised as a priority for most manufacturers were identified as:

1. On-site and in-factory product optimisation
2. Monitoring and management of goods across the supply chain
3. Connected goods: product life cycle management (including end of life)

However, despite the various technological advancements 5G offers in the industrial space, there are various barriers to market entry that keep UK manufacturers from massively deploying 5G to their sites. The top three barriers identified by manufacturers were:

1. Lack of understanding of ROI and value
2. Cost
3. Not knowing where to begin or who to contact

In 2020, Digital Catapult and industry partners sought to debunk the barriers to market entry by putting 5G up to the test. Five industrial use cases were determined to have the potential to generate a 10-20 fold return on investment in a five-year period. These were:

1. Condition based monitoring (CBM)
2. Predictive maintenance
3. Wireless robotics
4. Asset and tool tracking
5. Training enabled by augmented reality (AR)

Analysis showed a payback time of between 12-24 months and a five to ten times return on investment over five years across all companies and use cases. During this study other financial benefits were discovered. This initial investment lay the foundations to unlock various business models such as servitisation, realising higher revenue models for the industrial companies being assessed.

The early adoption of industrial 5G, increasingly allows industrial companies to build the trust required in management ranks, unlock the new business models available and establish the available market share.

<sup>3</sup> The full list of working group members is as follows: BAE Systems; Digital Catapult; Ericsson; GAMBICA; Huawei; Jaguar Land Rover; Mace; McLaren; Applied Technologies; MTA – The Manufacturing Technologies Association; The Manufacturer; Nissan; Nokia; Ocado; Ofcom; P&G; Real Wireless; Seagate; Thales; UK5G; Worcestershire 5G Testbed

5G is the first mobile technology system that has been designed with the deliberate intention to meet the advanced digital communication and connectivity requirements of industrial environments.

Case Study:

## 5G ENCODE



### Background

5G ENCODE is a £9m project, part of the Department for Digital, Culture, Media & Support (DCMS) 5G Trials and Testbeds programme, seeking to deliver a private industrial 5G Testbed within the National Composites Centre (NCC) to support three manufacturing use cases.

The primary aim of the project is to explore new business models and value propositions for enterprise private 5G networks within the composites manufacturing industry.

## 5G ENCODE

**The Challenge**

Multiple challenges related to the adoption of 5G in industry have been identified and are being addressed by the 5G ENCODE project. These industry challenges include the lack of demonstrable cost-efficiency and return on investment; concerns around compatibility and interoperability of mobile networks when it comes to integration into existing industrial systems; and the need for security in terms of the control over the security of connectivity and data, as well as the connectivity itself.

Further challenges focus on the general misunderstanding of how 5G differs from other connectivity solutions and the cultural barriers faced today in the digital and IT tech sectors.

**The Opportunity**

The project will strive to validate the premise that using private 5G networks together with new business models can deliver better productivity, efficiency and a range of new services and opportunities to help the UK lead the development of advanced manufacturing applications. The expected benefits include improved productivity, reduced costs and better yield target.

**Use cases:**

1. **In-factory and in-transit asset tracking** – The in-factory and in-transit asset tracking use case seeks to reduce costs while improving productivity by 5%. This will be enabled by providing accurate and live location and condition information of tracked assets in and outside the factory.
2. **Closed loop manufacturing in Liquid Resin Infusion (LRI)** – This use case aspires to improve efficiency and productivity in LRI composite manufacturing using 5G and digital technologies, with a 40% better yield target.
3. **Virtual 360 video training** – The Virtual 360 video training use case aims to improve efficiency and trainee satisfaction of in-house training using an immersive and interactive VR 360 platform over a 5G mobile network. This use case will allow two-way communication between trainer and trainee with the possibility of using interactive AR training scenarios, seeking to reduce costs by 20%.

To start, the use cases mentioned above will be assessed on a 4G network, providing a baseline to benchmark the 5G network capabilities, including higher reliability and flexibility. When the 5G system is enabled, 5G ENCODE will also aim to explore the ability to use VR and haptic interfaces to control an off-site robot arm for a real-time user experience.

5G ENCODE

**Consortium**

**Zeetta Networks**

Software company providing network automation tools for enterprises.

**Cytec+Solvay**

Science company, a global leader in materials, chemicals and solutions.

**Plataine**

Provider of intelligent automation and optimisation software solutions for advanced manufacturing.

**Telefonica**

One of the largest telecommunications companies in the world.

**Toshiba**

Personal computers, consumer electronics and home appliances manufacturer.

**Mativision**

Provider of bespoke virtual reality (VR) platforms for working and learning B2B solutions and B2C experiential products.

**NCC**

World-class research centre driving innovation in the design and manufacture of composites. Part of the UK High Value Manufacturing Catapult.

**University of Bristol**

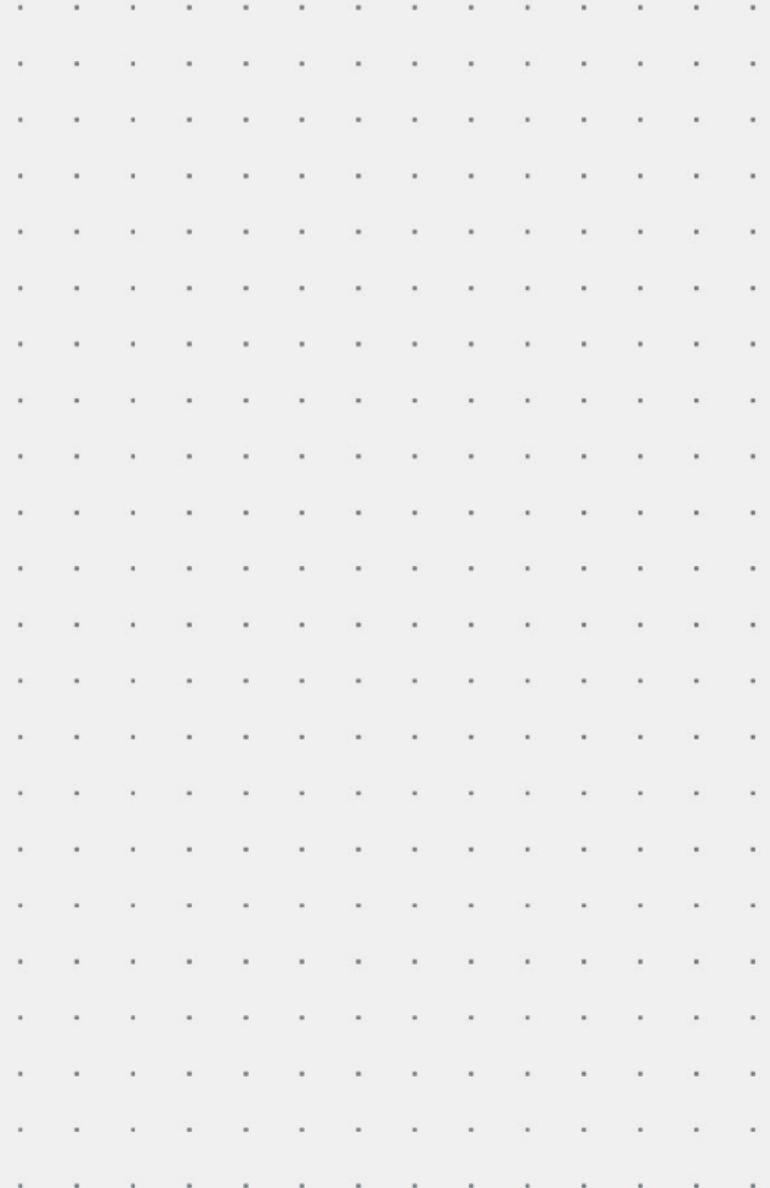
One of the most popular and successful universities in the UK.

**Siemens**

An industrial manufacturing company.

**Druid**

Market leaders in private cellular network technology.



Case Study:

## 5GEM-UK

### Background

The 5G Enhanced Manufacturing (5GEM) is a £3.9m project exploring the opportunities of 5G within manufacturing.

Specifically, the project aims to demonstrate the value that 5G will bring to industry by conducting testbeds at the Ford Motor Company's Dunton site and the TWI's Cambridge facility. These testbeds seek to demonstrate how 5G technology improves the monitoring capability of manufacturing machines and processes, allows for further data collection and facilitates the real-time monitoring and control of machines and processes.

## 5GEM-UK

**The Challenge**

Within manufacturing, product life cycles are shortening and customer demand is growing increasingly variable. As a result, the re-configurable factory is needed, and providing wireless, high-speed, and reliable connectivity will enable that. At the same time, manufacturing equipment is not only progressing in capability, but also in cost and complexity. As a result, equipment uptime is critical. Machine uptime can be maximised with 5G sensors to monitor machine status and improve intelligent predictive maintenance, with a network which supports remote expert assistance.

**The Opportunity**

Beyond the improved machine uptime, the project sees the opportunities to reduce the Mean Time To Repair (MTTR) equipment. This can be done using headsets connected via 5G to maintenance instructions that can be presented visually and with video, as well as connecting to experts for instant support preventing the loss of hours or days waiting for a service callout. Another opportunity, using real-time analysis and the consequent adjustment to machine parameters, aims to reduce the volume of rejects in the manufacturing process. All these improvements can enhance the sustainability of the manufacturing installation by reducing wasted energy and the travel required to support the process.

**Use cases:**

1. **Machine Connectivity** – The Machine Connectivity use case seeks to demonstrate the deployment of 5G in lieu of existing hardwired data connections, as well as the connection to new IoT sensors for environmental and maintenance system monitoring. Specifically, this use case covers real-time process analysis and control of machines on a Ford factory floor in Dunton, UK. By analysing data in real time from sensors installed throughout the factory, Ford is able to monitor the production process and make rapid adjustments automatically in response to changes in environment, input materials and other factors. Similarly, TWI and their partner VFE, explore how 5G can better support the gathering of data via IoT sensors and predictive analysis to improve the understanding of machine faults and degradation and considering how this is linked to the reduction or increase of power usage. The ultimate goal is to improve machine monitoring and planned maintenance with instant expert support from vendors facilitated by the use of an AR/MR headset and secure remote data access.
2. **Shopfloor Devices** – The Shopfloor Devices use case explores the deployment of handheld scanners for traceability and issue logging, alongside various devices (e.g. tablets, MR/AR) for remote expert support.
3. **5G Ecosystem** – This use case is dedicated to the deployment of 5G in a factory environment. In particular, it considers health and safety requirements, workforce and corporate security concerns and the comparison of 5G mobile private network (MPN) with other 5G and non-5G wireless solutions.

5GEM-UK

**Consortium**

**ATS**

Specialists in machine learning development and implementation.

**Ford Motor Company Ltd**

Automotive manufacturer.

**HSSMI**

Specialists in supporting the manufacturing industry on upscaling, digitalisation and circular economy practices.

**Lancaster University**

Specialist in data structure, processing and management.

**TM-Forum (TMF)**

Experts in closed loop automation, logistics management, leading to a reduction in down-time, waste and laying the foundations for the flexible factory.

**TWI**

Specialists in joining technology and non-destructive testing (NDT).

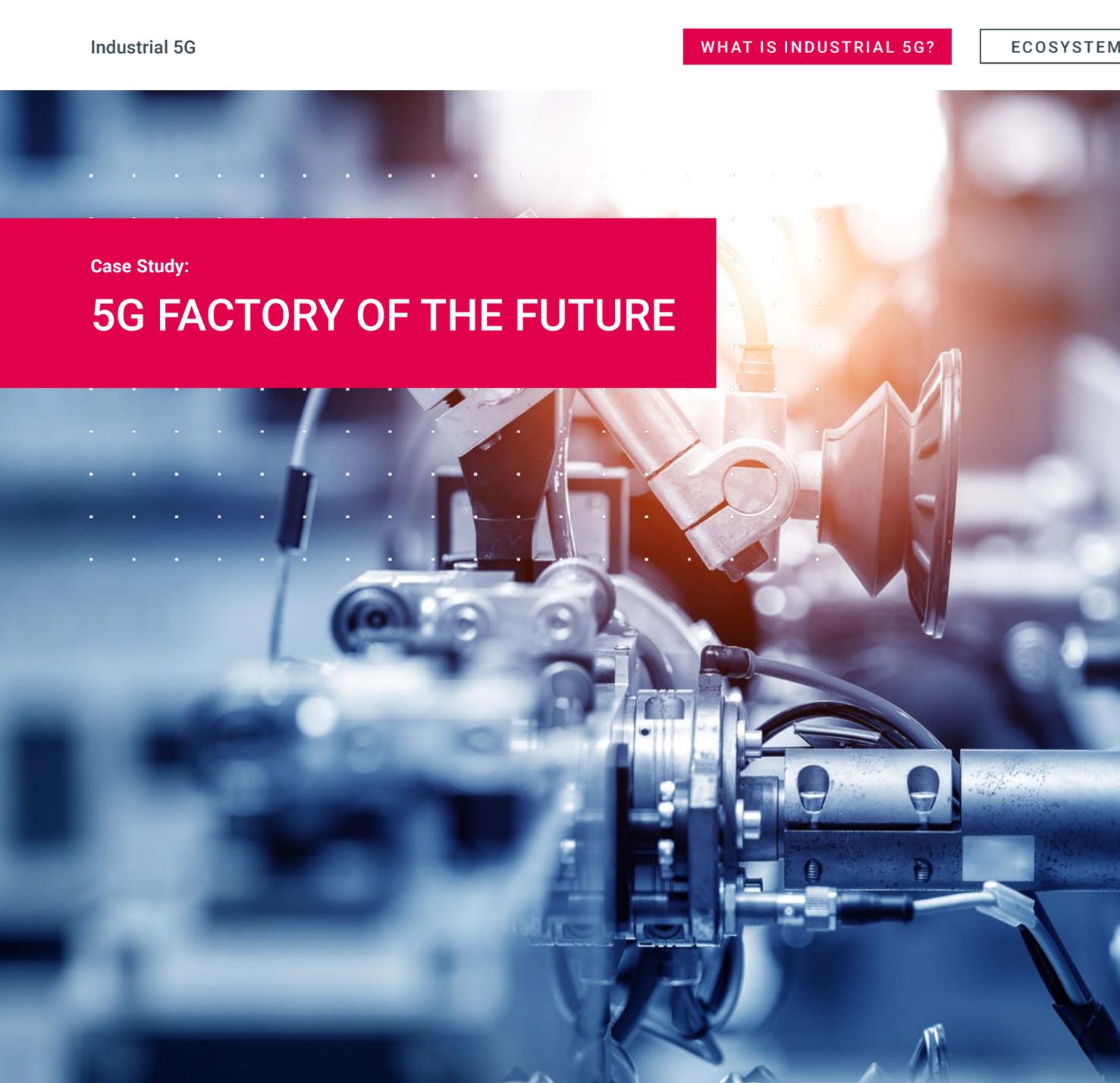
**Vacuum Furnace Engineering (VFE)**

Market-leading provider of maintenance servicing for the heat treatment industry.

**Vodafone**

One of the largest telecommunications companies in the world.





Case Study:

## 5G FACTORY OF THE FUTURE

### Background

Currently, UK Manufacturing productivity is lower than leading European nations, being ranked 9th in 2019 down from 6th in 2004, compared to peers such as Germany (4th), Italy (7th) and France (8th). To remain globally competitive, UK companies such as BAE Systems must embrace transformative capability.

The project aims to drive early adoption of 5G throughout one of the UK's most significant manufacturing supply chains, developing new opportunities for tech startups in the process.

5G FACTORY  
OF THE  
FUTURE**The Challenge**

UK manufacturing productivity is notably lower than the leading European nations (71.3, compared to the EU average of 105.3), an issue that the manufacturing sector has sought to address for years. Looking in more detail, Lancashire is home to several leading global businesses in the advanced manufacturing, aerospace, automotive and energy sectors. However, local manufacturing has high levels of economic activity but a lower level of productivity than the rest of the northwest and UK.

To survive and grow, enabling other UK companies to remain globally competitive, Lancashire manufacturers must embrace transformative capability. Large manufacturing programmes have significant affordability and lead-time challenges, particularly in the aerospace and maritime sectors. However, 5G technology can unlock the true potential for digital manufacturing.

**The Opportunity**

There are several expected outcomes from the 5G Factory of the Future project, including: improved quality – therefore resulting in waste reduction; reduced downtime of factory equipment; improved inventory accuracy resulting in faster production times; and asset damage detection to improve quality and speed.

Expected outcomes from the project also include supply chain transparency to increase on-time deliveries, improved effectiveness of training and support, as well as significant engagement with two manufacturing SMEs.

**Use cases:**

1. **Real-time Monitoring and Adaptive Closed-Loop Control (RTM)** – RTM is an important capability for BAE to reduce operational cost, quality defects and span time. Wireless real-time data streams from machines such as 3D printers will enable closed-loop process monitoring and problem detection, enabling automatic compensation.
2. **Digital Twin Track and Trace (DTT)** – DTT will enable reconfigurable assembly lines, supporting deployment manufacturing technology for in-service support of operational assets, such as aircraft, to enable factory in a box (FIAB). The high-level monitoring of machines and shop floors will allow partners to develop, integrate and test products-as-services (XaaS), previously limited by bandwidth/latency.
3. **Factory Ecosystem Monitoring (FEM)** – 5G integrated with emerging automation technology and IoT sensor networks will significantly reduce the requirement for elaborate environmental controls, enabling dynamic adjustment of automatic manufacturing systems through the exploitation of real-time data. As a result, reducing the running costs of a facility like this would create substantial annual savings.
4. **Chain of Custody System (CCS)** – Lost and late supply-chain production items cause significant loss in productivity, hitting suppliers hard and costing millions per year. One example is the loss of critical production tooling when in storage or transport. Tracking this through the supply chain could save BAE significant annual costs.
5. **Distributed and Shared Hybrid Reality Spaces (HRS)** – BAE Distributed and shared VR/AR enabling information, such as process or manufacturing instructions, to be fed directly to the worker at the point of use, using devices such as wireless hand-held tablets and personal headsets. On average, low latency enabled by 5G technology could save seconds per instruction read, compared to traditional methods. This reduction, across 50 aircraft produced each year, could achieve significant annual savings.

5G FACTORY  
OF THE  
FUTURE

**Consortium**

**The University of Sheffield Advanced  
Manufacturing Research Centre (AMRC)**

A network of world-leading research and innovation centres working with manufacturing companies.

**AQ Limited**

One of the UK's most innovative telecoms operators with experience in numerous 5G applications and testbeds.

**BAE Systems**

One of the world's leading global defence, security and aerospace companies.

**Digital Catapult**

The UK's leading agency for the early adoption of advanced digital technologies.

**Miralis**

Logistics optimisation software and consultancy practice, providing expertise in packing, routing and scheduling and electric vehicles.

**MTT**

The largest independent CNC machine tool support company in the UK.



## Case Study:

## 5G CAL

**Background**

5G Connected Automotive Logistics, uses 5G to demonstrate the key features for successful CAL deployment. When a situation arises outside of the autonomous logic of a vehicle, this deployment requires the safe and secure operation and handover of the CAV from autonomous mode to remote manual operation (teleoperation) and vice versa.

This project contributes a crucial demonstration of the capabilities of 5G and CAL, is critical for their operation in potential emergencies and could represent a world-first innovation.

## 5G CAL

**The Challenge**

The industry challenge arises from the apparent need to use 5G to maintain awareness of a vehicle's operational status using real-time telematics. For example, the required level of detail is currently unavailable to facilitate advanced scheduling and maintenance of a vehicle, reduce downtime and improve efficiency.

Knowledge gained from the demonstration and deployment phases of the project will facilitate understanding of how the proposed 5G-enabled CAL system could be deployed at scale, bringing initial benefits across the site, then the wider North East region and the UK as a whole, with world-leading technology.

**The Opportunity**

The following outcomes are expected from the application of 5G in the project:

- Kick-starting a CAL regional operational test facility for the North East
- The design and deployment of a 5G-enabled CAL testing facility at the Nissan UK test track, incorporating traffic signals and a simulated loading bay
- Conducting trials and evaluation of the CAL operational test facility by Newcastle University, using a light vehicle and a heavy-duty vehicle developed by StreetDrone, leading to an operational real-world trial of autonomous logistics with teleoperations between Vantec and Nissan
- Developing a strategic roadmap for the operational roll out of 5G-enabled CAL on the wider site and throughout the UK
- Threat assessment and mitigation of cyber risks using CAL with 5G by piloting the Institute for Future Transport and Cities
- Assessing the economic impact and export potential through the Connected Places Catapult
- Initiate collaborations with other projects for joint outcomes

**Use cases:**

1. **Handover between autonomous mode and remote manual mode in autonomous vehicles** – Applying 5G to the operation of connected and autonomous vehicles to allow the seamless and easy handover between autonomous mode to remote manual operation and vice versa.
2. **HGV to Infrastructure** – enabling the usage of 5G enabled cameras and LiDAR to build an external view of the HGV; and HGV to Traffic Management Centre – rethinking traffic control management such as traffic lights and rephasing them for priority traffic.
3. **SASMI** – The SASMI Building (Skills Academy for Sustainable Manufacturing and Innovation) is the Nissan Global Training Centre and is currently the heart of the region's role in the Driving the Electric Revolution. The use case will enhance training through 5G, support PEMD and become a Made Smarter Smart Factory Innovation Hub.

5G CAL

**Consortium**

**Connected Places Catapult**

The UK's innovation accelerator for cities, transport and places.

**Coventry University**

Public research university in Coventry, England.

**Newcastle University**

Public research university based in Newcastle upon Tyne, North East England.

**Nissan**

Multinational automobile manufacturer.

**North East Automotive Alliance**

Industry-led cluster group, established to support the economic sustainable growth and competitiveness of the sector in the North East of England.

**Perform Green**

Strategy and change consultancy, focused on delivering digitally-inspired change for good.

**Sunderland City Council**

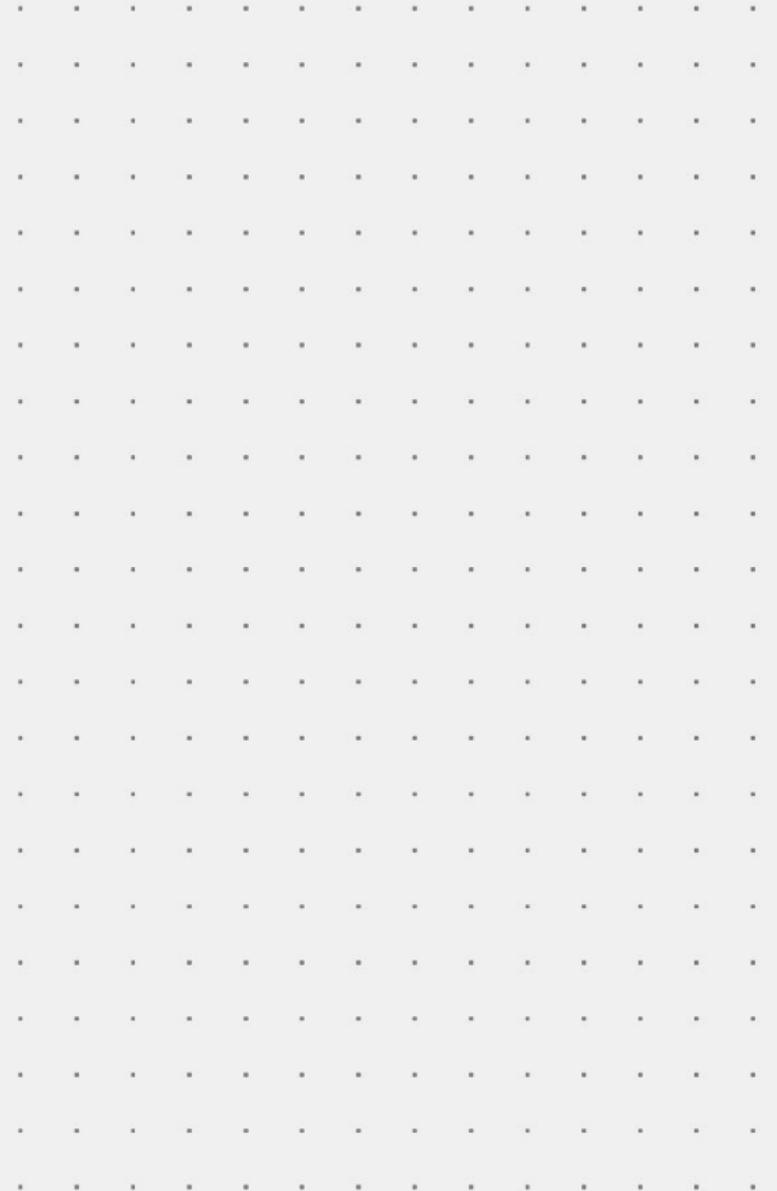
Local authority of the City of Sunderland in Tyne and Wear, England.

**StreetDrone**

Oxford based autonomous vehicle company.

**Vantec**

Lean innovative logistics partner, specialised in providing integrated solutions.



Case Study:

## AMC2

**Background**

Digital applications can significantly improve construction productivity. Using drones and cameras, for example, provides managers with real-time information to better manage processes or facilitate the use of an autonomous plant. However, construction projects are often delivered in locations with poor data connectivity, presenting a challenge for applications that need to process high data volumes. 5G can address this challenge, significantly improving construction process management whilst creating a new market for UK telecoms and technology providers.

The project seeks to establish a private, nomadic 5G network as a testbed at two BAM Nuttall managed sites.

## AMC2

**The Challenge**

Construction contributes around £110bn to UK GDP. Due to process and technology innovation, overall industrial productivity has improved by approximately 40% in the past few decades, although construction productivity has stagnated and even fallen. Causes for this decrease in productivity are well documented, ranging from bespoke projects to high labour intensity, fragmented supply chains and low innovation investment. The government and industry have set ambitious targets for productivity improvements (e.g. 50% quicker, 33% more cost-effective) with investments made in modern construction methods and digitally-enabled manufacturing techniques from funds including Innovate UK and ISCF Transforming Construction.

**The Opportunity**

There are several projected outcomes from the AMC2 project. These include a Private 5G network (installed on a BAM Nuttall construction project and the BAM offices/depot in Kilsyth), integrated with existing BAM construction data management systems. The deployment and assessment of 5G-enabled solutions for on-site data capture, such as IoT/sensors and surveying enabled by drones or cameras, is also expected.

Opportunities also include 5G-enabled solutions such as a Connected and Autonomous Plant (CAP) and 5G-enabled mixed reality (MR) solutions enabling construction productivity improvements.

The project would also identify business models for 5G-enabled solution deployment on construction programmes as well as the potential to integrate 5G into the physical asset to supply a permanent network and to support services beyond the immediate scope of infrastructure construction. The final expected opportunity is non-confidential information for dissemination to the construction and telecom sectors.

**Use cases:**

1. **Digital Construction Workspace** – BAM embraces digital ways of working, using technological innovations to build digitally before building commences on site. These technologies demand large/complex data sets, accessible by all construction process parties.
2. **Advanced Surveying and Data Streaming (ASDS)** – This includes the enhanced benefits derived from using an unmanned aerial vehicle (UAV) to capture video and stream it live over the private 5G network. This greatly improves the communication of current site activities and leads to better informed discussions and decisions by remote stakeholders.
3. **High Accuracy Asset Location and Tracking (HAALT)** – Providing two opportunities for construction, enabled by 5G: first, it allows ready identification of under-used items enabling rationalisation; second, it provides the measurement and analysis of asset use, delivering process improvements using lean principles.
4. **Connected and Autonomous Plant (CAP)** – Currently, construction equipment operators need to be in the machine. Work advancing an autonomous plant for construction is some years away from mainstream deployment. A near-term solution is to remotely operate a plant, enabled by the ultra-low latency of 5G.
5. **One Source of Truth (OSOT)** – AI analysis of live video feeds from sites. OSOT is an Innovate UK-funded R&D project bringing real-time monitoring to construction.

AMC2

**Consortium**

**AttoCore**

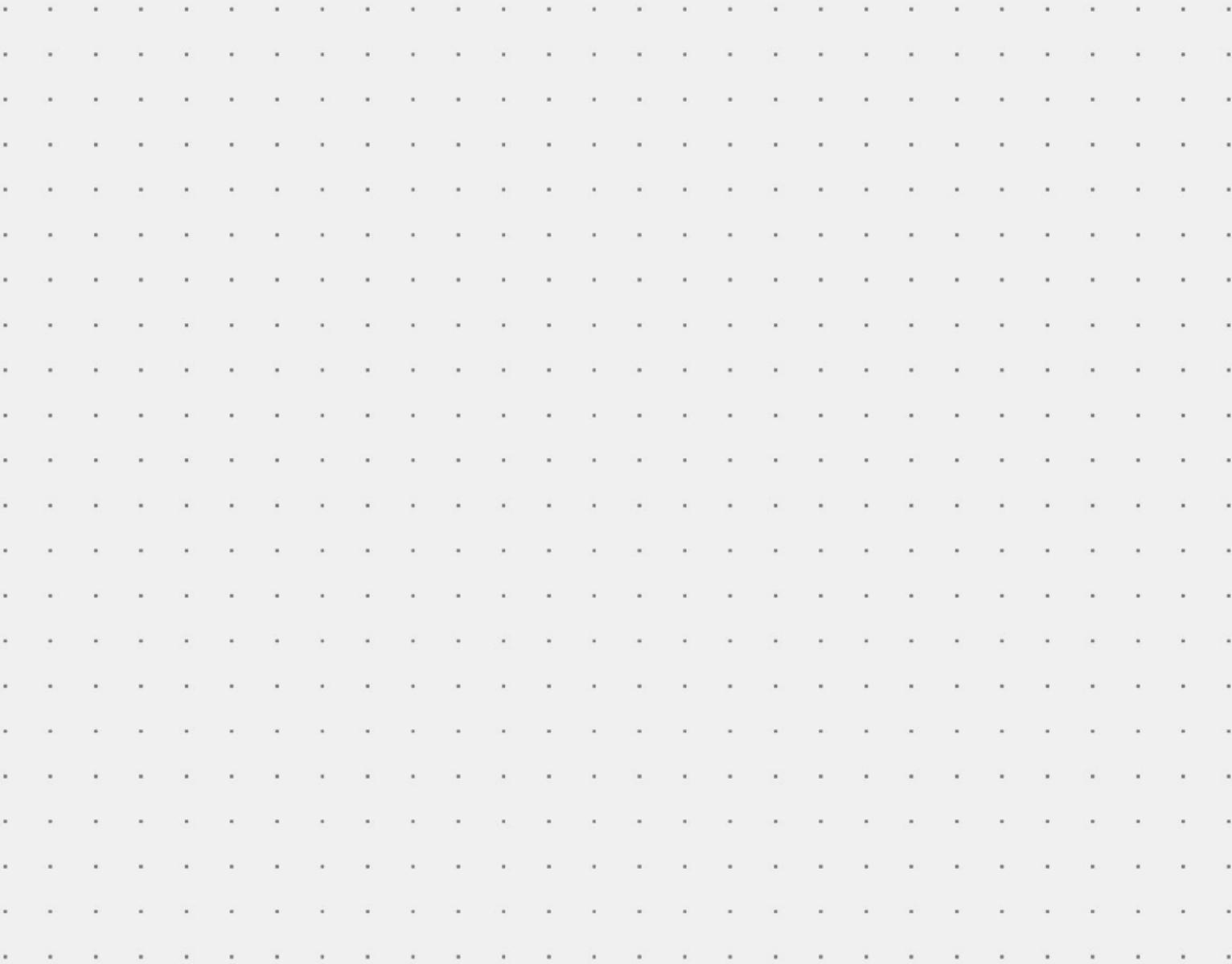
UK based supplier of scalable and flexible 4G and 5G core solutions for private networks.

**BAM Nuttall Ltd**

UK based civil engineering contractor and part of Royal BAM Group.

**Building Research Establishment (BRE)**

Centre of building science with extensive experience in managing collaborative R&D programmes of this type.





Case Study:

## SMART JUNCTIONS

### Background

The Smart Junctions project aims to deliver AI traffic control systems to reduce congestion and pollution, as well as improving productivity by reducing the waiting times at traffic signals.

The project aims to use a 5G small cell network to decrease infrastructure costs for the connection of sensors at every junction, removing the need to mount hardware onto buildings in district centre locations as well as supporting connected bus projects and other mobility-based public services. This project fosters innovation in the telecoms sector using open architectures and a new commercial approach based on network as a service (NaaS).

SMART  
JUNCTIONS**The Challenge**

The Smart Junctions product requires low latency communications between the system and the cloud. However, current MNO solutions do not provide sufficient levels of resilience, making it difficult to ensure the required levels of latency. The costs of a wired connection are also expensive, which has a knock-on effect on industry productivity. This lack of available connectivity also impacts wider Smart City innovation in Manchester and prevents industry in the city from reaching its full potential in productivity levels.

**The Opportunity**

**The Smart Junctions project seeks to take advantage of the following opportunities:**

- To remove civil works and hardware costs, with a potential overall cost reduction of the installation of Smart Junctions
- To fully understand the impact of latency in the Smart Junctions product
- To analyse the use of 5G versus other alternatives for future rollouts

**The project is expected to demonstrate the long-term commercial benefits of combining 5G with Smart Junctions. This includes:**

- A sustainability plan with new revenue models for a local authority owning infrastructure
- The use of a network as a service business model to create a platform for Smart City connectivity provided by Weaver Lab's Cell-Stack product
- Explore opening the neutral host infrastructure using NaaS capabilities from Cell-Stack

**Smart Junctions will explore the following benefits on new deployment models for 5G:**

- Priority on cybersecurity best practices and security by design built in Cell-Stack
- Seamless integration of multi-domain/multi-vendor using WireMQ and Cell-Stack products from Weaver Labs

**Use case:**

The **Smart Junctions** is currently in the process of exploring the wider set of use cases that can be trialled in this platform. At present, the trials will focus on the Smart Junctions test, and the open and shared infrastructure commercial model for local authorities to monetise the communications platform.

SMART  
JUNCTIONS

**Consortium**

**Transport for Greater Manchester**

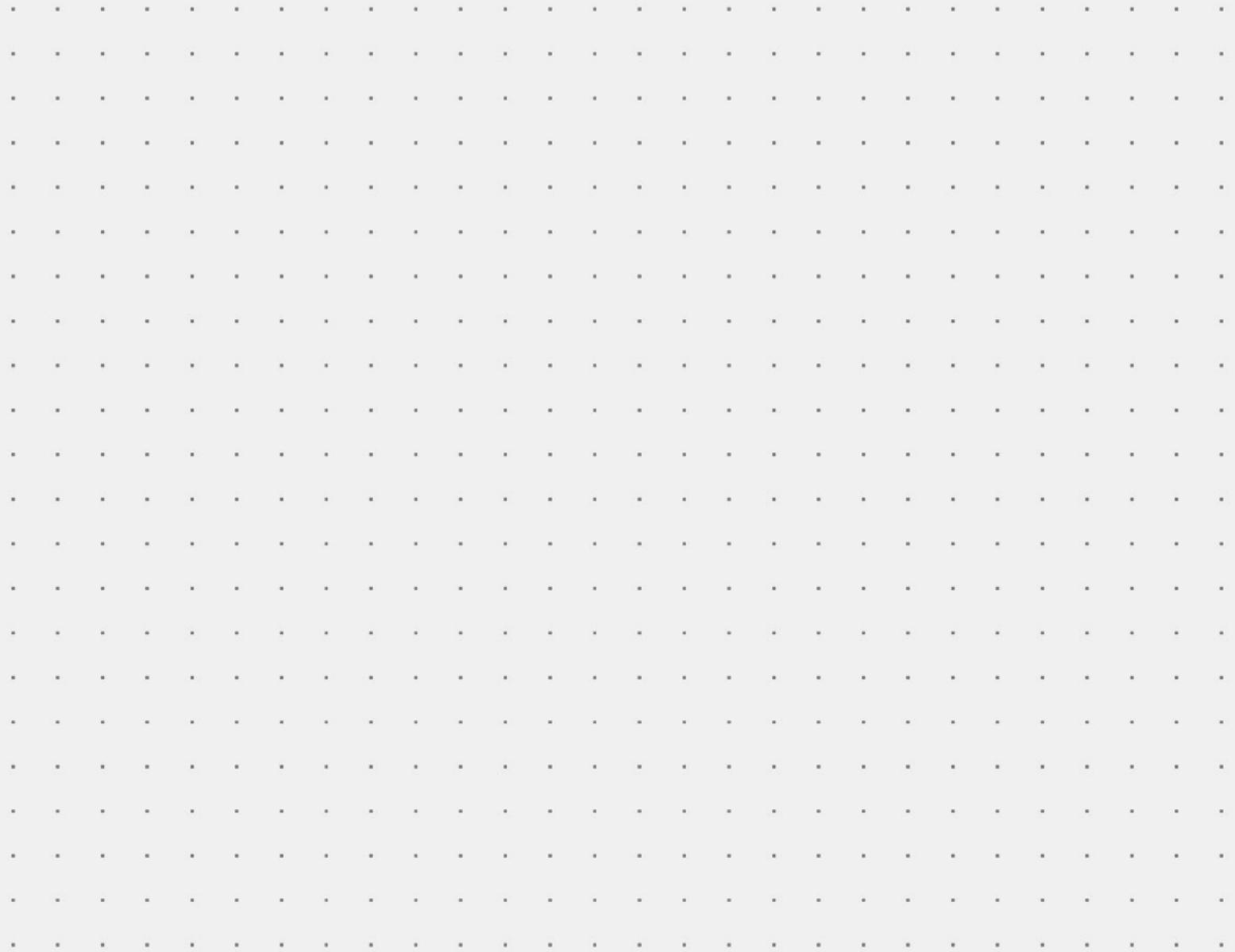
Transport authority with an established relationship with the Smart Junctions product and a track record of fostering innovation in the transport sector.

**Vivacity Labs**

Project Lead – Innovative SME who specialise in bringing machine learning products to the road infrastructure market.

**Weaver Labs**

Innovative SME creating an open and shared network as a service marketplace, with an extensive focus on security, to help unlock the opportunities 5G brings.



Case Study:

## 5G PORTS



### Background

The 5G Ports project is based at the Port of Felixstowe, Britain's biggest and busiest container port, handling more than four million containers from approximately 3,000 ships each year, including the largest container vessels afloat today.

The project aims to prove that 5G has industrial capabilities in the context of logistics and port operations across the fields of automation and IoT.

## 5G PORTS

**The Challenge**

The availability and efficient operation of quay cranes represent a key factor in port logistics productivity. Unexpected failures can lead to stoppages in loading and unloading operations, affecting turnaround times for vessels. Cranes are prone to failures due to the extensive stresses and cyclic loading they experience during operations. In Felixstowe alone, crane failures account for 1.4% of the total downtime, resulting in 1,732 hours of delays each year.

Another challenge goes alongside the plan of container ports to convert manually operated yard cranes to remote control automated systems utilising Programmable Logic Controllers (PLC) and cameras, to improve the efficient use of labour working on the cranes. However, current remote control solutions use powerline fixed communications, which limits the quality of CCTV imagery and exhibits unacceptable latency for the operator. The fixed network solutions do not scale well across the port and limit the port's ability to flex and reconfigure its operations to meet changeable demand.

**The Opportunity**

The deployment of a 5G network at the port of Felixstowe creates the opportunity to test the application of new types of technology capable of reducing asset downtime, therefore increasing port productivity. It will also enable the adoption of technologies that require significantly higher throughput, without the need for physical networking across an operational dock and berth space.

**Use cases:**

1. **Using 5G for remote control of yard cranes** – This use case focuses on the transition of large amounts of CCTV data and interoperability with the PLC of the cranes over 5G.
2. **Predictive maintenance of quay cranes** – This use case focuses on the application of IoT sensors to quay cranes and integrating key data sources from within the business, to predict, using AI and algorithms, the optimum time to drop assets out of service. The ultimate goal is to minimise unexpected downtime and to optimise the time that the assets are in use.

5G PORTS

**Consortium**

**Port of Felixstowe, Hutchison Ports UK**

Project lead and port operator providing the business problem, assets and operating environment for testing.

**Hutchison Three UK**

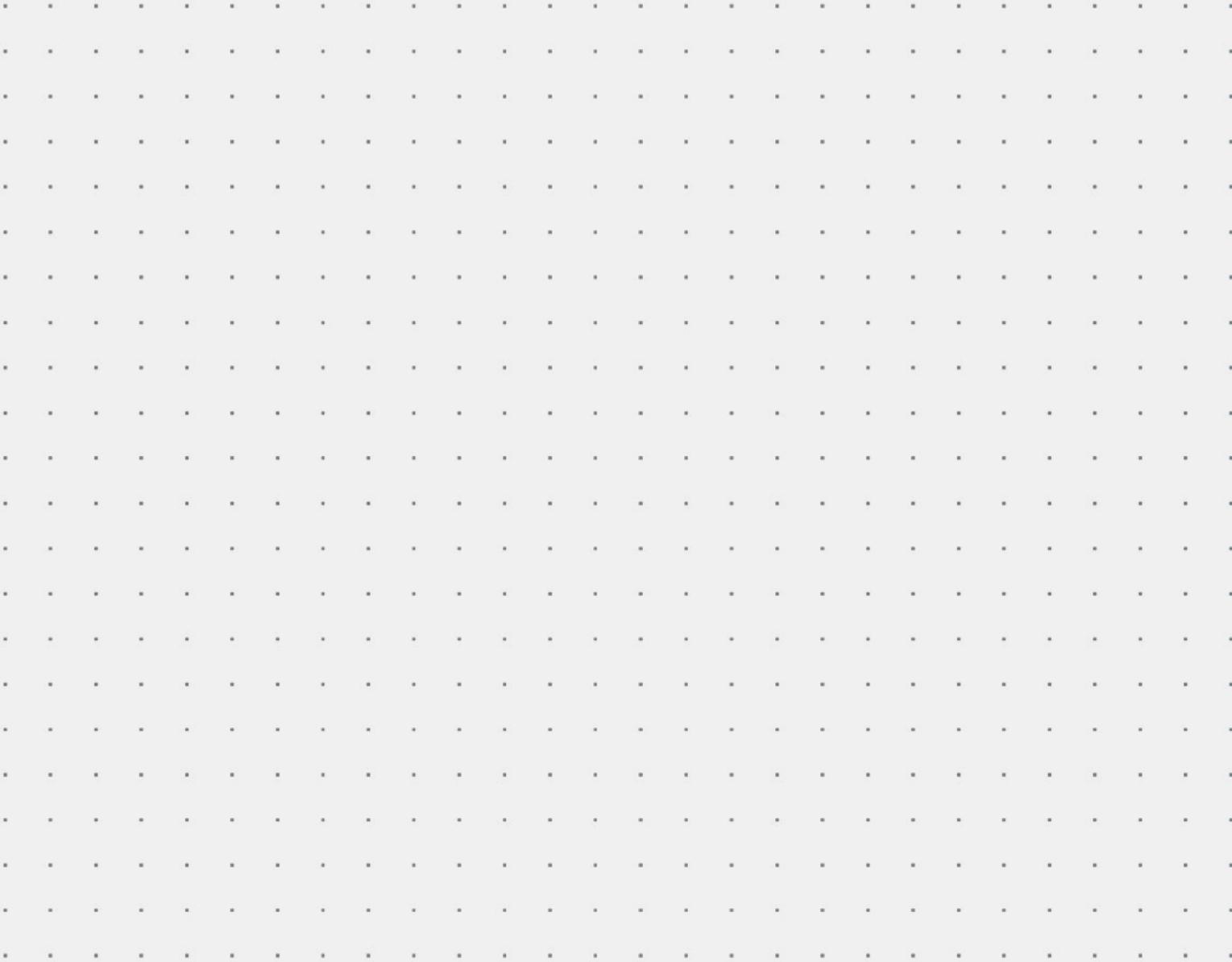
5G provider and lead on the automation of a yard crane over 5G test case.

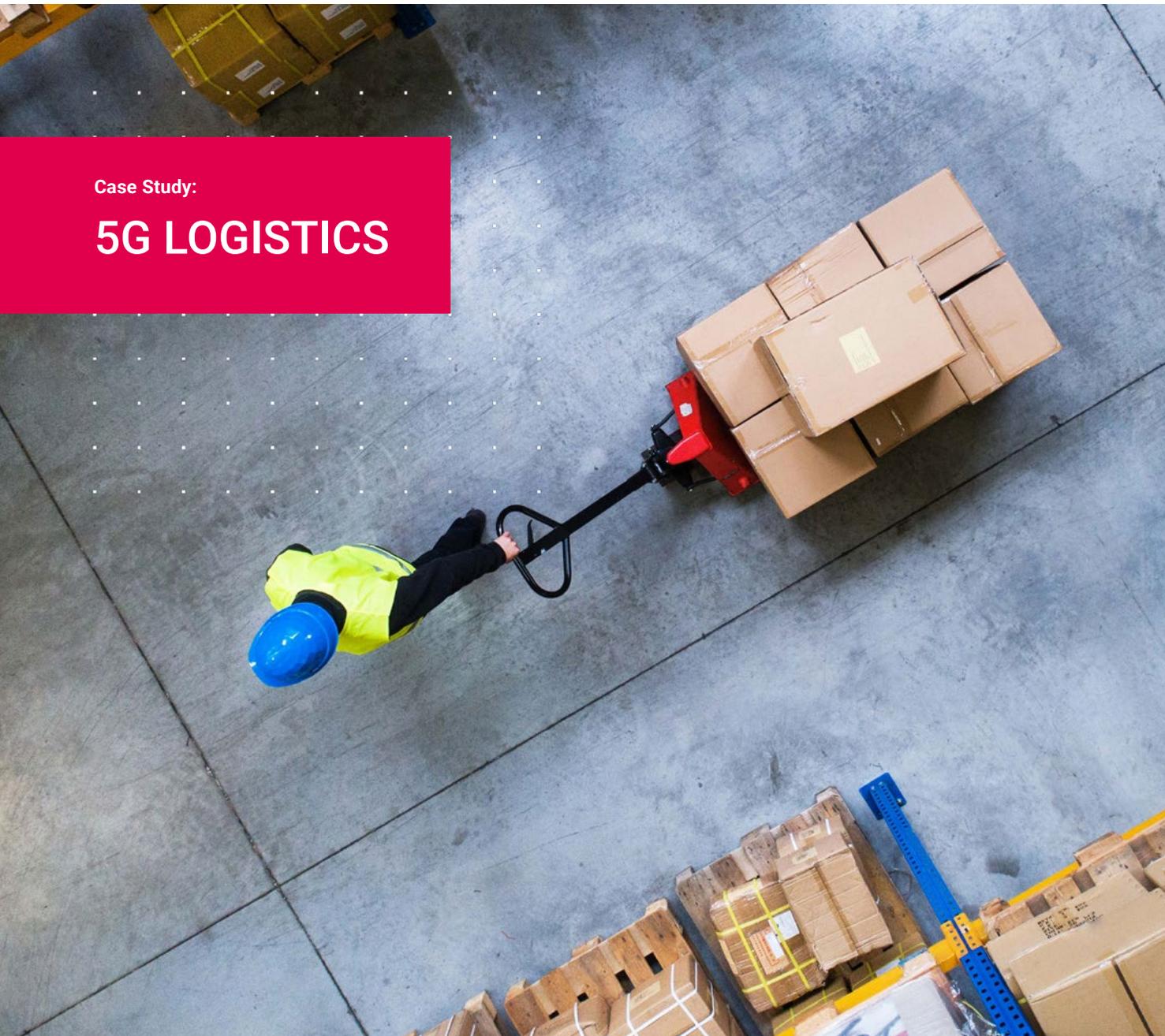
**University of Cambridge**

AI and data analytics skills for the creation of an algorithm for predictive maintenance of quay cranes.

**Bluemesh Tooth Solutions Ltd**

SME start up specialised in sensor and IoT enabling the predictive maintenance use case through data collection.



A high-angle photograph of a warehouse floor. A worker wearing a blue hard hat and a high-visibility yellow vest is operating a red pallet truck. The truck is carrying a stack of several cardboard boxes. The floor is a light grey concrete. In the background, there are more stacks of boxes on pallets, some with yellow straps. The lighting is bright and even.

Case Study:

## 5G LOGISTICS

### Background

5G Logistics is a £5.2 million project that will create a 5G private network linking Bristol Port and the Gravity Smart Campus site in Somerset.

Use cases will be trialled on this network to demonstrate how 5G private network capabilities can offer efficiency and productivity improvements to the logistics sector, with potential for the resulting solutions to be implemented in ports, enterprise zones, business parks, and local authorities. Use cases will demonstrate the secure tracking of goods within and between the sites, traffic management at smart junctions around the port and automated drone flights to support port police operations.

## 5G PORTS

**The Challenge**

To accelerate the deployment of 5G networks and ensure the UK can take early advantage of these applications, it is necessary to illustrate how these networks can be used and the benefits that can be realised. For industries such as logistics management and traffic management there is a need to demonstrate that 5G networks can augment legacy technologies to address existing productivity and competitiveness challenges.

**The Opportunity**

The project aims to demonstrate how 5G private network capabilities can offer efficiency and productivity improvements to the logistics sector. The dynamic creation of zones and corridors based on 5G enabled digital/virtual geofencing will support: accurate location tracking of goods; detection of goods leaving a geofenced zone or an anchoring RFID-5G-NanoCell router; and automated speed of digital transfer of goods between two RFID-5G-NanoCell routers replacing manual operations.

Additionally, 5G-enabled automated drones aim to reduce inspection and incident response times for port police operations, while connecting smart junctions to the 5G network will provide new location tracking data to support traffic control applications.

**Use cases:**

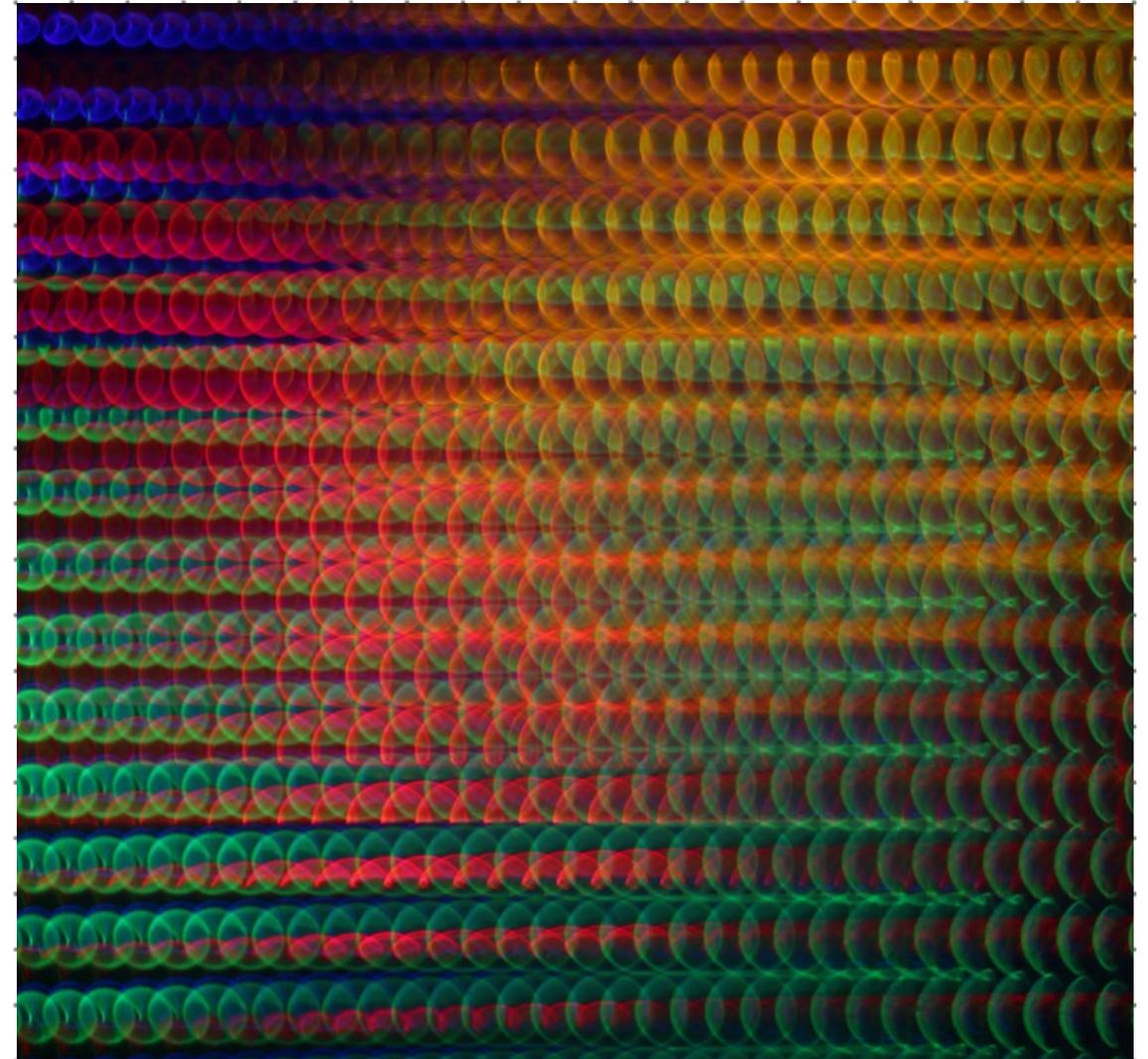
1. **Freeport** — Creating 5G-enabled digitally/virtually geofenced zones and corridors to demonstrate security, traceability and real-time tracking of goods in a Freeport and Freezone scenario.
2. **Port police drones** — Automated drone flight for boundary inspection, ad-hoc surveillance and response to trigger events, supporting more efficient port police operations.”
3. **Smart junctions** — 5G upgrades to existing smart junction automation will support new functionality for extracting data to a multi-access edge computing (MEC) platform and cloud, departing from today’s self-contained systems.



## Lessons learned

As project participants continue to work on demonstrating the ways in which innovative use cases in 5G can work in manufacturing and logistics, they have developed several insights, both in technical and non-technical areas.

So what have they found throughout the course of the programme? Here are a few points that emerged from the Industrial 5G Uncovered webinar series.



## Lessons learned

### 5G is an enabler of digital transformation

As the innovators progress through the programme, it is becoming more apparent that as UK businesses look towards the future and the best ways in which to improve productivity and remain competitive with both domestic and international peers, new capabilities are needed. The low latency and connectivity specifications that modern industrial environments, factories and construction sites are beginning to see as a core need require the digitisation of the sector and a gradual shift to 5G.

During the first Industrial 5G Uncovered webinar, the benefits of 5G for logistical use cases were discussed, as trials showed that it was particularly of use in making intensive processes more reliable and robust, as well as reducing business costs. Also highlighted was the use of 5G for both safety and environmental issues. Industrial 5G can also be leveraged to automate processes and alleviate the burden of the workforce.

### Collaboration is key, but uncertainty still remains

For technology startups and scaleups that want to leverage 5G capabilities, collaboration is key. Programmes such as the Industrial 5G Testbeds and Trials, and the 5SPRING accelerator programme can help small businesses to work with larger industrial players, which provide them a field to demonstrate and prove the legitimacy of their solutions. On the other hand, corporate challenge owners can learn more from innovation processes instead of solely relying on established solutions.

This is particularly important as experimenting with 5G is both time and resource intensive. The numerous procedures that must be followed by large corporations can prevent them from rapidly implementing use cases. It was also remarked that in some use cases, 5G is still in too much of a nascent stage to see exactly where the value from 5G lies - particularly as the sector is still in its exploration phase of finding out what can be done.

### Domestic and international policy and partnerships - key for sharing best practice

The importance of leveraging national and international policy incentives as well as participating in international consortia were also highlighted as vital means of sharing best practice and thinking about the long term viability of 5G deployment. The second Industrial 5G Uncovered webinar delved into the details of the use cases being conducted in each branch of the programme, as part of a broader industry transformation trend towards Industry 4.0. Panellists agreed that industrial digitisation is “undoubtedly the next step in the industry” and that 5G will be a key enabler in this process.

With the programme maintaining relationships and building upon the recommendations of the Made Smarter programme and other key domestic policy programmes, discussion focused on the deployment and sustainability of projects through sustainable smart factories, as well as the importance of sharing best practice both within the UK and internationally.

## Lessons learned

Featured project 5G Smart - a smart manufacturing 5G based in Sweden - shared some lessons learned from their experiences. The 5G Smart use case prompted the deployment of a strategy based on three pillars, essential to the success of the use case:

- A research period on 5G integration and on the value created by 5G for factory owners
- Demonstrating, evaluating and validating 5G capabilities
- Enhancing the 5G technology and its implementation in the existing infrastructure

inGENIOUS - a cross European Horizon 2020 project using IoT and 5G to provide next-generation solutions for the Universal Supply chain - also shared several use cases being explored in 5G, intended to cover all the main steps of the supply chain, conducted in Spain and Greece and Italy.

- Asset tracking in real time
- AI tools to monitor the access of vehicles into ports to reduce the waiting time
- Safety centric part of the port: to keep the employees safe
- Transportation to sites: satellite connectivity needed

Project representatives reflected that multi-dimensional cross-layer architecture is needed to ensure the success of all these use cases, incorporating 5G as well as other technologies such as AI across all architecture layers.

Discussions also included the first findings of the business challenges that were attempted to be solved. In one example, participants spoke of a 5G network that aims to wirelessly connect a number of connected factories, thereby reducing and/or eliminating the extensive number of wired machines that currently exist in them. Whilst pulling data from all the different systems and connecting everything wirelessly in the cloud is something that has yet to be resolved, 5G is recognised as playing a major role in the quest to streamline these processes and reduce the number of wires, therefore improving agility and flexibility of processes.

Programme participants also expressed the notion that it is important to give consideration to the political, legal and insurance implications of new technologies, and the various factors that are required to be analysed, tested and looked at in depth to ensure practical, legal and ethical harmonisation.

## Skills - an issue across the board

As previously mentioned, skills remains one of the primary issues that early adopters of 5G face, with hiring managers needing to look outside of the UK to find people with the required skills. Webinar panellists highlighted the difficulty of finding the right skillset in IT departments as well as in other necessary business functions. Programme participants noted that 5G is not a 'plug-and-play' technology, but that it must be adapted to the existing infrastructure. To facilitate this, new talent is often needed to both integrate brand new processes and equipment into the existing infrastructure, and maintain the overall network.

## Lessons learned

### Device availability, maturity and security concerns

When focusing on features and challenges that have arisen during the course of the projects, insights from the third Industrial 5G Uncovered webinar reinforced some existing ones - such as the current availability of 5G enabled devices, as well as revealing some previously unknown challenges - such as ones around cybersecurity.

Panellists commented that although the ecosystem is slowly advancing and more devices exist now than there did at the beginning of the programme, and that the I5GTT programme has forced the technology to mature somewhat faster to enable wider deployment, the 5G ecosystem remains at a fairly low level of maturity. Programme participants have revealed that advanced capabilities that rely on the wireless elements of 5G are, for the most part, not available yet. There can be several reasons for this, such as that the specifications may not be complete, or these wireless elements may not be implemented in products (devices, core functions) and/or services (networks do not support them). In one example, programme participants found that some vendors could only transmit over the lower component of the required radio frequency band, or did not provide support for 5G location features - attributes that can be indicative of an immature market.

Whilst from the outset this immaturity may appear to be a challenge, the following should be considered:

- It may be an opportunity for companies who want to make 5G products or provide services
- Many Industrial 5G use cases do not require these capabilities – with several I5GTT projects having demonstrated many benefits without them

Many 5G networks operate in “non-standalone” mode, meaning that 4G devices are compatible with them. This allows products to be developed with a clear transition path to full 5G in due course.

Moreover, because the technology is still relatively new, compatibility issues may persist. However, it should be noted that whilst device availability is still a hurdle to the deployment of 5G in industrial environments, a wide diversity of performance has been seen in the products. Additionally, products are gradually scaling, which in time should help to address the maturity and availability issues.

In terms of the security aspects of 5G, representatives shared broadly similar cybersecurity learnings - namely that it is of key importance that those involved in designing and implementing these networks should ensure that factory security is more than a network problem relating to availability, confidentiality and integrity of information, but is also about a wider range of topics. As such, it requires multiple levels of control. Here, authentication is very important for device identity - more specifically end-to-end authorisation and access control. Accountability for critical phases of network configuration, or operations invoked by IoT devices are also essential to maintain system integrity. Here we see the opportunity for other emerging technologies such as distributed ledger technologies including blockchain, which could have a strong potential role in ensuring this integrity, as well as for helping to ensure forensic traceability if there are data intrusions or mistakes. Projects have also explored zero-trust approaches which are key for infrastructure sharing.

Many open threats are emerging from a new and rich ecosystem, such as in virtual traffic segregation, remote operations and maintenance, building access and data sharing. 5GEM has developed a framework to ensure solutions meet certain security criteria.

## Lessons learned

It is necessary to configure security controls so that they are interoperable with other systems' controls using 5G. Industry does not have a common approach and needs one, particularly for risk assessment which is an expensive process.

According to a representative for 5G ACIA, early adopters and those considering deploying 5G should be aware of the need for a dialogue around risk assessment, and to gain a sound understanding of the security risks and needs across different use cases. It was also recommended that interested parties and early adopters build a sufficient safety response in settings where employees are gradually integrated with automated devices. Key for early adopters and equipment alike to recognise is that the security frameworks governing communications hardware and software still need further development. Lastly, it was revealed that trustworthiness of the data and trust between the systems is still a challenge that use cases should address.

### **Accelerating 5G adoption - the potential of O-RAN and interoperability**

Managing a solution across multiple vendors has been noted by participants to be a particular challenge in the quest to deliver a successful use case, highlighting the part that Open Radio Access Network (O-RAN) products could play in solving this problem of interoperability. Panellists reflected that in order to mitigate this, several actions can be taken. One recommended example given is that orders with the suppliers should be done with staggered invoices that are adapted to the stages of integration, in order to ensure full functionality and organisation. A second recommendation given is that strong ties should be established with each vendor's technical support, by identifying their 5G specialists as early as possible to help solve technical and compatibility challenges as they arise. Finally, panellists recommended that when considering areas of interoperability, vendors should jointly identify what is needed.

Panellists in the fourth webinar observed that the potential for O-RAN use cases is large and driven from a point of view of efficiency, cost saving and sustainability. Panellists shared that O-RAN adds security and resiliency to the network by reducing the amount of hardware on sites. It also creates flexible manufacturing systems, with reconfigurable environments to adapt to changes in customer demand.

However, it was said that the supply chain needs to diversify further, in order to allow competition to flourish. Panellists also revealed that opening up the network to third parties will create value for both companies and end customers, as the network will be able to comply with different applications in manufacturing and new requirements. Bringing new vendors into the system can also challenge interoperability issues.

### **Accelerating the adoption of 5G technology in manufacturing and logistics**

Companies are slowly moving away from just considering 5G technology to the activity of actually investing in it, with the COVID-19 pandemic also acting as an accelerator of the desire to use remote and advanced technologies for manufacturing. Businesses saw an acceleration in their journey to digitisation as they sought to improve their operations, especially in light of the disruption caused by both the pandemic and the UK's departure from the European Union. While there are still network infrastructure delays and a lack of coordination between partners, project participants and panellists revealed that these speed bumps are assumed for any new technology. The level of interest is increasing for O-RAN solutions and hardware devices are increasingly coming to market.

## Lessons learned

Prior to the disruptions caused by the pandemic and the departure of the European Union, connectivity was not a priority for UK manufacturers according to panellists. However, companies are now realising that connectivity strengthens the other technologies that manufacturers previously wanted to implement. Panellists revealed that companies are exploring other ways in which to improve the workplace and make it safer, including improving employees skills and enhancing their inputs. Moving from trials to real-world commercial applications depends on the success of the use cases across the industry. As programme participants approach the end of their testbeds and trials, and noting what impact 5G can have on their businesses, consortium, and industry as a whole, it is now more important than ever that awareness of the benefits, challenges and barriers that can be overcome need to be increased.

### **Deployments need sufficient planning so as to fully exploit the benefits**

Insights from participants have revealed the importance of fully planning deployment as best as reasonably possible, including spectrum allocation and infrastructure (e.g. fixed network, computing) to get the necessary performance and benefits. This is the same for all wireless networks where a certain performance type is needed. The 5G radio system has to be optimised for traffic requirements and the supporting ICT systems require careful configuration and strict management.

### **Future Timescales and Functionality**

#### **Policy initiatives for adoption**

At the adoption level, we observe in Europe and around the world that different countries are taking proactive initiatives to accelerate the deployment of industrial 5G. France is a typical example where a report on their industrial 5G mission was published<sup>4</sup> in the beginning of March 2022. Like in the UK, this mission has three objectives: (i) establish a dialogue with the industrial and telecom players to incentivise the usage of 5G, (ii) depict the barriers of the development of this technology within the industry, and (iii) formulate a concrete proposition for the deployment of the 5G high-impact use cases for the industry of future.

<sup>4</sup> Rapport de la mission 5G Industrielle», French Ministry of Economy and Finance, March 2022.

Lessons learned

Standardisation

3GPP, as the main organisation where 5G technologies are developed, has a rolling schedule of Releases (Rel.n) of its Technical Specifications (TSs). The initial TSs for 4G were issued with Rel.8 whilst the current release for 5G is Rel.16. Stage 2 of 3GPP Release 17 was frozen in June 2017.

The following Figure shows an overview of the features of Rel.16 and those that will be delivered in Rel.17.

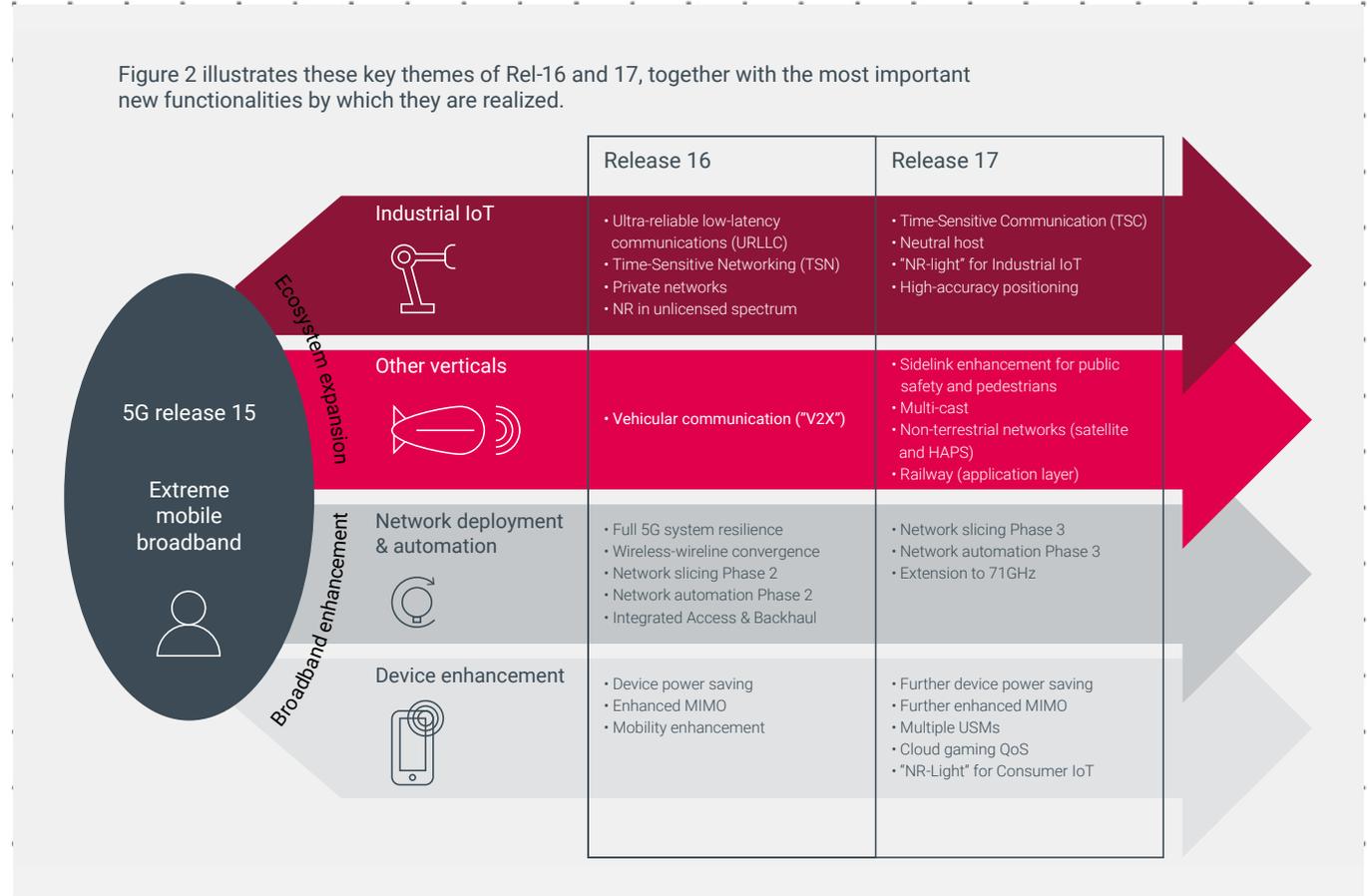


Figure. Snapshot of Features of Rel.16 and Rel.17<sup>5</sup>

<sup>5</sup> M. Baker and M. Poikselkä, "5G Releases 16 and 17 in 3GPP", Nokia white paper, April 2020.

## Lessons learned

The ongoing standardisation work on the Release 18 will be the first specification on what is called Advanced 5G. Advanced 5G will constitute all the releases 18, 19, and 20 that will be developed from now to around 2025. The philosophy of this standardisation process remains the same as it aims to serve different vertical sectors.

For the industrial sector, many requirements have already been introduced in the 3GPP Rel. 16 and 17 SA1 documents. The requirements in Release 17 are quite complete to reflect the current needs of this vertical sector. There will be some enhancements due to the experience with first deployments and the important thing is to forward Rel. 17 requirements to Rel. 18. From 5G-ACIA perspective, examples of features to tackle in Release 18 include a fully decentralised TSN configuration model and more general concept for Proximity Services / Sidelink usable in different domains.

## Research, Development and Innovation initiatives

In parallel to the standardisation process, several research and development initiatives around the world have started to support such activities. Notably in Europe, the major initiatives are under the umbrella of the 6G Smart Networks and Services (SNS) programme just launched in January 2022. This programme includes two paths, one evolutionary aiming to develop components for Advanced 5G and its 3GPP standardisation, and the second one is more revolutionary with the objective to drive the future looking fundamental research for 6G. The evolution towards Advanced 5G will be done considering the new advanced user services (e.g., immersive communication, holographic telepresence, and AR/VR), while at the same time targeting to have open connectivity, reduced energy consumption, lower operational and ecological costs. The programme focuses specifically on developing defined technical areas to support standardisation (e.g., green radio technology, evolved architecture for global green systems, edge computing evolution). In parallel to that, it will launch large scale projects and pilots to demonstrate both technological and business validation with verticals and build the business ecosystem notably in the industrial sector.

## Next steps for industrial 5G

Mainstream discussions and understandings of the capabilities of 5G are still in relatively early stages, compared to other modes of telecommunication such as 4G and WiFi. As a result, the widespread adoption of 5G in business, including manufacturing and logistics organisations, remains slow, with some early adopters taking those first steps.

As developments in 5G testbeds and trials continue within this project and those further afield, the understanding of and validity of demonstrable use cases will become more apparent, allowing early adopters and the early majority of manufacturers to begin their development of 5G. The development of devices and software will also usher in a new wave of organisations in manufacturing and logistics to begin implementation, as: more products are improved; product lines are expanded and become more widely available; and 5G solutions become cheaper. This development will reduce the barriers to accessing 5G-ready devices and offer guidance of where money should be spent in 5G. This will also help to reduce any perceived risks on the return on investment and a lack of understanding of 5G capabilities.

As the Industrial 5G Testbed and Trials Programme navigates its second year, it is important to continue to leverage the knowledge of industry representatives across the areas of manufacturing and logistics, working closely with government departments, industry bodies, technology firms and other relevant stakeholders to further assist industry in this transition.

This will require a step change in proactive actions from those in industry, ensuring comprehensive and far-reaching changes in attitude towards 5G understanding and fostering a culture of openness and innovation within the sector. By remaining closely connected to the government, disseminating to them the learnings that highlight the specific, as well as the broader systematic needs of the sector, more opportunities may arise to quickly address any gaps and keep up with the rapid progression of technology.

Keeping abreast with questions surrounding technological developments, as well as innovation and culture issues in 5G adoption, will be vital for determining how to best support companies in the journey towards increased productivity and competitive advantage. This will include addressing issues mentioned earlier in this paper, such as the security of 5G connectivity and devices, regional differences in the adoption of 5G and many other gaps in understanding that could impact 5G adoption.

Next steps for industrial 5G

In looking towards the future and the best ways in which to drive the necessary technical, interoperability and market availability challenges, a drive towards diversifying market options and improving interoperability of devices through services such as Open-RAN will become a necessity. This is particularly important if the UK is to become a leader in both adoption of 5G and as a producer of key equipment. Programmes and activities within DCMS' 5G Diversification Strategy will be key for driving the necessary industry learnings and conversations, technical innovations and policy environment to achieve this. The SmartRAN Open Network Interoperability Centre (SONIC Labs) is a joint programme between Digital Catapult and Ofcom, and a primary activity in the Diversification Strategy. As one of the most important projects of its kind in Europe, the programme is working to foster the emergence of new solutions in the telecom supply chain in the UK, focusing on multi-vendor open, disaggregated and software-centric network products, solutions and services, starting with Open RAN.

With the SONIC programme focussing on Open RAN and the potential for disaggregated RAN to be a game-changing technology in the diversification of the telecoms supply chain, it offers the potential to drive investment and growth for the UK telecoms industry as well as the UK economy as a whole. In turn, this also lowers the barriers to deployment for end users in manufacturing and logistics, presenting them with the opportunity over time to benefit from increased choice of equipment and services, lower costs and more industry examples of successful use cases and return on investment amongst other benefits, all in the quest to improve industry productivity.



# Ecosystem mapping

CLICK TO JUMP TO A SUBSECTION

5G DEVICES 56

5G MANAGEMENT AND ORCHESTRATION 59

5G BSS/OSS 61

4G AND 5G RADIO ACCESS NETWORKS 63

4G EPC/5G CORE 67

5G NETWORK SLICING 69

5G SECURITY 71

5G WEARABLES 73

5G TESTING 74

5G SILICON AND CHIP MANUFACTURERS 76

5G DISTRIBUTED ANTENNA SYSTEMS AND SMALL CELLS 79

CLOUD SERVICE PROVIDERS 80

5G EDGE PLATFORMS 81

5G OPEN SOURCE PROJECTS AND LABS 84

5G SYSTEM INTEGRATORS 86

REGULATORS AND STANDARDS DEVELOPMENT ORGANISATIONS 90

5G NETWORK ROLLOUT BY NETWORK OPERATORS 93

5G ENABLED STARTUPS AND SCALEUPS 94

INDUSTRY ORGANISATIONS AND INSTITUTIONS 101

The deployment of 5G in the areas of manufacturing and logistics and in the wider world will be challenging, requiring new and innovative business models and corresponding regulations to maximise the benefit to the UK economy.

## Ecosystem mapping

The deployment of 5G in the areas of manufacturing and logistics and in the wider world will be challenging, requiring new and innovative business models and corresponding regulations to maximise the benefit to the UK economy. However, with the industrial IoT market expected to be worth \$15.7 billion by 2026, current and future telecommunications companies are expected to rise to these challenges and produce market-suitable solutions.

Discussions around the technology continue to evolve. In recent years they have led to the current 5G ecosystem being affected by factors including market failure and increased focus on the need for a secure and resilient digital network.

The UK government has stated that its long-term intention is to focus on diversifying the market and present multiple options to avoid reliance on one provider. In doing so, they are also considering the place of open, interoperable network infrastructures.

The following list of organisations, products and businesses is by no means exhaustive and only captures a portion of the vast landscape of the constantly growing 5G ecosystem.



## 5G devices

Often the cheapest and most accessible entry into 5G devices that manufacturers can access, the availability of 5G-enabled phones, laptops and tablets is key in enabling those in industry to adopt 5G.

However, various factors in 2020 and 2021, including bans on the use of some brands and other political factors, have led to a shortage in chip supplies for some companies in Asia.

The number of 5G devices continues to grow and passed the 600 mark in February 2021, when around 400 devices were commercially available according to the GSA (Global Mobile Suppliers Association). When describing 5G devices it is important to mention that there can be a number of different categories within 5G devices, based on factors including functionality, use, purpose or shape.

**Note:**

Cellular IoT specifications are not mature in 5G yet. NB-IoT and LTE-M products, two main cellular IoT technologies, were designed and made for 4G and mainly available in 4G systems in spectrum providing LTE services. The operation of NB-IoT in spectrum assigned to 5G-NR was standardised in 3GPP Rel.16 but there are no devices supporting it in the 5G-NR bands yet, nor operators offering services. It is likely that LTE-M will be replaced by new air-interfaces and access protocols in future 3GPP releases, but that will take another couple of years.

**These categories are:**

**5G phones:**

Over 300 5G phones, where 90% of them are commercially available.

**Examples include:**

Apple, Samsung, Sony, OnePlus

**5G CPE (Customer Premises Equipment) devices (indoor and outdoor):**

Over 120 5G CPE devices used for FWA (Fixed Wireless Access).

**Examples include:**

Huawei, Oppo, Zyxel, Inseego, WNC, GosuncnWelink, ZTE, Jaton Tech

**5G modules:**

Over 80 5G modules.

**Examples include:**

Telit, Quectel, Simcom, Sierra Wireless, Nordic Semiconductor, GosuncnWelink

**Industrial/enterprise routers/gateways/modems:**

Over 30 different GWs/routers/modems.

**Examples include:**

Huawei, WNC

**5G Hotspots:**

About 30 5G hotspots.

**Examples include:**

Askey, GosuncnWelink

**5G-enabled laptops/notebooks:**

15 5G-enabled laptops.

**Examples include:**

Dell, Lenovo, HP

**5G Tablets:**

About 10 5G-enabled tablets.

**Examples include:**

Samsung, Apple, Huawei

## 5G devices

### AR/VR headsets etc:

5G-enabled AR/VR headsets are still very scarce and hard to find, but this is changing. Two new AR/VR headsets with 5G capabilities from Pico Interactive were released in 2021: Neo 3 Pro, Neo 3 Pro Eye

### Other 5G devices:

Over 30 other 5G devices, including drones, displays, dongles and cameras.

### Examples include:

MTM, Huawei, Oppo



## Further 5G device companies

### Apple

American multinational technology company, headquartered in California, USA. Apple is the world's largest technology company by revenue. Apple's iPhone 13 models support 5G network connectivity, working with both mmWave and Sub-6GHz 5G.

### Digital Matter

USA company providing cellular IoT modems and sensors.

### Everyware

UK company selling Digital Matter products.

### Huawei

Headquartered in Shenzhen, China and founded in 1987. The world's second largest smartphone manufacturer, it has an estimated value of \$160 billion. Huawei has offered 5G enabled phones since 2019 and was the top 5G phone vendor in 2019, with 37% of the global market share.

### LG

South Korean multinational technology company headquartered in Seoul, Korea. LG has offered 5G-capable phones since 2019. Although the company has been steadily offering 5G-enabled phones, production has been halted on some recently announced phones and it is unclear when production will restart.

### Motorola

With the original company headquartered in Illinois, USA, the consumer electronics and telecommunications division is now known as Motorola Mobility, and the enterprise focused division known as Motorola Solutions. Motorola Mobility launched the world's first 5G-enabled smartphone in 2018 and is developing a reputation for affordable 5G connectivity.

### OnePlus

Headquartered in Shenzhen, China and majority owned by Oppo, OnePlus is a consumer electronics manufacturer that has recently launched a new line of affordable 5G smartphones.

### Oppo

Chinese consumer electronics and mobile communications company, headquartered in Dongguan, Oppo has been operating in the UK since 2019 and has announced a target to become the leading smartphone brand in Europe.

### Samsung

A multinational conglomerate headquartered in Seoul, Korea. At the time of writing, Samsung has the biggest global market share for smartphones, often competing against Apple for the top spot. Samsung also produces 5G-enabled tablets, laptops and notebooks, and has recently announced that they have set a record for 5G speeds.

### Xiaomi

Headquartered in Beijing, China, Xiaomi is a Chinese multinational technology company, Xiaomi ranked third in global smartphone shipments in Q4 2020.

## 5G management and orchestration companies

Management and Orchestration (MANO) is not specific to 5G or to wireless networks, nor are the virtualised objects that are orchestrated, such as network slices and related communications functions at lower layers. While some of the companies listed below focus on 5G, most provide general purpose services for any large scale multi-tenanted infrastructure.

### ADVA

Headquartered in Munich, Germany, ADVA is a telecommunications manufacturer whose Enterprise Orchestrator platform aims to make Network Function Virtualisation significantly easier for customers.

### Amdocs

Originally founded in Israel, Amdocs is an American-headquartered multinational telecommunications firm with a management platform titled Network Cloud Service Orchestrator.

### Blue Planet

A division of American telecommunications firm Ciena, Blue Planet has a 5G automation portfolio including a management offering.

### Cisco

American multinational technology conglomerate. Cisco manufactures hardware as well as software, including their management and orchestration function.

### Ericsson

Headquartered in Stockholm, Sweden, Ericsson was founded in 1876. One of the biggest global players in the manufacture of 5G equipment, Ericsson also offers a 'new generation of management system' in their e2e management Network Management solution.

### Hewlett Packard

Headquartered in Palo Alto, California, HP is an American multinational conglomerate, with a significant offering in the public computer market as the world's second largest PC vendor, but has also developed a 5G offering.

### Cloudify

An open source orchestration platform and network services framework, Cloudify provides edge orchestration, Kubernetes orchestration and infrastructure automation using multiple clouds. Cloudify is headquartered in Herzliya, Israel.

### Infinera

A supplier of networking solutions for business, Infinera is headquartered in San Jose, California and presents an offering in the area of network management and orchestration.

### Nokia

A multinational intercoms company headquartered in Espoo, Finland. Initially founded in 1865, Nokia has a varied 5G portfolio, and is known for being one of the largest global vendors of 5G network equipment, but also offers OSS and MANO solutions.

## 5G management and orchestration companies

### Rift.io

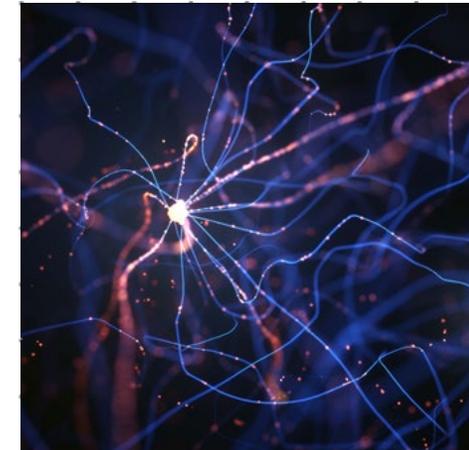
Offers rift.ware — an orchestration and automation platform to Automate the Deployment and Operation of virtualised Network Services. Rift.io is headquartered in Burlington, Massachusetts, USA.

### Whitestack

Headquartered in Miami, Florida, USA, Whitestack aims to promote SDN, NFV, cloud and related deployments all around the world, and offers WhiteNFV — an open source NFV Orchestrator.

### Wireless Excellence

Subsidiary company of Oxford based wireless product manufacturer CableFree, selling the wireless networking equipment of CableFree.



## 5G BSS/OSS

Business Support Systems (BSS) and Operations Support Systems (OSS) are an integral part of the management facilities for all kinds of communications service, including mobile communications networks of any generation. As well as requiring extension and refactoring to support new capabilities integral to 5G, such as managing network slices or MANO, they must maintain the tools needed to keep 4G, 3G and 2G systems running.

### Alepo

American communication company providing expertise around 5G core network solutions and BSS transformation and offering network infrastructure software solutions.

### Amdocs

[Described above.](#)

### Blue Planet

[Described above.](#)

### Cerillion

Headquartered in London, UK, Cerillion is a software provider known for their billing, charging and CRM solutions to various sectors including the telecommunications industry. Their Enterprise BSS/OSS suite is currently used by mobile network operator Three to power their launch of 5G high speed broadband in London.

### DGIT Systems

A product and service provider company serving the telecoms industry, DGIT systems is headquartered in Melbourne, Australia.

### Enghouse

Based in Reading, United Kingdom, Enghouse is a solution provider for customer communications with a portfolio of BSS and ODD software.

### Ericsson

[Described above.](#)

### Hansen

Global provider of software services to various sectors including telecommunications, Hansen provides a BSS/OSS offering to clients. Headquartered in Victoria, Australia.

### Huawei

[Described above.](#)

### Lifecycle Software

UK based BSS solutions provider company for network operators and other companies conducting 5G projects.

### MDS

UK headquartered software company MDS is specialised in BSS/OSS as a service for B2B, MVNO and IoT solutions.

### Netcracker

A subsidiary of Japanese multinational NEC, Netcracker specialises in both BSS and OSS, as well as NFV and software defined networking solutions. The company is headquartered in Massachusetts, USA.

### Nokia

[Described above.](#)

## 5G BSS/OSS

### Openet

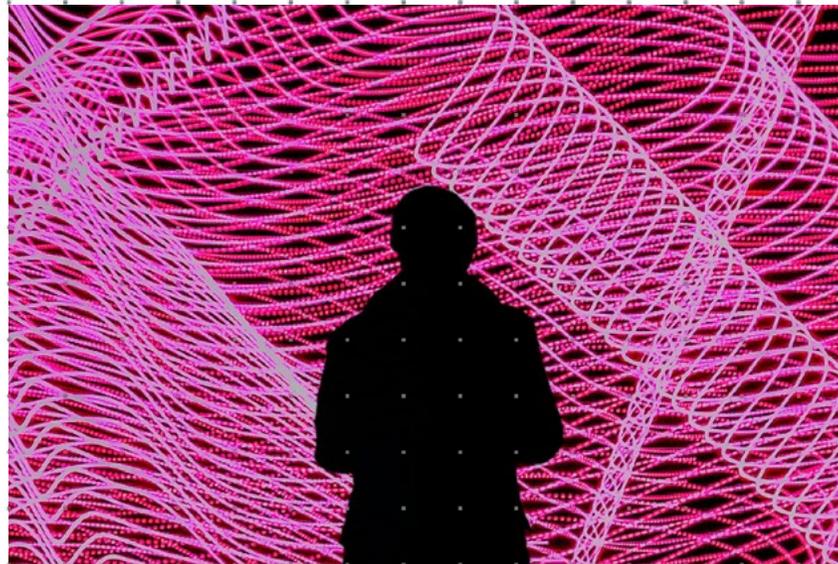
Based in Dublin, Ireland, Openet is a global Digital BSS vendor specialising in charging, policy and data solutions for business.

### Optiva

Canadian solutions provider Optiva provides BSS and OSS solutions to the global telecoms industry. Products include rating and charging, converged billing, customer experience management and customer care.

### Ranplan Wireless

UK company specialising in the design and automation of 5G wireless networks, as well as the provision of software solutions to operate the network.



## 4G and 5G radio access networks (RAN)

The radio access network (RAN) is the collection of physical hardware, including: remote radio units; baseband units; antennas of varying complexity; computation and storage; and edge communications infrastructure, that hosts the physical and virtualised functions that bring the services of the core of the mobile communications network to their users.

The RAN architecture has evolved into the 3GPP NG-RAN which embraces the trend for function disaggregation already happening in the rest of the network and also enables the integration of network slicing at the edge of the mobile network. For the network to achieve this, it must be integrated with MANO functions and the OSS and BSS.

The OpenRAN initiative is the industry response to exploiting this disaggregation to open participation in the RAN supply chain to a wider range of companies of all sizes, including many of those in the list below.

### Accelleran

Belgian software company developing an O-RAN software solution gathering cloud native techniques, AI and open architecture.

### Aceaxis

British based company developing 4G and 5G test radios to support network testing for smart buildings, healthcare and industrial sites.

### Airspan

USA based telecommunications solutions provider, known for developing RAN in products such as their Sprint Magic Box. Headquartered in Boca Raton, Florida.

### Altran

Part of the CapGemini Group, Altran is a Paris based innovation and engineering services firm, working with high tech company Baicells to jointly develop a multi-platform RAN solution for 5G.

### Altiostar

US based company providing virtual RANs which aims to integrate the operation of equipment from multiple vendors.

### ARM

British semiconductor and software design company specialising in ARM processor design as well as other chips. ARM designs 5G infrastructure solutions, including for edge computing, 5G-enabled devices and network operating systems.

## 4G and 5G radio access networks (RAN)

### Asocs

Israeli cloud solutions company providing virtual Radio Access Networks including Cyrus 2.0 – described as a truly open solution that delivers both standalone and non-standalone 5G cellular connectivity in a single software stack.

### Benetel

Based in Dublin, the company develops radio units and radio solutions for 5G RAN, 4G and LTE small cells.

### Bling Networks

Canadian based telecoms service provider, offering 5G wireless solutions including a Radio Access Network.

### Cablefree

Telecoms equipment provider based in Oxford, England with LTE 4G and 5G RAN equipment.

### Comba

Hong Kong based telecommunications equipment and services provider including radio access network solutions.

### Effnet

Swedish company providing different sets of 5G mobile and C-Ran solutions for OEMs, private networks, and industrial applications.

### Ericsson

[Described above.](#)

### Foxconn

Taiwanese electronics multinational, manufacturing products including O-RAN solutions and radio units.

### Fujitsu

Japanese multinational telecommunications firm, providing a radio access network for mobile networks. Fujitsu's 5G services aim to support the 5G evolution with 'open, customisable equipment and an integrated network architecture.'

### Huawei

[Described above.](#)

### IS Wireless

Polish telecoms company providing hardware and softwares to build 4G and 5G networks. It specialises in the delivering of RAN and core solutions.

### Mavenir

American telecommunications software organisation based in Texas, USA, offering an end-to-end Cloud Native Network Software Provider for 4G/5G and Open RAN based solutions.

### Maven Wireless

Swedish communications equipment company delivering wireless coverage solutions worldwide, for large sites such as public transport, stadiums and buildings.

### Movandi

Wireless systems company based in California, USA, aiming to offer a 'radically different approach' to 5G, including Radio Access Network solutions.

4G and 5G radio access networks (RAN)

**NEC**

Japanese multinational information technology and electronics company, headquartered in Tokyo, Japan. A large player in the integration of IT and network technologies, NEC is working with several partners in the UK including O2 and the UK government to develop the area of Open RAN and established the Global Open RAN Center of Excellence in London.

**Nokia**

[Described above.](#)

**Parallel**

5G native software architecture firm based in New Hampshire, USA, Parallel offers an Open RAN software suite for 5G New Radio.

**Phluido**

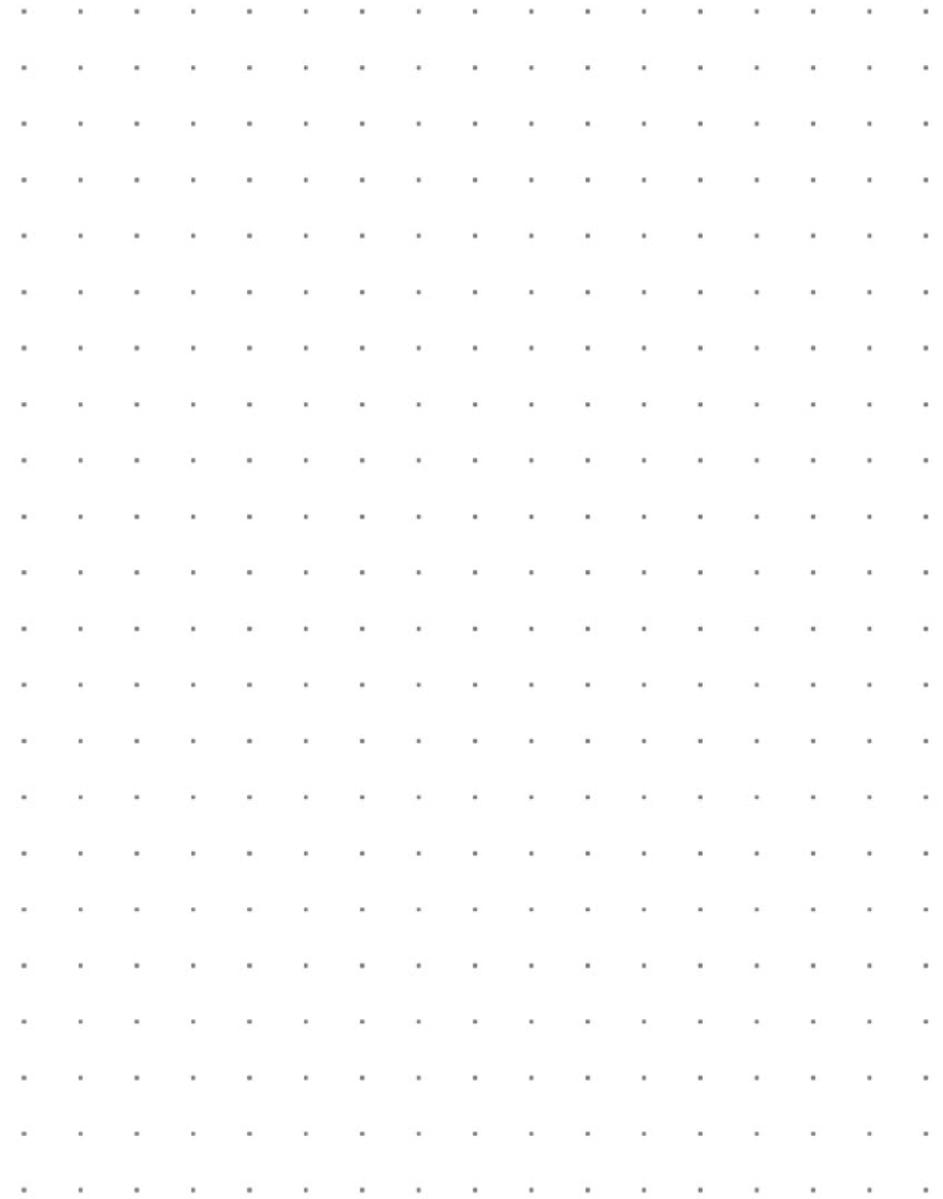
American telecoms company specialised in wireless communication offering Radio-as-a-service and deploying 5G C-RAN systems.

**Qualcomm**

Qualcomm has recently announced three new 5G RAN platform offerings: Qualcomm Radio Unit Platform, Qualcomm Distributed Unit Platform and Qualcomm Distributed Radio Unit Platform.

**ZTE**

Partially state-owned Chinese technology firm specialising in telecommunications. ZTE offers a cloud RAN solution, recently launching their Precise RAN solution including precision planning, slicing, scheduling and other features.



The 5th generation of mobile cellular network telecommunications represents a step change in network performance capability and provides business-grade service levels, reliability and availability.

This will enable Industry 4.0, Smart Factory, safety and mission-critical use cases.

## 4G EPC/5G core

Each generation of mobile cellular network communications brings a step change in architecture, functions and protocols. When 4G was introduced, the change came in the move from specialised telecommunications standards to an internet protocol platform, the EPC, which was much more accessible to any company competent in IP technologies and the virtualisation of (mainly) software functions, which run concurrently with the 2G and 3G hardware.

Currently, the ICT industry ensures that these changes are supported by commercial commodity products and services. The change from 4G to 5G is to move the network core further towards virtualisation and implementation in cloud platforms.

These opportunities within these two steps have been taken up by companies, large and small, including:

### Athonet

Italian telecommunications company Athonet provides a complete in-house software-based LTE/5G connectivity platform, operating in cloud or virtualised data centre environments and on ruggedised hardware.

### Cumocore

Based in Finland, Cumocore is a telecoms service provider delivering 4G and 5G core for private and local 5G networks, usually applied to rural and industrial sites.

### Casa Systems

US communications equipment provider supporting the 5G core requirements of 5G networks, by offering ultra-broadband 5G solutions for mobile applications, as well as 5G core and O-RAN solutions.

### Druid

A software company headquartered in Ireland. The company specialises in core cellular network software.

### Ericsson

[Described above](#). Ericsson offers both a virtual evolved packet core vEPC as well as their cloud packet core.

### floLIVE

London based IoT company with a cloud-based solution to join together private, local cellular networks to create private global IoT 5G networks.

### Huawei

[Described above](#). Huawei is considered to be a world leader in 5G core products and has previously won awards for Best 5G Core Network Technology.

## 4G EPC/ 5G core

**IPLook**

Chinese software company with an expertise in 4G and 5G core network for industries.

**Kaloom**

Headquartered in Montreal, Canada, Kaloom is a distributed data centre networking software company.

**Mavenir**

[Described above](#). Mavenir offers several core software products including their converged packet core solution to provide an 'end-to-end fully containerised 5G core product portfolio with combo nodes for 2G/3G and 4G support.'

**MetaSwitch**

British network software provider delivering private 5G, LTE and 5G core solutions.

**Nokia**

[Described above](#). Nokia produces 5G hardware and software, offering products such as a cloud packet core solution, the Nokia Universal Adaptive Core solution. In the UK Nokia has contracts with providers such as British Telecom (BT) and Three to provide core equipment and services.

**Ofinno**

US research and development lab providing wireless technology solutions such as LTE-advanced, 5G core and RAN.

**Quortus**

British software company Quortus provides 5G core products including private 5G and cellular core network virtualisation. Headquartered in Camberley, UK, the company offers their award-winning EdgeCentrix (ECX) virtualised mobile core solutions aimed at helping to increase operator margin and stickiness.

**Samsung**

[Described above](#). Samsung offers virtualised core solutions including their EPC, 4G/5G common packet core and IP Multimedia Subsystem (IMS) solutions. The company is considered to be among the key competitors for 5G core products globally.

**ZTE**

[Described above](#). A large player in Asian markets, ZTE has won a significant amount of work with the world's largest mobile network operator China Mobile to provide products and services for the 5G standalone core.

## 5G network slicing

The number of companies facilitating network slicing is expected to continue to grow, as more single physical communication networks are able to be split into different multiple virtual networks.

### ADVA

Described above. 5G solutions developed by ADVA are built on a Software Defined networking model, allowing for the early deployment of NFV and network slicing.

### Blue Planet

Described above. Blue Planet offers a 5G Automation solution, aimed at allowing mobile network operators to seamlessly manage an end-to-end network slice's life cycle through the automation of its design, creation, modification and monitoring and provisioning underlying resources to a slice when required.

### ENEA

Swedish company ENEA provides software for the telecommunications and cybersecurity industries. The company produces the ENEA Policy Manager, a product that provides the PCRF and PCF functions in 4G and 5G networks and supports network slicing.

### Ericsson

Described above. Ericsson has recently launched Ericsson 5G RAN Slicing, aimed at supporting customised business models and growth requirements of advanced use cases.

### Etiya

A software provider serving various sectors including telecommunications, offering a 5G Intelligent Slicing Platform, with the aim of enabling operators to offer 'flexible AI-based slicing to monetise and manage their 5G ecosystem.'

### Druid

Described above. Offers their Raemis™ platform with built-in virtualisation support for all of Druid's solutions, including 4G and 5G network slicing.

### Kaloom

Described above. Offers their Cloud Edge Fabric™ with native support for network slicing.

5G network slicing

**Huawei**

Described above. Huawei has recently launched their 5G network slicing application for power grids and announced plans to be the world's first in the area.

**Mavenir**

Described above. Mavenir is partnering with Amdocs to make sure that product portfolios deliver monetisation and slicing of a 5G network. Mavenir utilises open integration interfaces and microservices-based 5G core architecture to show how slicing works in real life.

**Nokia**

Described above. The Finnish company has recently launched what it calls the world's first automated 4G/5G network slicing within RAN, transport and core domains.

**Samsung**

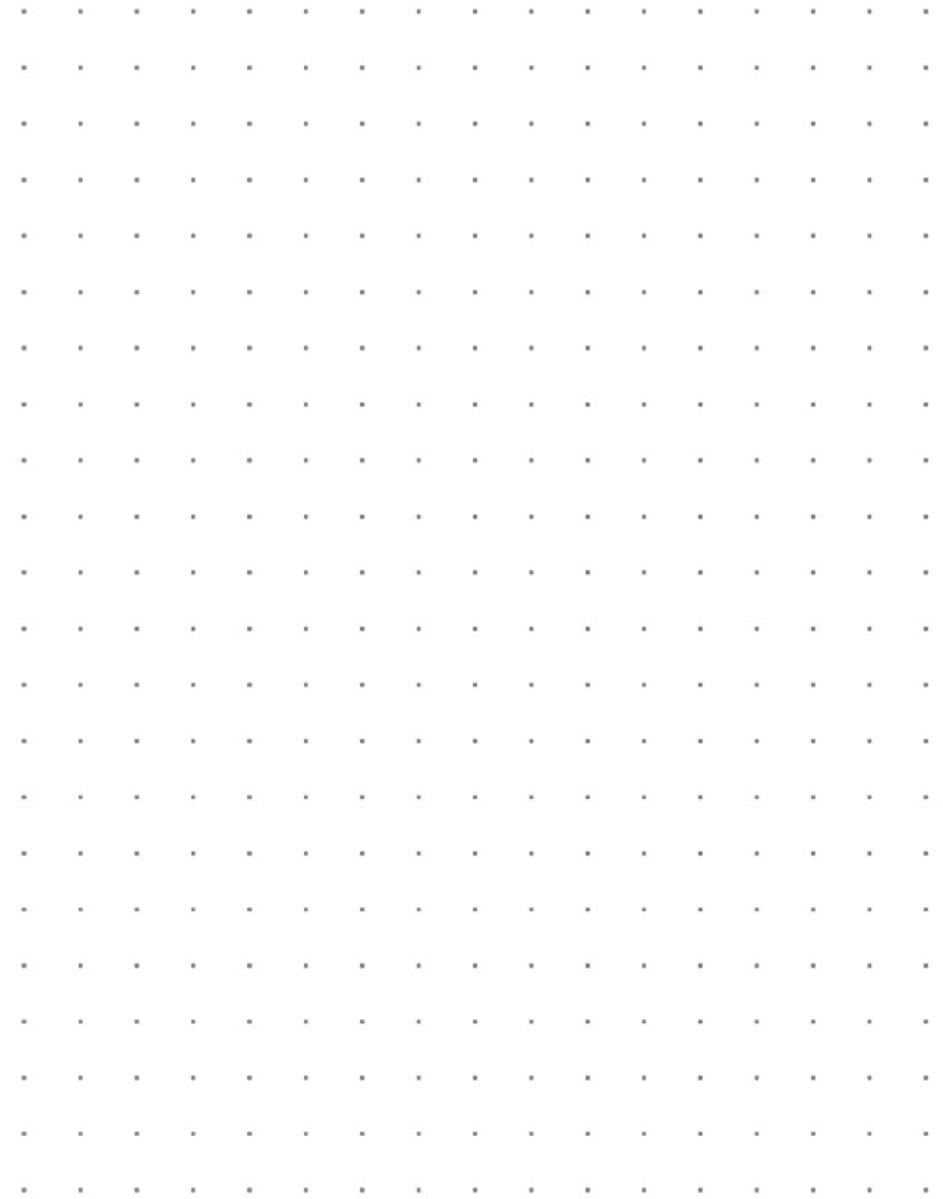
Described above. Samsung provides an end-to-end network slicing solution, consisting of an orchestration platform, slice management system and each network domain (radio access, core, transport).

**TeckNexus**

US consulting firm providing strategy consulting around 5G, notably around 5G edge, BSS/OSS, network slicing and solution architecture.

**Zeetta Networks**

Bristol based software company participating in the deployment of private network and network slicing.



## 5G security

Many of the organisations operating in the 5G security space are noted to operate more in the IT security space, with the capabilities of offering the necessary 5G-specific security services, while others have proposed 5G-specific security systems.

### A10 Networks

American software company providing a service seeking to enable service providers and businesses to deliver business-critical applications described as secure, available and efficient for multi-cloud transformation and 5G readiness.

### Allot

Israeli telecommunications manufacturer, Allot produces 5GNetProtect – a fully virtualised 5G security solution that uses multiple layers to prevent cyber attacks at all potential points.

### Cisco

Described above. Cisco produces educational literature on the security risks associated with 5G and 5G security architecture software to provide physical and virtual security resources.

### f5

American technology company headquartered in Seattle, Washington, offering security solutions for the deployment and operation of cloud native 5G networks.

### Broadcom

Headquartered in California, Broadcom is an American manufacturer of semiconductor and infrastructure software solutions. The company has launched devices aimed at increasing security requirements for 5G and cloud services.

### Checkpoint

American-Israeli technology company, providing hardware and software IT security solutions. The company provides security solutions for IoT and other devices on 5G networks.

### Digicert

American digital security company headquartered in Utah, USA. The company has a 5G Network Security Solution targeted at cloud infrastructure, apps, devices and 5G backbone.

### Fortinet

American cybersecurity company headquartered in California USA, Fortinet provides security for 5G RAN to core as well as solutions for API and application-level security.

### Juniper

American software company providing network and cybersecurity solutions. The company provides 5G solutions for service providers.

## 5G security

### Keysight

Technology company headquartered in Santa Rosa, California. Keysight offers a 5G solution that allows secure and connected 5G services to be run across a network.

### Netnumber

Headquartered in Massachusetts, USA, Netnumber is a software communications company that in recent years has won the 5G World Summit Best Network Security Technology award.

### Nokia

[Described above](#). Nokia has been selected as the technology partner for the US Federal 5G Cybersecurity Project.

### Paloalto

Multinational cybersecurity company, Paloalto has launched what it sees to be industry's first 5G-native security solution, offering containerisation and secure network slices.

### Spirent

British multinational telecommunications company headquartered in Crawley, United Kingdom. The company produces Harden Security Defenses – cybersecurity solutions targeted at 5G and WAN.

### TeskaLabs

London based vendor of cybersecurity and data privacy products, building advanced software, notably for mobile applications.

### Trend Micro

American-Japanese cybersecurity company headquartered in Tokyo, Japan and Texas, USA. The company produces 5G and IoT security solutions for campuses.

### QinetiQ

British multinational defence technology company, delivering consultancy services for the cyber security of 5G networks.

## 5G wearables

Whilst the market is currently small, as 5G begins to become more widely adopted in manufacturing and logistics, we are likely to see an increase in the number of devices, as use cases are proven in areas such as 5G-enabled health and safety devices.

### HaptX

Seattle based wearable manufacturer specialising in the conception of haptic gloves for immersive experiences and haptic robotics. HaptX has been looking at integrating 5G Ultra Reliable Low Latency Communications and a cloud infrastructure within its equipment to reduce its weight.

### HTC

Taiwanese electronics manufacturer operating worldwide. HTC has recently released its VIVE Focus 3, a wireless mobile 5G-enabled VR headset.

### Nreal

Headquartered in Beijing, China, Nreal is a startup that produces mixed reality glasses for application in retail, fashion, smart homes and other environments for consumer and enterprise use. In Europe they are enabled by Vodafone's Gigabit 5G network.

### Plinx

UK technology company developing a construction safety system to prevent hazards for workers. Plinx technology comes in the form of 5G-enabled beacons overseeing worker access to the plant at all times.

### Tobii

Swedish wearable technology company specialising in eye tracking technology and attention computing solutions for healthcare, education and behavioural studies, among others. Tobii launched XR2 Platform, a XR headset equipped with 5G connectivity through the Qualcomm Snapdragon mobile platform.

### XR Space

Taiwanese software company specialising in extended reality and providing immersive applications for the Metaverse. XR Space launched Manova, a mobile VR headset powered by Qualcomm Snapdragon 845 allowing 5G, LTE and WiFi connectivity.

## 5G testing

Companies in this category often conduct or manufacture products for 5G network testing, participating in activities such as verifying latency, coverage density and speed.

### Accuver

British headquartered provider of 5G wireless test and measurement solutions.

### Anritsu

Japanese manufacturer of telecommunications testing equipment. Anritsu offers a 5G testing platform, aimed at strengthening both 5G signalling and RF Measurements.

### Exfo

Canadian telecoms equipment company manufacturing test instruments and service assurance products including 5G network testing solutions.

### Infovista

British network performance firm, offering solutions for network testing, network life cycle automation and enterprise edge management for 5G.

### IoTAS

Wireless telecommunication company based in Cambridge supplying network testing solutions for 5G devices and networks.

### Keysight

[Described above](#). Produces products for 5G device testing, and claims to be the first test equipment vendor to offer 5G device test solutions.

### Metricell Ltd

British software company delivering a series of services related to expanding the 5G network, from testing-as-a-service, system integration for MNOs and private networks to RAN and core solutions.

### National Instruments

American company specialising in automated test equipment, including for 5G devices.

### Netrounds

Swedish software company producing a programmable test and service assurance solution.

### NETSCOUT

Technology corporation headquartered in Massachusetts, USA specialising in security, application and network performance.

### PCTEL

American telecoms equipment company headquartered in Boston, offering pre and post deployment testing for 5G NR.

### Rohde & Schwarz

German technology company headquartered in Munich that offers mobile network testing equipment and services. The company offers 5G test solutions for eMBB testing, mMTC and URLLC.

## 5G testing

### Simnovus

Telecommunications service provider headquartered in New Delhi, India offering software solutions to accelerate 5G testing and validation.

### Spirent

[Described above](#). Provides automated 5G test and assurance solutions.

### Teradyne

American test equipment company based in Massachusetts, USA producing 5G test solutions for mmWave semiconductors.

### Valid8

USA based network testing company for fixed and mobile networks in 5G and IoT.

### Viavi

Headquartered in San Jose, California, Viavi produces solutions for network testing, measurement and assurance for 5G and Fibre networks.



## 5G silicon and chip manufacturers

There is a wide range of chipsets available for all established communications technologies, for general purpose computing and for processing complex signals and data streams. As a core component that executes commands and computes data in 5G hardware, silicon, chip and semiconductor manufacturers are vital to the growth and development of the 5G ecosystem. Some of the key players operating in this category include Qualcomm, AMD, Skyworks Solutions and NVIDIA.

### AMD

American semiconductor manufacturer that has recently acquired Xilinx, a company that is regarded as one of the predominant programmable gate array (FPGA) chip manufacturers.

### Arm

British semiconductor manufacturer headquartered in Cambridge. Arm produces chips used in devices designed for 5G networks.

### Blu Wireless

Wireless services company based in Bristol specialising in mmWave communications to meet reliable ultra-low latency requirements for industries such as Defence and Transport.

### Broadcom

[Described above](#). Broadcom provides chips to companies such as Nokia for 5G networking equipment.

### Chromosol

London based technology company developing advanced Silicon Photonics solutions to improve transceiver technologies both in the data centre environment and for the fronthaul of 5G networks.

### DeepSig

American early-stage startup leveraging AI and machine learning to optimise wireless communication. It uses AI-native design of communication system components to ameliorate the performance of the network.

### Eridan

Headquartered in Mountain View California, Eridan manufactures 5G radios.

### Filtronic

British telecommunications company designing and producing microwave and mmWave products for aerospace, defence and other communication sensitive sectors.

### Graphcore

British semiconductor manufacturer headquartered in Bristol producing specialised hardware accelerators for AI and machine learning.

### HiSilicon

Chinese fabless semiconductor company headquartered in Shenzhen, China producing chipsets used in 5G.

## 5G silicon and chip manufacturers

### Imagination Technologies

Based in Hertfordshire, UK, Imagination Technologies is a semiconductor manufacturer working on cards to power 5G connectivity in cloud gaming and data centre applications.

### Infineon

One of the largest semiconductor manufacturers in the world, German company Infineon provides solutions and products for 5G.

### Innovium

American startup Innovium provides switching silicon solutions for cloud and edge data centres for AI and 5G applications.

### Inseego

Headquartered in California, USA, Inseego provides 5G and IoT devices to cloud solutions.

### Intel

American multinational technology company is the world's largest semiconductor chip manufacturer and manufactures 5G server and base station chips.

### Lattice Semiconductor

American manufacturer of semiconductors including programmable logic devices and millimetre wave devices. Lattice produces products that are programmable to accommodate 5G standards.

### Macom

Manufacturer of radio, microwave and millimeter wave semiconductor devices and components.

### Marvell

American semiconductor designer and manufacturer that has previously partnered with Nokia on 5G chipsets.

### MaxLLG

American software company producing magnetic components and devices for different 5G applications such as radio-frequency, microwave and millimetre wave. It also develops softwares for cloud computation.

### MediaTek

Taiwanese semiconductor manufacturer producing 5G modems and chips for 5G devices.

### Micron

Micron Technology is an industry leader in silicon-to-semiconductor solutions, headquartered in Idaho USA, making chips that enable 5G devices.

### NVIDIA

American technology company that produces graphics processing units (GPUs) used in 5G equipment.

## 5G silicon and chip manufacturers

### NXP

Dutch semiconductor manufacturer headquartered in Eindhoven, Netherlands providing solutions for use in 5G access edge and mmWave.

### Qorvo

Semiconductor manufacturer headquartered in North Carolina, USA.

### Qualcomm

Described above. Qualcomm is the major producer of chips and licensable IP for 5G networks in IOT devices, modems and other 5G equipment.

### Samsung

Described above. Samsung is producing ultrafast chipsets and produces some chips for Qualcomm.

### Sivers

Swedish semiconductor company producing a range of mmWave frequency integrated circuits for 5G and satellite communications.

### Skyworks Solutions

American company based in Irvine, California, Skyworks is a consumer electronics and smartphone manufacturer, also known for manufacturing 5G chips.

### Synopsys

American software company designing chips and other components for the 5G network.

### Texas Instruments

Global semiconductor design and manufacturing company headquartered in Dallas, Texas, USA. Texas Instruments has worked with Xilinx to produce energy-efficient 5G radio chips.

## 5G distributed antenna systems and small cells

Companies operating in the Distributed Antenna Systems (DAS) and small cells space play a vital part in the 5G ecosystem, as they provide RAN infrastructure that help add to the densification and coverage of 5G networks.

As current estimates predict that significantly more small cells for 5G will need to be erected than the current number of traditional cell towers, companies from around the world are offering solutions to meet future demand and the UK is now starting to roll out small cells.

### Cellnex

Headquartered in Barcelona, Spain, Cellnex is a wireless telecommunications company, specialising in the deployment of networks prepared for 5G technology including DAS and small cells. Cellnex is engaged in a strategic partnership with BT which allowed them to become the UK's largest independent operator of wireless telecommunications infrastructures.

### Cobham Antenna Systems

UK based telecommunications equipment manufacturer, Cobham produces a wide range of antennas, including distributed antennas for use in car parks and transport hubs.

### Clarke Telecom

Headquartered in Manchester, UK, Clarke Telecom is a telecommunications service provider that focuses on project managing network roll outs for UK mobile network operators. They also design and construct small cells and distributed antenna systems.

### IP Access

IP access is a UK based manufacturer of carrier grade small cell radio solutions for both commercial networks and for private networks. Owned by Mavenir, it also develops solutions for open RAN.

### Helios Towers

Headquartered in Xiamen, China, Helios is a developer and manufacturer of telecommunications infrastructure including DAS and small cells equipment.

### Zinwave

American manufacturer of telecommunications equipment, headquartered in Dallas, Texas. Zinwave specialises in distributed antenna systems for commercial networks to provide in-building wireless coverage.

## Cloud service providers

As mobile network operators continue to go through the process of cloudification in anticipation of the increased data capacity, speeds and offerings that 5G will bring, cloud service providers are particularly important in supporting the process and providing the capacity to handle these influxes of data.

The largest cloud service providers include Amazon Web Services (AWS), Google Cloud and Microsoft Azure, with Chinese companies Alibaba and Tencent also increasing global market share.

### Alibaba Cloud

Part of the Alibaba Group, it is a Chinese multinational cloud computing company. Alibaba Cloud is part of the consortium for the Camberly be Inspired Testbed for the application of 5G in retail in Camberley, England.

### AWS

Amazon Web Services (AWS) is an American cloud computing platform by tech giant Amazon. It offers software as a service (SaaS), platform as a service (PaaS) and infrastructure as a service (IaaS). It enables 5G network functions including network slicing and has partnered with Nokia on cloud-based 5G radio solutions.

### Equinix

American data centre and colocation company, Equinix has the greatest market share in the world for colocation data centres. Equinix has a public cloud service and has been the cloud delivery partner for Three UK's network and IT infrastructure transformation.

### Google Cloud

A cloud platform offered by American tech giant Google, it has partnered with companies including Nokia and Intel to provide cloud solutions for 5G.

### IBM Cloud

Multinational technology company that was an early player in computing and is known for many inventions that are used in both computing and societal life. The cloud service offers SaaS, PaaS and IaaS including services for 5G and edge computing.

### Microsoft Azure

Industry giant Microsoft provides several computing services, including the Azure platform which has partnered with telecom operators such as Verizon in the USA and Singtel in Singapore as well as Samsung to offer support for 5G services.

### Tencent Cloud

Chinese cloud platform headquartered in Shenzhen, China. One of the largest cloud providers in the world, Tencent Cloud is part of the Tencent technology conglomerate. Whilst the cloud system is focussed on helping global enterprises succeed in China, the service is starting to be available globally, with the UK being a partner region for the company.

## 5G edge platforms

Related to 5G cloud service providers are companies operating in 5G edge, where 5G networks interact with cloud service providers to bring data storage and computational storage closer to where data is generated, processed and used.

As an emerging market, 5G edge platforms are beginning to see increased investment, benefitting both new companies in the ecosystem and established players developing their offering.

### **Adlink Technology**

Specialised in edge computing, the company participates in the deployment of 5G Open RAN and small cells by developing servers for 5G Multi-access edge computing solutions.

### **Alef**

Software company headquartered in New York, USA, with an edge platform titled EdgeNet, aimed at enabling developers to build 5G edge services including industry 4.0.

### **Affirmed**

US based software company offering edge networking services, including Affirmed Cloud Edge, a fully-virtualised gateway solution.

### **Axellio**

Formally known as X-IO Technologies, Axellio is a Colorado, USA based company specialising in high performance network packet capture and network monitoring, offering edge-computing solutions, emerging as a key player in the field.

### **Altran**

French engineering and innovation firm, and is part of the CapGemini group. Altran offers their Enhance Edge Computing platform and has recently integrated Intel software into the platform.

### **Azion**

Based in Palo Alto, California, Azion offers an edge platform that facilitates 5G deployment by making it easy to build edge infrastructure and providing a flexible platform for developers to build, scale and run edge-native applications.

### **Cachengo**

American software and cloud-computing company redesigning the network storage architecture to enable 5G edge computing.

### **Coreedge**

American software company building an edge compute platform to manage the cloud infrastructure, for low latency applications such as streaming services, immersive experiences or autonomous vehicles.

### **DinosPlusAI**

Californian computer hardware developing AI processors for 5G and edge cloud data centres in order to meet low latency requirements.

## 5G edge platforms

### Edgeworx

Open source universal edge computing platform based in San Jose, California. Founded in 2017, the company's open source ioFog platform is based on the Eclipse ioFog open source project and targets developers looking to deploy and manage any application or containerised microservice at the edge.

### Edzcom Oy

Recently acquired by Cellnex, network provider and operator specialising in advanced connectivity and building private 4G and 5G networks.

### Google Cloud

First launched in 2008 as App Engine, Google Cloud is a suite of cloud computing services that run on the same infrastructure used by Google for its end-user products. It became available for use by the general public in 2011.

### IBM

IBM offers solutions to help telecommunication providers modernise their networks and deliver new services at the edge. As an example, the IBM Cloud for Telecommunications is an open, hybrid cloud architecture designed to accelerate business transformation with the power of edge and 5G. IBM Edge Application Manager is a platform that provides autonomous management for edge computing.

### Kaloom

Programmable data centre networking software based in Montreal, Canada. Kaloom offers a programmable and automated cloud networking solution designed to change how edge and data centre networks are built, managed and operated. Its Cloud Edge Fabric is a network fabric with built-in support for network slicing. Kaloom has also recently committed to join IBM's ecosystem of partners supporting the new IBM Cloud for Telecommunications.

### Kontron

Based in Germany and part of the technology group S&T, Kontron offers embedded computing technology (ECT) with a combined portfolio of secure hardware, middleware, as well as services for internet of things (IoT) and Industry 4.0 applications. Kontron is committed to delivering deployable hardware and software solutions which set the foundation for improving 4G and deploying 5G.

### Microsoft

Microsoft's Azure cloud platform comprises over 200 products and cloud services. In 2020, Microsoft Azure announced new advances to combine the power of Azure, 5G, carriers, and technology partners through Azure Edge Zones.

### MobileEdgeX

Initially founded by Deutsche Telekom, MobileEdge X is an American software company offering mobile edge networking services.

### Mutable

US based company with a microservices Platform as a Services offering, using micro data centres right at the edge, close to end users. The platform allows users to be hosted on their cloud.

### NVIDIA

[Described above](#). NVIDIA produces edge AI systems for 5G networks to enable AI and enterprise applications in data centres to be run in the cloud, on the edge.

## 5G edge platforms

### Ori

UK headquartered startup offering an on-demand mobile edge computing platform. The platform is focussed on providing PaaS on top of any type of edge.

### Qwilt

Founded in 2010 and headquartered in Redwood City, California, Qwilt offers a content and application delivery layer at the edge. Its open edge cloud establishes a software layer leveraging standard compute and storage distributed across service provider networks creates a powerful content and application delivery solution.

### Radisys

Founded in 1987 in Hillsboro, Oregon, Radisys provides communications service providers with new open architecture business models and meet the demands of the 4th Industrial Revolution with 50B connected devices.

### Red Hat

American multinational software company founded in 1993 and headquartered in Raleigh, North Carolina. Red Hat provides open source software products to enterprises and became a subsidiary of IBM in July 2019.

### Saguna

Israel based company offering any-access edge cloud solutions transforming communication networks into cloud computing infrastructures for augmented and virtual reality, IoT, edge analytics, connected cars, autonomous drones and more.

### Silicom

Provider of networking and data infrastructure solutions headquartered in Israel, designed to improve performance and efficiency in Cloud and Data Centre environments.

### Vapor IO

Computer software company based in Austin, Texas, providing a network that combines edge exchange, edge colocation and edge networking. The Kinetic Edge enables new edge-driven applications and reduces the cost requirements for CDN, cloud and network operators. The Kinetic Edge enables 5G by providing fronthaul connectivity between the tower and small cell sites hosting 5G radio equipment and the Kinetic Edge micro data centres, hosting both the virtualised RAN and 5G core network, whether data or control plane.

### Volterra

Company focused on edge computing founded in 2017, based in Santa Clara, California. Volterra offers a distributed cloud platform to deploy, connect, secure, observe and operate apps and data across multiple clouds and the edge.

### Wind River

Based in Alameda, California, Wind River develops embedded system software. Its Wind River Studio product offers an integrated platform delivering cloud infrastructure, orchestration and analytics capabilities enabling operators to deploy and manage their intelligent 5G edge networks globally. Wind River Linux is an open source operating system for connecting, securing and running network infrastructure (including systems, networks, and devices).

## 5G open source projects and labs

As 5G networks are being built on many open source platforms, moving on from the proprietary systems that much of 4G was built on, many projects and labs focusing on 5G open source have been supporting this shift to develop community-focused standards and options.

### **Aether™ by ONF**

Aether™ is an open source platform for 5G/LTE-Edge-Cloud-as-a-Service delivered by the Open Networking Foundation (ONF), providing cloud managed mobile connectivity and edge cloud services for distributed enterprise networks.

### **Akraino Edge Stack**

Created by AT&T and Intel, Akraino is a Linux Foundation project, which aims to develop a fully-integrated edge infrastructure solution. The open source software stack provides critical infrastructure to enable high performance, reduce latency and lower operational overheads. Additionally, the Akraino community addresses multiple edge use cases to develop solutions and support carriers, providers and IoT networks.

### **E2ENS**

The End-to-End Network Slicing project is overseen by the Telecom Infra Project (TIP) in the US. This group is aimed at developing a commercially viable end-to-end network slicing ecosystem that can be deployed over fixed and mobile operator networks. The network slices are mobile broadband, AR/VR and ultra- low latency, mission critical IoT and manufacturing.

### **O-RAN Alliance**

The Operator Defined Open and Intelligent Radio Access Networks (O-RAN) Alliance aims to make the radio access network industry open, intelligent and have fully interoperable RAN. They run the O-RAN Software Community with the Linux Foundation to support the creation of software for the Radio Access Network. The aim is to achieve a solution that can be utilised to unify and accelerate the evolution and deployment in the RAN.

### **ONF**

The Open Networking Foundation (ONF) is a non-profit operator-led consortium based in the US, which aims to drive transformation of network infrastructure and carrier business models. It has over 200 member companies including network-equipment vendors, telecom service providers and computer companies. The ONF aims to promote networking through software-defined networking (SDN) and standardising the OpenFlow protocol and related technologies.

## 5G open source projects and labs

### OPNFV—now named Anuket

Anuket or the Open Platform for NFV (OPNFV) facilitates the development and evolution of NFV components across various open source ecosystems. Anuket addresses a wide range of use cases from core all the way to the edge and is part of LF Networking and was created to enable members from the communications communities, operators and supporting companies alike, to mutually develop reference models, standardised reference infrastructure specifications and conformance and performance frameworks for virtualised and cloud-native network functions and workloads. Additionally there are the OPNFV Community Test Labs, hosted by the Linux Foundation and developing an OPNFV lab infrastructure that is geographically and technically diverse, with controlled access for key development and production activities.

### ONAP

The Open Network Automation Platform (ONAP) is an open source software platform for real-time orchestration and automation of physical and virtual network functions. This will allow software, network, IT and cloud providers and developers to rapidly automate new services and support complete life cycle management.

### Open Computing Project

The Open Compute Project (OCP) is a non-profit organisation created by Facebook in 2011. OCP is a collaborative community that shares designs, ideas, specifications and other IP of hardware technology (including data centres) and best practices among companies to efficiently support the growing demand on infrastructure and reduce tech-component complexity.

### Open Core Network

The Open Core Network is delivered by the Telecom Infra Project and focuses on developing a cloud-native, open and converged core which will run on standardised software and hardware and can allow 4G and 5G for deployments in licensed, unlicensed or a shared spectrum.

### OpenDaylight

OpenDaylight (ODL) is part of LF Networking in the US, and is a modular open platform for customising and automating networks of any size and scale, coming from the SDN movement to allow for network programmability. It is the largest deployed SDN controller platform powering networks with over 1bn subscribers.

### OpenRan 5G NR

OpenRAN 5G NR is a gNB device based on an open and disaggregated architecture for 5G mobile infrastructure. OpenRAN 5G NR enables operators to source RAN components from different vendors to build a complete disaggregated solution. This is in the Telecom Infra Project (TIP) in conjunction with Sprint and Vodafone.

### The Linux Foundation

The Linux Foundation (LF) is a non-profit US based technology consortium founded in 2000 to standardise Linux and increase its commercial adoption. The Linux Foundation hosts and promotes the collaborative development of open source software projects.

### Wray Castle

British telecommunication organisation offering a variety of training courses to upskills workers building and operating 5G communications networks.

## 5G system integrators

The system integrator area is one of the most visible parts of the 5G ecosystem.

Some of the world's largest consultancy firms, such as Accenture, Deloitte and Cognizant take centre stage in this field to integrate existing communications systems in businesses with new and updated systems and applications that function with 5G networks.

### Accenture

Irish based multinational consulting firm headquartered in Dublin. In 2019, the company launched a new cloud-based Network Decision Platform to provide network operators with an integrated, end-to-end view of 5G, fibre and traditional mobile communications services.

### Amdocs

Multinational software company founded in Israel and currently headquartered in Chesterfield, Missouri. The company launched its 5G Slice Manager to help service providers manage slices, services and network resources end to end across network domains and multiple vendors. In 2019, Amdocs and Samsung Networks announced a collaboration to integrate virtual network functions (VNFs) allowing the use of Samsung's 5G network solutions with Amdocs' Open Network Automation Platform (ONAP).

### Atos

French multinational information technology service and consulting company headquartered in Bezons, France. Atos is a vendor-independent partner that supports telecom operators to transform existing 4G networks and introduce 5G services and solutions. Air-Lynx (part of Atos group) provides a 4G LTE/5G private network.

### AWTG-UK

End-to-end engineering services and technology solutions provider for telecoms, Smart Cities, Industry 4.0 and others, headquartered in London, UK. In 2014, AWTG deployed the first 5G testbeds in the UK and continues to be a 5G supplier. It has extensive experience in shared spectrum management performance.

### Bearingpoint

Dutch management and technology consulting firm headquartered in Amsterdam. In 2020, the company announced the availability of its digital marketplace solution to help communications service providers integrate and monetise 5G, IoT, and edge technology opportunities.

### Blacc

UK company specialised in Modern Methods of Construction and leveraging 5G to make transport networks in the West Midlands more efficient.

## 5G system integrators

### Capgemini

French multinational corporation that provides consulting, technology and outsourcing services headquartered in Paris. In October 2020, Capgemini announced a set of Intelligent Industry offerings focused on 5G and edge, including Ecosystem Orchestration & Integration – integrating and testing end-to-end solutions to ensure convergence of network and IT.

### Circet UK

European service network provider that builds and maintains fixed and mobile telecommunications networks. The company is participating in the deployment of 5G on the continent.

### Clear Mobitel

UK telecommunication company integrating machine learning and artificial intelligence with 5G core technologies to improve the 5G network and cloud computing platforms.

### Cognizant

American multinational technology company providing business consulting, information technology and outsourcing services, headquartered in Teaneck, New Jersey. Its digital services platform Integrated 5G offers a multi-dimensional approach to data integration – that includes customer journey data, network and IoT streams – through 5G slice management and a 5G digital marketplace.

### Cyient

British IT services and consulting company taking part in the deployment of 5G networks worldwide. The company offers engineering and consulting services to companies carrying out 5G, from the design to the maintenance and operation of the network.

### Deloitte

One of the 'Big Four' accounting firms, Deloitte is a multinational corporation offering audit, consulting, financial, risk advisory and related services. Headquartered in London, UK, the company partners with service providers such as AT&T to bring 5G integrated services to Deloitte University, its leadership and learning centre or Verizon's 5G and mobile edge computing, to improve store operating efficiency via a retail industry digital platform.

### Dense Air

British telecommunication company specialising in wireless network technology and developing 4G and 5G components, including for core and RAN solutions. It specialises in the densification and the expansion of 4G and 5G mobile networks.

### Dimension Data

Global hybrid systems integrator and managed services provider for hybrid IT, offering consulting, support and technical services, based in Johannesburg, South Africa.

## 5G system integrators

### DXC Technology

American multinational corporation that provides B2B IT services headquartered in Tysons, Virginia. DXC is a system integrator that brings value by utilising its manufacturing system integration and data capabilities.

### Ericsson

Swedish multinational networking and telecommunications company headquartered in Stockholm. In June 2020, it launched antenna integrated radio (AIR) solutions to allow communication service providers to deploy mid-band 5G networks on a faster and wider scale without adding to their site footprint. In October 2020, the company also launched the Ericsson Industry Connect partner program.

### Freshwave-UK

Network service provider that builds and operates wireless infrastructure in the UK. Headquartered in London, Freshwave has experience in network sharing and is supporting the roll out of 5G in the UK, particularly through its wireless systems integrator iWireless Solutions, which joined Freshwave in 2019.

### Groundhog Technologies

Spin-off technology company from the MIT developing solutions for the maintenance and operation of a 5G network. It also offers RAN, OSS/BSS services and integration solutions for MNOs and private networks.

### HCL

Indian multinational technology company that specialises in IT services and consulting, headquartered in Noida, Uttar Pradesh. HCL provides a solution to meet 5G access needs for all radio frequency bands which can be integrated with 5G access portfolios and deployed in backhaul networks.

### IBM

American multinational technology company headquartered in Armonk, New York. IBM recently launched IBM Cloud for Telecommunications with over 35 partners to help accelerate 5G and edge innovation. The platform integrates and extends IBM Edge Application Manager and IBM Telco Network Cloud Manager to reduce network-related infrastructure costs, increase automation, and speed deployment of services.

### Nokia

Finnish multinational telecommunications, information technology, and consumer electronics company, headquartered in Espoo. Nokia has a varied 5G portfolio and is known for being one of the largest global vendors of 5G network equipment. It launched the Nokia 5G Future X solution, built on open systems with pre-deployment integration, which minimises post-deployment integration and eases the deployment of core, transport, radio infrastructure and IT systems for 5G network roll outs.

### Radisys

[Described above](#). US company developing open RAN, LTE software and small cells solution services.



## Regulators and standards development organisations

### Standards Development

Organisations have some of the most prominent voices in 5G, often playing an authoritative role in the 5G ecosystem. While the 3GPP is the leading authority for 5G specifications, other prominent organisations include IETF; IEEE; ISO; and ITU, including the ITU-T and the ITU-R. Within industry sectors, where 5G is expected to play a role, many other standards are implemented from bodies including: SAE in automotive; ASTM, RTCA and EUROCAE in aviation; and NIST, ANSI, TIA, ECMA and the IEEE across all sectors.

### 3GPP

The 3rd Generation Partnership Project (3GPP) is a group of standards organisations that develop protocols for telecommunications, including 5G NR and related 5G standards, specifications and reports. Headquartered at the European Telecommunications Standards Institute in France, the consortium consists of seven national / regional telecommunications standard development organisations from Asia, Europe and North America (ARIB, ATIS, CCSA, ETSI, TSDSI, TTA, TTC) alongside other associate member organisations. Their aim is to determine the general policy and strategy of 3GPP.

### 5G PPP

The 5G Infrastructure Public Private Partnership (5G PPP) is based in Brussels and is a joint initiative between the European Commission and European ICT industry. Its aim is to ensure the EU industry successfully competes in global markets and to access new innovation opportunities. 5G PPP will deliver solutions, architectures, technologies and standards for the next generation communication infrastructures of the coming decade.

### AECC

The Automotive Edge Computing Consortium (AECC) is a multinational organisation headquartered in the UK. It works with leaders across industry to drive a smarter, more efficient connected-vehicle future. This is done through the development of use cases, technical reports and reference architectures. Charter members include Toyota, Intel, NTT, Ericsson and DENSO.

### BIF

The Broadband India Forum (BIF) functions as an independent policy forum and thinktank, enhancing the broadband ecosystem in a holistic and service-neutral manner. BIF supports all policy, regulatory and standards initiatives for the proliferation of high-quality broadband throughout India to empower its consumers. BIF works closely with the Government and the Regulator in this mission. Corporate members include AT&T, Ericsson, Huawei, ATC India, Microsoft and Nokia.

### CTIA

CTIA (originally the Cellular Telecommunications and Internet Association) is a non-profit trade association representing the wireless communications industry in the United States. CTIA advocates for legislative and regulatory policies, convenes the industry and promotes members, including AT&T, Nokia, Samsung, Intel and T-Mobile among others.

## Regulators and standards development organisations

### ETSI

The European Telecommunications Standards Institute (ETSI) is an independent, non-profit, standardisation organisation in ICT. It provides a platform for interested parties to collaborate on the development and testing of global technical standards for ICT-enabled systems, applications and services. ETSI is a European Standards Organisation (ESO) and the recognised regional standards body dealing with telecommunications, broadcasting and other electronic communications networks and services.

### GCF

The Global Certification Forum (GCF) is a London based non-profit organisation with global membership, advocating mobile and IoT certification programmes for conformity to agreed standards of interoperability. Their mission is to enable the three GCF certification steps: testing, certification and connecting, which are based on technical requirements from 3GPP, 3GPP2, OMA, IMTC, the GSMA and others. GCF works with mobile network operators, over 40 leading mobile device manufacturers and over 65 test equipment manufacturers and test labs.

### GSMA

The Global System for Mobile Communications (GSMA) represents the interests of mobile operator organisations globally (750+ operators) to ensure policy is fair, flexible and futureproof, that radio spectrum is made available in a timely manner and to promote mobile services in emerging markets. Organisations include handset and device makers, software companies, equipment providers and internet companies.

### GSA

The Global mobile Suppliers Association (GSA) is a UK based non-profit organisation representing companies across the globe in the mobile ecosystem involved in the supply of infrastructure, semiconductors, test equipment, devices, applications and mobile support services. Members include Ericsson, Huawei, Intel, Nokia, Qualcomm, Samsung and ZTE. GSA has developed GAMBoD, a search and analysis tool to allow searches of mobile broadband devices and new global data on Mobile Broadband Networks, Technologies and Spectrum (NTS). This LTE Devices database can be searched by supplier, peak downlink and uplink speeds or operating frequency, among other queries. GSA produces around 240 unique industry reports, white papers and industry snapshots annually from the GAMBoD database.

### IEEE

The Institute of Electrical and Electronics Engineers (IEEE) is the world's largest technical professional organisation for electronic engineering.

### ISO

The International Organisation for Standardisation is an international standard-setting body composed of representatives from various national standards organisations. The ISO is the world's largest developer of voluntary international standards.

### ITU-T

The ITU Telecommunication Standardization Sector (ITU-T) is one of the three Sectors of the International Telecommunication Union (ITU), a United Nations specialised agency based in Geneva, Switzerland. Its mission is to ensure the efficient and timely production of worldwide standards covering all fields of telecommunications and ICT. The ITU-T coordinates standards between its member states, private sector members, and academia members. The ITU-T assembles study groups (made up of experts from around the world) to develop international standards known as ITU-T Recommendations for the various fields of international telecommunications. These recommendations become mandatory only when adopted as part of national law.

## Regulators and standards development organisations

### Ofcom

Ofcom is the communications services regulator and competition authority for the UK. Ofcom is working alongside Government on the 5G rollout, including making sufficient spectrum available for 5G and in international discussions on bands for 5G in CEPT and ITU.

### Kinetic Edge Alliance

Kinetic Edge Alliance was established by Vapor IO in the US and is an industry consortium solving problems in essential edge use cases and enables the scaling out of edge computing infrastructure and services to ensure low-latency in new applications and content.

### NGMN

The Next Generation Mobile Networks Alliance (NGMN) is a mobile telecommunications association of mobile operators, vendors, manufacturers and research institutes. Founded in 2006 by major mobile operators to evaluate candidate technologies for future wireless networks, its aim is to ensure successful launches of future mobile broadband networks. Based in Germany, the NGMN focuses on supporting 5G implementation, sustainability and initial work on 6G.

### NIST

The National Institute of Standards and Technology (NIST) is a physical sciences laboratory and a non-regulatory agency of the US Department of Commerce, aiming to improve innovation and competitiveness. The NIST leads federal engagement in 5G development, secure communications, advanced communications R&D and testing spectrum.

### SCF

The Small Cell Forum (SCF) is based in the UK and aims to drive worldwide network densification crucial to 5G networks. Although not a standards organisation, the SCF delivers technical inputs to determine standards development.

### Telecom Infra project

Formed in the US in 2016 with the aim of enabling global telecom network access for all. This global community of over 500 participating member organisations (including operators, suppliers, developers, integrators and other entities) drive infrastructure solutions to advance global connectivity. Member companies can host technology incubator labs and accelerators and TIP hosts an annual infrastructure conference, TIP Summit. Participants include BT, Vodafone, Telefonica, Intel, T-mobile and others.

### The Open Group

A global consortium of over 800 organisations based in the US that enables the achievement of business objectives through technology standards. It develops open, vendor-neutral technology standards and certifications. The Open Group Platinum Members include Huawei, IBM, HCL, Philips and Intel.

### TM Forum

A London based alliance of 850+ global companies, helping CSPs and their suppliers grow in the digital era and disassembling barriers between service providers, technology suppliers, consultancies and systems integrators.

## 5G network rollout by network operators

In the UK, all four of the major mobile networks operators provide a 5G offering, with some smaller virtual mobile network operators also launching 5G services.

Some global mobile operators without large presences in the UK have begun to explore British partnerships.

### EE/BT

British mobile network operator and internet service provider, which joined the fixed communications network BT Group in 2016. EE spent the most out of all operators during Ofcom's principal stage of the 5G mobile spectrum auction for the 700MHz and 3.6-3.8GHz bands. EE already had the 40 MHz 5G-specific spectrum.

### O2

British mobile network operator headquartered in Slough, Berkshire, owned by Spanish multinational telecoms provider Telefónica. O2 is expanding its consumer 5G network across the UK and working to help develop 5G private networks for industry, partnering with aerospace company Leonardo to test capabilities in manufacturing and Industry 4.0.

### TeleResearch

British mobile network operator, providing private 5G network and 4G and 5G fixed wireless internet.

### Three UK

British telecommunications and internet service provider based in Maidenhead, England. Three UK used to have the most 5G spectrum out of all operators – with 140MHz of 5G spectrum in 2019, thanks to their acquisition of UK Broadband Ltd – before EE won the principal stage of Ofcom's latest 5G spectrum auction in 2021. Three UK is gradually rolling out 5G across the UK.

### Verizon

US wireless network operator also operating in the UK. The company develops 5G private networks for business applications. Verizon is also looking at 5G-enabled AR use cases, notably for crowd management and public safety.

### Vodafone

British multinational telecommunications company headquartered in Newbury, Berkshire, England. Vodafone is rolling out 5G to a number of locations across the UK and Europe and owns 90MHz of the 3.4-3.6GHz band.

## 5G enabled startups and scaleups

The development of 5G in recent years has led to a variety of new companies exploring 5G as a part (or primary part) of their service, whether contributing to the pure 5G and telecommunications ecosystem or helping to enable other company offerings, such as augmented/mixed reality, robotics or the monitoring of 5G equipment.

### **1stzoom**

US based company which designs and operates real-time analysis solutions on existing CCTV infrastructure. They use their proprietary AI to provide detailed insights into complex situations and behaviour, from the occupancy of buses and train carriages to the flow of people across entire transport networks.

### **AccelerComm**

British semiconductor IP-core company specialising in the development of products and software compliant with 5G wireless communications.

### **AllRead**

Spanish spin-off in the Smart Logistics ecosystem, developing cutting edge computer vision software to detect, identify and track assets in operations. Through a plug and play solution, they are democratising automatic identification and data collection tools for ports and terminals of all sizes.

### **Ambify**

British based company making the invisible air visible, leading to actionable interventions that reduce the impact of environmental pollution on human health and wellbeing.

### **Angoka**

IoT Cybersecurity start-up with a focus on smart mobility and smart cities. They developed a solution that protects devices' identities and safeguards communication integrity and data provenance.

### **Attocore**

UK based supplier of scalable and flexible 4G and 5G core solutions for private networks. AttoCore's core network software technology can be deployed in consumer, professional and enterprise scenarios.

### **Blockz.io**

UK based cloud provider looking at developing and hosting their own 5G core, and edge-cloud solutions, as well as private 5G networks and services including rural location targets.

### **Blue Mesh Solutions**

London based technology company providing IoT-based Street Mesh created for in and on-street IoT devices. Initially operating a SMART parking solution for Smart Cities and Smart Communities, the technology can also be used in air quality monitoring and pedestrian counting.

## 5G enabled startups and scaleups

### C2RO

Canadian enterprise software company providing cutting-edge privacy-aware AI video analytics for physical spaces using proprietary edge-cloud AI and computer vision technologies.

### CommAgility

Wireless telecom group headquartered in Loughborough, producing hardware and software. CommAgility's products are used in test equipment, specialised radio and intelligence systems, R&D demonstrators and trial systems.

### Construction Acadmi

Intelligent Mobile Training provider with an app to help to reduce on-site errors and risks as well as increasing efficiencies through building immersive learning & training content for the construction industry.

### Delphisonic

American predictive maintenance solutions provider with real-time system monitoring and predictive maintenance using the language of vibration to understand machines' condition and detect flaws.

### Druid

[Described above.](#)

### D-Sig

UK based cybersecurity company specialising in data security that develops data security software to protect industrial data from unauthorised access and modification. Their products extend data security solutions within and beyond 5G.

### Eave

British startup that has developed a smart ear defender solution, which continuously collects data on noise and maps worksite noise-levels. The data is sent to an online platform for viewing where insights can be gathered.

### Epitomical

British tech startup operating in the autonomous robots space with a focus on the Logistics, Agriculture, and Industry 4.0 sectors. They have built their Autorover platform, which is a connected modular, rugged and flexible AV that can carry a number of different attachments.

### EVA

Drone infrastructure provider that helps drone operators in improving, sustaining and rescuing lives.

### Evercam

Visual software for the construction industry. Their solution has several features and use cases including capturing the time-lapse evolution of sites, site management and dispute avoidance.

### Extend Robotics

A robotics company building affordable light-weight robotics arms that are capable of remote operation using cloud-based teleoperation virtual reality software. Extend Robotics uses 5G to leverage the large bandwidth and low latency to facilitate operation of the robotic arms.

### Findaa Technology

British IoT data company developing a platform and leveraging AI, blockchain, and 5G technologies to enable the real-time monitoring of physical assets.

## 5G enabled startups and scaleups

### Focal Point Positioning

Cambridge based software company developing 5G positioning solutions for cell phones, wearables and vehicles and to make 5G more affordable and efficient.

### Graymatics

Video analytics company using passive CCTV cameras and converting them into IoT devices. Their use cases for the manufacturing are associated mainly with PPE compliance, zone demarcation, and defect detection.

### Grayscale AI

Package inspector company building an AI platform they are able to turn live video data into actionable insights for real-time safety, quality assurance and project monitoring on construction sites.

### Gravity Sketch

3D design platform that builds multi-platform tools to improve the efficacy and efficiency of developing 3D products. Gravity Sketch aims to remove friction from workflows and make collaboration in cross-functional teams faster and more cost effective.

### Hanhaa

Based in London, UK. A mobile network operator combining a mobile network with proprietary hardware and services platform to provide IoT solutions. These include an IoT product that enables cost-effective deployment of private LTE and 5G wireless networks.

### Heptasense

A video analytics platform for surveillance cameras that reports and alerts about human behaviours, without jeopardising privacy.

### Immersive Computing Labs

Software company headquartered in Slough, UK. Having tested their solutions for 5G networks, the company produces virtual reality (VR) and augmented reality (AR) installations for various sectors.

### InTechnology WiFi

Operator of 5G blanket WiFi networks within city centres, providing superfast WiFi free of charge for councils, aimed at giving connectivity to the poorest areas, as well as allowing businesses to connect.

### Isotropic Systems

Satellite communications company, specialising in antenna design. Isotropic aims to develop the most spectrally efficient, low-profile antennas in the world described as con-formal, multi-band and electronically steerable. Isotropic's antenna is designed for satellite broadcast, VSAT, microwave, multipoint wireless and 5G broadband communications.

### Mafic

IoT construction company using machine learning and IoT to improve health, safety and productivity in construction workplaces. They developed an Industrial IoT device which can be attached to a hardhat to measure progress and identify opportunities to improve productivity on construction sites.

## 5G enabled startups and scaleups

### Mativision

A specialist in the fields of immersive video and interactive content, Mativision produces interactive 360° content and immersive VR applications across business sectors. The London based company has developed the first 5G-ready immersive content distribution platform. Mativision is on the 5G Encode project, using virtual reality and 5G to improve training and maintenance in composite manufacturing.

### Net AI

A spin out from the University of Edinburgh, Net AI is an early stage network analytics company using AI to provide real-time intelligence of different services that go through a network, looking at traffic aggregates, composing the aggregates into different parts. The company functions overall as a telco business but also works in software and AI.

### Neutron

Spanish based startup, Neutron offers a multi-vendor private LTE/5G orchestration platform.

### Ori

Ori is an orchestration platform built to give access to edge computing resources for application development, including smart cities. It aims to build the world's largest edge cloud to power the next generation of intelligent applications.

### Passageway

Smart City SaaS start-up that provides real-time public transport digital signs.

### Plataine

Provider of intelligent automation and optimisation software solutions for advanced manufacturing. Plataine is the leading provider of solutions for manufacturers who produce composite components for aerospace, wind energy, personal armour, industrial fabrics and the sports and leisure industry.

### PLINX

UK based technology company producing safety products for the construction sector. PLINX's connected tags improve on site safety, security and the quality of operations by digitising hazards and providing early warnings to help prevent incidents from occurring.

### Plutomen Technologies

An Augmented Reality based SaaS platform that provides AR solutions to industrial enterprises for frontline digitalization.

### Quadible

IoT and cybersecurity based British company that helps organisations mitigate identity and financial fraud by offering an artificially intelligent platform with the ability to authenticate end-users based on behavioural patterns.

### Reactec

Edinburgh based prevention engineering company with wearable sensors which gather data to take the guesswork out of workplace health and safety. The data can be monitored in real-time, providing managers the information necessary to make better decisions.

## 5G enabled startups and scaleups

### Riiot Digital

Scottish computer hardware company providing E2E Corporate Training, Compliance & Education Solutions in Virtual & Augmented Reality. Riiot Digital provides IoT Integration with predictive AI models, leveraging data analytics and visualisation for collaboration and actionable insights.

### RoboK

Cambridge University spin out RoboK build efficient 3D sensing software solutions optimised for low-power computing platforms. Their solution has been applied to the Automotive, Security & Surveillance, and Industrial sectors.

### Robotiz3D

A spin out from the University of Liverpool, Robotiz3D are developing an advanced detection and repair system embedded in autonomous robots to reduce risks to maintenance crews, cost of repair and facilitate the advancement from reactive to preventative road maintenance.

### Scenic

Headquartered in London, Scenic produces Watch Together software technology which powers co-viewing experiences for media companies, telcos, sport leagues and OTT vendors, inside their own platforms.

### Sensfix

American digital workflow company that uses multi-modal AI and mixed reality to automate workflows and decision-making in logistics, maintenance, repairs and operations for industrial customers.

### Sensing Feeling

Sensing Feeling is a London based software company using advanced sensing software that is powered by Computer Vision and Machine Learning to detect in real-time how people, machines and vehicles behave in real-world spaces.

### SixSq

Swiss cloud-based smart automation solutions company, producing secure, scalable and distributed products. In particular, SixSq developed a smart and secure orchestration platform which turns computers into edge devices connected to a powerful app store.

### Tagdat

IoT company based in Scotland, the company has an Intelligent Data Capture Platform, designed to monitor assets at any – or indeed all of - the stages of their lifecycle, from manufacture through the logistics and supply chain cycle, to storage, operation and end of life.

## 5G enabled startups and scaleups

### Tendertec

Tendertec is a startup that seeks to build the next generation of AI-powered safety, security and personalised care technologies. The company was listed as one of Vodafone's top 20 5G Dig Startups.

### Tharsus

Designers and manufacturers of strategic machines. Tharsus helps companies take advantage of emerging robotics and machine technologies to disrupt, lead and grow their markets. Tharsus works with companies across the entire product development life cycle from first imagining conversations and technical exploration, through innovative design and engineering, to quality-assured manufacture and after-market support. The company is part of an accelerator to develop use cases in industrial 5G.

### TUBR

London based technology company TUBR built a time-series machine learning to provide faster and more frequent real time predictions.

### Turation

Industrial AI startup based in Cambridge, UK that enables Quality 4.0 in manufacturing with more adaptable and scalable AI.

### UDLive

IoT platform company based in the UK, UDLive designs and builds products for a variety of IoT scenarios as well as platform and location software.

### U-Linc

Headquartered in Guilford, UK, U-Linc is a spin out from the University of Surrey's 5G Innovation Centre. It was formed to facilitate a newly developed IoT discovery and interaction technology and to incorporate other innovative solutions in the IoT space.

### Unmanned Life

AI for Autonomy SaaS Platform aimed at enabling industries to be fully autonomous, deploying autonomy as a service for Industry 4.0 over wireless networks including 5G. Unmanned Life works across various sectors including supply chain logistics, manufacturing, telecommunications and smart cities.

### Vision Intelligence

British AI company developing Violet AI, an AI technology product designed to help manufacturers to enhance productivity by providing continuous real-time insights on manual production operations leading to better training, fewer defects and reduced waste.

### Vivacity Labs

Described above. Headquartered in London, UK, Vivacity Labs is a transportation service company, specialising in bringing Machine Learning products such as autonomous vehicles to the road infrastructure market.

## 5G enabled startups and scaleups

### Weaver Labs

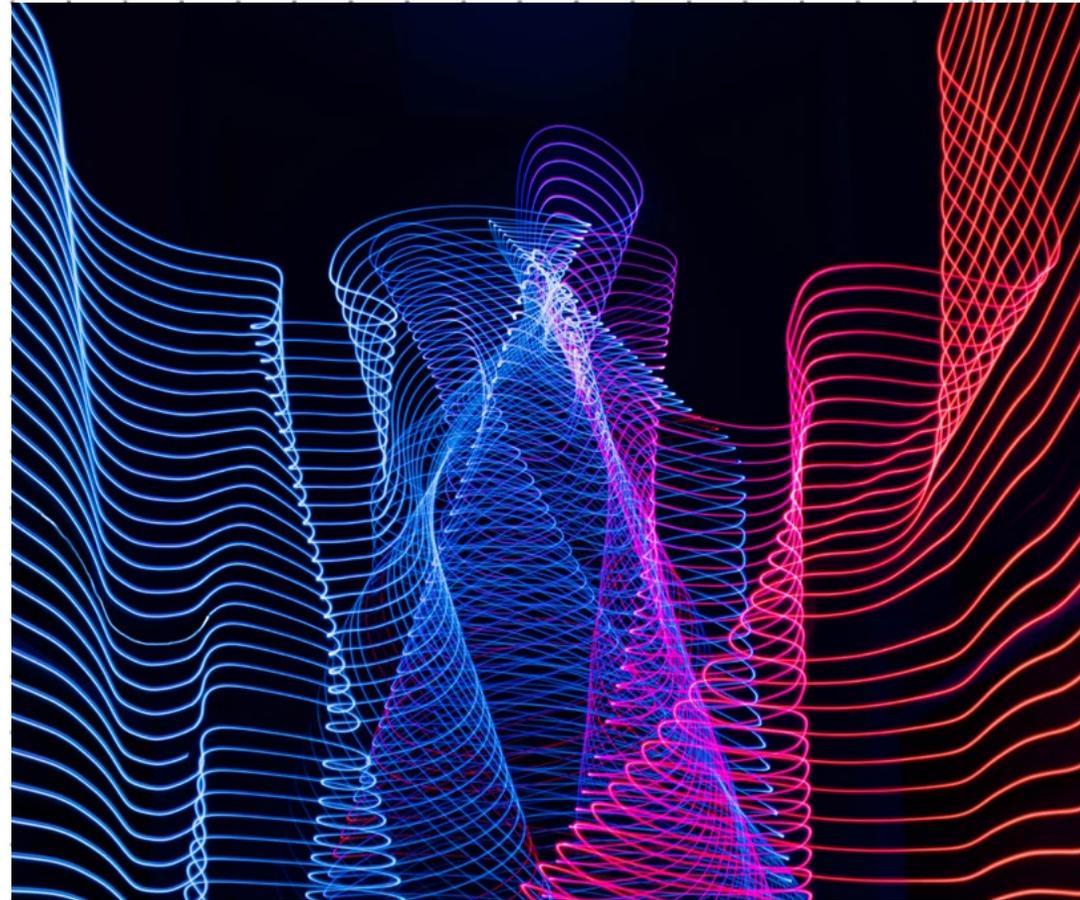
London based telecommunications infrastructure provider, focused on creating an open and shared network as a service marketplace, with an extensive focus on security, to help unlock the opportunities 5G brings.

### YouGo.World

An online global platform, allowing users to connect with people or content that can take them to places and events around the world. Using mobile, augmented or virtual reality technologies, it allows visitors to virtually attend and interact with people at the location.

### Zeetta Networks

[Described above](#). Bristol, UK based software company providing telecommunications infrastructure automation tools for enterprises.



## Industry organisations and institutions

A large number of forums and alliances have been formed to promote 5G, disseminate experiences, and form consensus. Some develop industry standards and specifications that are applied in various ways in 5G and more importantly, in vertical applications of 5G. These have been described in the section on standards bodies above.

Running in parallel, there are similar organisations concerned with other aspects of telecommunications, the industrial internet of things, security and other developments, which overlap with 5G and industrial 5G.

Professional institutions also play a role as certifiers of competences, leaders in their sectors and as forums for building skills, knowledge and experience through conferences, training programmes and by publishing journals. Some of the organisations listed represent the needs of manufacturers and produce information related to Industry 4.0/The 4th Industrial Revolution, that may not yet include 5G.

### 4IR APPG

The All-Party Parliamentary Group on the Fourth Industrial Revolution (4IR), chaired by Member of Parliament Alan Mak, aims to support and promote the Fourth Industrial Revolution (4IR) in Parliament and encourage proactive engagement with policy implications of new and emerging technologies, including industrial 5G.

### 5G-ACIA

Based in Germany, the 5G Alliance for Connected Industries and Automation (5G-ACIA) is the central global forum for shaping 5G in the industrial domain. The single platform allows various industries to create a new ICT and OT ecosystem and set the framework for this emerging market.

### 5G PPP

The 5G Public Private Partnership (5G PPP) is the 5G collaborative research programme of the European Commission's Horizon 2020 program, the EU Program for Research and Innovation. 5G PPP fosters industry-driven research, monitored by business-related, technological performance and societal KPIs.

### 5G IA

As part of the EU's 5G Public Private Partnership (5G PPP), the 5G Infrastructure Association (5G IA) brings together the telecoms and digital global industry and carries out strategic activities related to standardisation, frequency spectrum, R&D projects, technology skills, collaboration with key vertical industry sectors and international cooperation.

## Industry organisations and institutions

### Broadband Forum

Based in California, US, this communication industry organisation focuses on accelerating broadband innovation, standards, and ecosystem development. Broadband Forum's projects span across 5G, connected home, cloud and access.

### Make UK

Formerly known as EEF, Make UK is the manufacturing organisation that supports engineering and manufacturing in the UK. Make UK produces resources on the 4th Industrial Revolution (4IR) and works with companies operating in the 4IR.

### Manufacturing APPG

Chaired by Jack Dromey MP, the All-Party Parliamentary Manufacturing Group (APMG) exists to encourage the exchange of knowledge and understanding between Parliament and the UK's manufacturing industries.

### OPC Foundation

Founded in 1999 in Arizona, US, the OPC Foundation is dedicated to ensuring interoperability in automation by creating and maintaining communications standards between production devices. It is responsible for the OPC standard, the interoperability standard for the exchange of data in the industrial automation space and in other industries.

### Royal Academy of Engineering

In collaboration with fellows and partners, this UK based charity helps to drive innovation, build global partnerships and influence policy. It counts a number of 5G technology experts among its fellows, including: Professor Rahim Tafazolli, Founding Director of the 5G Innovation Centre at the University of Surrey and Professor Simeonidou, Director of Smart Internet Lab and the Co-Director of Bristol Digital Futures Institute.

### techUK

UK based trade association that brings together people, companies and organisations in the digital technology space, which includes the adoption of 5G. The association helps deploy secure and resilient network infrastructure and ensure the UK is a leader in the adoption of 5G services by bringing together key players from local and central government, Ofcom and vertical industry players such as energy companies.

### UK5G

UK5G is the UK network dedicated to the promotion of research, collaboration and the industrial application of 5G to ensure that the UK is at the forefront of global 5G development.

### WiFi Alliance

Worldwide network of WiFi companies driving global adoption and evolution through thought leadership, spectrum advocacy and industry-wide collaboration. Its work includes the development of innovative technologies, requirements, and test programs to ensure WiFi provides users with interoperability, security and reliability. It supports the deployment of WiFi 6, a new generation of WiFi connectivity launched in 2019. This is the first edition of the I5GTT ecosystem mapping research activity conducted by Digital Catapult. As developments in the 5G, manufacturing and logistics industries continue to develop at an increased pace and more organisations provide knowledge, products and services relevant to 5G, this ecosystem mapping will continue to be updated in future releases with more categories and updated descriptions. Future releases will also include relevant industry players in areas such as Academia, Research and Technology Organisations, Secure Access Service Edge (SASE), Virtual Infra Managers (VIM) and Data Centres and Colocation Service Providers.

# Webinar recordings

CLICK TO JUMP TO A SUBSECTION

WHAT IS 5G? 104

INDUSTRIAL 5G IN THE UK 104

INDUSTRIAL 5G UNCOVERED 104

## Webinar recordings

As part of the integral educational activities of the Industrial 5G Testbeds and Trials Programme, Digital Catapult held several webinars to educate those in the manufacturing and logistics industries and foster communication between innovators and early adopters of industrial 5G.

Additional resources created during the course of Year 1 (2020–2021) include recordings from the following webinars:

### What is 5G?

A presentation by Claire Caminade (Head of 5G Product) delivered on 27 July 2020 as part of the Q2 innovation workshop which attracted 91 attendees.

[CLICK HERE TO WATCH](#) →

### Industrial 5G in the UK

A webinar organised within 5G Week (8 September 2020). This webinar was facilitated by Digital Catapult and invited speakers from DCMS, 5GEM-UK, 5G ENCODE and Ericsson to share first hand experiences, learnings, challenges and opportunities that have come from delivering significant and groundbreaking activities for industrial 5G in the UK.

[CLICK HERE TO WATCH](#) →

### Industrial 5G Uncovered

An industry essential webinar series exploring 5G innovation in manufacturing and logistics, sharing sector specific knowledge from industry and innovators, demonstrating the latest 5G-enabled solutions and debating the biggest 5G-related questions facing industry today. The four part series also showcased real-world examples of 5G applications in the UK and beyond, inviting industry and technology experts, policy makers and tech startups to discuss the ways in which businesses of all sizes can work together to accelerate the digital transformation and adoption of 5G.

[CLICK HERE TO WATCH](#) →

# Glossary

CLICK TO JUMP TO A SUBSECTION

0-9 106

I 109

T 114

A 106

K 110

U 114

B 107

L 110

V 114

C 107

M 111

W 114

D 108

N 111

E 108

O 112

F 109

P 112

G 109

R 113

H 109

S 114

## Glossary of commonly used industrial 5G and connectivity terms

This glossary lists simplified definitions of some of the key terms, phrases and organisations pertinent to the topic of industrial 5G, both in the UK and internationally. As many of the terms listed are nuanced and complex, several of them are linked to web pages that offer more detail.

### 0-9

**3GPP – 3rd Generation Partnership Project** – A partnership composed of global standards organisations, intended to develop protocols for mobile cellular network telecommunications.

**4G** – 4th generation of mobile cellular network telecommunications. The successor to 3G, 4G is based on an internet platform and allows devices to connect to the internet faster than was previously possible. It led to the development of new and transformative internet services, applications and technologies.

**5G** – The 5th generation of mobile cellular network telecommunications. Represents a step change in network performance capability and provides business grade service levels, reliability and availability. This will enable Industry 4.0, Smart Factory, safety and mission-critical use cases.

**5G Testbeds and Trials** – Established by the Department of Digital, Culture, Media and Sport, it is the UK Government's nationally coordinated programme of investment in 5G. The programme covers various applications of 5G within the UK, including tourism, 5G security, 5G in rural communities, health and social care and industrial 5G.

**5G New Radio (NR)** – A new air interface designed by 3GPP for 5G networks, designed to be the global standard for 5G networks.

**5G Public-Private Partnership** – A joint initiative between the European Commission of the EU European ICT professionals, including mobile network operators, manufacturers of ICT equipment, researchers and service providers to deliver architectures, technologies and standards for 5G communication infrastructures.

### A

**Access Network** – A network that allows users to connect to their service provider. It includes the Radio Access Network (RAN), which provides wireless connectivity for end user devices.

**Access Point Name (APN)** – The name given to a gateway that exists between a computer data network (often the internet) and a mobile cellular network.

**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.

## Glossary of commonly used industrial 5G and connectivity terms

### B

**Backhaul network** – A network which connects RAN devices to the mobile cellular network core infrastructure.

**Bandwidth** – The range of frequencies used by a communications channel, e.g. 25 kHz for a radio-frequency channel. It is also often used to refer to the maximum data-rate that can be transmitted using a channel, e.g. 100 Mbps for an ethernet.

**Base station** – A radio transmitter and receiver installation that is used in a mobile communications network to communicate with user equipment – a smartphone for example. It is the edge of the RAN.

**Beamforming** – A signal processing technique that allows the energy of a transmitted radio frequency signal to be more targeted in a certain direction. This is particularly useful for massive MIMO base stations as it implements spatial multiplexing, allowing many more higher quality signals per base station and therefore transmitting much more information.

**Big data** – Large sets of data associated with a variety of applications, different speeding processes and value for the purpose of gathering useful insights and developing new strategies to maximise profit and performance. It is particularly driven by the internet of things and is interconnected with the concept of 5G because of the crucial role this wireless technology will play in the pre-processing and handling of data, whilst providing increased network storage capacities and computing capabilities.

**Broadband** – The high-capacity transmission of large amounts of data across long distances and via multiple types of technologies including fiber optics, wireless, cable, DSL, satellite and 5G. 5G broadband will provide even faster speed and greater capacity for connecting multiple devices.

### C

**Carrier Aggregation (CA)** – Combining several radio frequency bands by using a primary carrier and one other or multiple secondary carriers in order to increase radio capacity for a user.

**Cloud RAN (C-RAN)** – An architecture for cellular networks, in which RAN functions are implemented over a cloud platform instead of a hardware platform.

**Cloud Computing** – The location of on-demand computing services and storage of data remotely in the internet (the cloud), instead of in local on-premises hardware.

**Constrained Application Protocol (CoAP)** – A specialised internet application protocol that enables constrained devices/nodes to communicate with each other and with hosts (servers) in the wider Internet.

**Common API Framework (CAPIF)** – A part of the service frameworks developed to integrate 5G vertical applications with the 3GPP ecosystem.

It offers a single point of entry for 3rd party applications, with the ability to uniformly discover and securely access the underlying 3GPP network capabilities through API exposure. CAPIF enables a unified northbound API framework across 3GPP network functions, and ensures that there is a single and harmonised approach for their development.

**Coordinated Multipoint (CoMP)** – Enables devices to be connected to multiple base stations simultaneously. It extends coverage for devices that are operating at the edges of cells.

**Communications Service Provider (CSP)** – 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.

## Glossary of commonly used industrial 5G and connectivity terms

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

**Control Production Network** – The factory floor communications network connecting manufacturing equipment with their control equipment (e.g. PLC) and with the manufacturing production network.

**Core network** – The central element of a connected system, connecting all other elements of an access system. The core network provides a path for the exchange of data between LANs or subnetworks.

**Coverage** – The physical area of a wireless communications network where user's equipment is provided with a radio signal of usable quality (downlink) and where base stations can receive a signal of usable quality from user's equipment.

### D

**Data network** – A network of routers, access points and other gateways interconnected by intermediate communications media and communications services that connects computers and other devices with one another – a local area network (LAN), in a business or offices, for example.

**DCMS** – Department for Digital, Culture, Media and Sport. A department of the UK Government, responsible for several topics including aspects of radio-frequency regulations and their implementation, media, broadband, internet, broadcasting and the digital economy.

**Delay** – the time taken for a signal to propagate between a transmitter and a receiver.

**Densification** – The process of making networks denser by increasing the number of cell sites (base stations) in existing infrastructure, in order to increase capacity and support higher traffic levels.

**Device-to-Device (D2D)** – a radio technology that enables devices to communicate directly with each other without routing the data paths through a network infrastructure. The delay is reduced and the latency of data transfer is correspondingly lower.

**Downtime** – The period of time in which any aspect of manufacturing factory operations is scheduled to stop or is not in service for other reasons.

**Domain Name System (DNS)** – A protocol that serves as a phone book for the internet. It associates meaningful names with assigned IP addresses.

### E

**Edge Computing** – Computing that is done at the edge of the network, bringing lower latency, reducing core network traffic, and bringing data storage and computing closer to the location where it is needed.

**Enhanced Mobile Broadband (eMBB)** – One of the use cases that 3GPP has defined for 5G. Using 5G New Radio, it is an improvement on 4G services: it will increase data rates, provide higher capacity in densely populated areas, and increase general availability of connectivity.

**Ethernet** – The most common fixed-wired method of connecting computers or other devices to a network in a local area network (LAN). It is used in home and office networks and in industrial networks and can be used in wide area networks (WANs).

## Glossary of commonly used industrial 5G and connectivity terms

### F

**Fixed Wireless Access (FWA)** – Wireless communication between a core network, such as DSL or fibre broadband and fixed devices such as CPEs, FWA is one of the use cases for 5G rollout.

### G

**Global Certification Forum (GCF)** – An independent certification scheme for mobile phones and wireless devices that are based on 3GPP standards.

**GSM Association (GSMA)** – The representative body for mobile operators, encompassing players across the industry globally, including software providers, hardware and device manufacturers, network operators and other stakeholders. The GSMA hosts the annual Mobile World Congress event.

### H

**Health and Safety Executive (HSE)** – a UK government regulator whose goal is to prevent workplace death, injury or ill health, working with industries to help them understand the risks they create and how to manage them.

**Home Subscriber Service (HSS)** – A database that contains subscriber-related information, such as the authentication information and the list of services to which each user is subscribed in their home network.

### I

**International Commission on Non-Ionizing Radiation Protection (ICNIRP)** – Publishes guidelines for safe exposure levels from radio signals. All sites emitting a signal within the UK must comply with these safe exposure levels. The guidelines also ensure that no-one can accidentally expose themselves to unsafe levels by requiring a safe by design approach.

**Internet Engineering Task Force (IETF)** – The organisation that brings engineers and scientists together to draft and approve specifications of protocols and services to be implemented on the Internet.

**Industrial 5G** – A term set out to capture the conceptual framework, architectures, principles and best practices guiding 5G deployment and integration with specific vertical industrial processes and systems.

**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 using internet protocols.

## Glossary of commonly used industrial 5G and connectivity terms

**Industrial, Scientific and Medical (ISM) bands** – Parts of the radio spectrum that are internationally reserved for the use of radio frequency (RF) communications intended for scientific, medical and industrial applications. A licence is not needed to use an ISM band but any use must comply with conditions stated in the ITU-R Radio Regulations, e.g. a maximum limit on transmit power.

### K

**Key Derivation Function** – A function used in encryption to generate secret keys from a secret master key to allow various security functions in the 5G network architecture.

### L

**Layer 2 Tunneling Protocol (L2TP)** – An internet networking protocol that encapsulates lower layer protocols in IP. It enables virtual private networks, allowing users to access networks and hosts connected to them remotely and isolated from other VPNs.

**Latency** – The time elapsed between initiating a data transfer, and the completion of the delivery of the data.

**Local area network (LAN)** – A network in which computers or other devices are within a physical location or area such as a school, office, residence or other limited area.

**Local Break-Out (LBO)** – The routing of internet traffic between roaming users and a local visited data network and thence to and from the internet, avoiding relaying it through the user's home network.

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

**Liquid Resin Infusion** – LRI is a closed loop process to make composite materials. It offers higher rate and lower cost production.

**Long-Term Evolution (LTE)** – The collection of specifications from 3GPP Release 8 that are the foundation of 4G mobile cellular networks.

**Long-Term Evolution for Machines (LTE-M)** – A specific air interface and protocol compatible with LTE providing a service suitable for machine type communications (MTC).

## Glossary of commonly used industrial 5G and connectivity terms

### M

**Machine to Machine (M2M)** – Technology that allows machinery or manufacturing equipment to connect and transmit information to other equipment for various means such as gathering efficiency information and operational data.

**Made Smarter** – A UK national programme aimed at accelerating the growth of UK manufacturing through the adoption of emerging technologies. It is backed by the UK government and world-leading manufacturers and arose following a review into UK manufacturing practices that recommended more ambitious leadership, more innovation in developing new technologies and faster implementation and adoption of those technologies.

**Massive Machine Type Communications (mMTC)** – 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 in very large numbers.

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

**Millimetre Wave Communications (mmWave)** – In 5G this term refers to the use of spectrum bands that fall in the millimetre wave communications frequency range (from about 30–300 GHz). The 5G mmWave pilot bands include 26-28 GHz.

**MIMO (multiple input and multiple output)** – A method for increasing the capacity and quality of a radio link using multiple transmit and receive antennas.

**Mobile Network Operator (MNO)** – Also known as a wireless service provider, cellular company, or mobile network carrier, this 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, backhaul infrastructure, billing, customer care, provisioning computer systems and marketing and repair organisations. In the UK, there are currently four MNOs (BT/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.

**Multiprotocol Label Switching (MPLS)** – is a connection-mode service implemented on the internet. MPLS packets are tagged with a label, which is used by Internet routers to select directly the next hop interface for the packet. This is much faster than the usual address matching process that routers have to do for normal IP packets. MPLS is used to provide quality of service suitable for telephony services.

### N

**National Cyber Security Centre** – The UK government body, part of the Government Communications Headquarters (GCHQ) that provides guidance and support to public and private entities on computer and cyber security.

**Narrowband IoT (NB-IoT)** – A low power wide area network technology defined in 3GPP Release 13, improving the power consumption of user devices, system capacity and spectrum efficiency. NB-IoT typically focuses on high density, low costs and long battery life (10 years +).

**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.

**Network splicing** – Combining previously created network slices to provide end to end services across different domains.

## Glossary of commonly used industrial 5G and connectivity terms

**Neutral host** – Describes a communication infrastructure that provides a platform for multiple operators wishing to deploy communications services in a particular location. A common scenario is for the neutral host to provide access to the location, installation, power and/or backhaul connection.

**Non-standalone/Standalone (NSA/SA)** – There are several options for deploying 5G networks. A SA network provides 5G New Radio services supported by a 5G core network using 5G signalling protocols. A NSA network provides 5G New Radio services supported by a 4G core network and 4G LTE signalling protocols. NSA networks allow MNOs to benefit from the increased performance of 5G NR without having to invest in a 5G core or phones that implement 5G signalling protocols.

**Network Time Protocol (NTP)** – An internet protocol that allows for clocks on devices to be synchronised to Universal Time Coordinated (UTC), typically to a tenth of a millisecond.

**Network Function Virtualisation (NFV)** – A method of implementing certain functions in standard servers rather than dedicated hardware.

## O

**Ofcom** – The regulatory and competition authority in the UK for communications industries.

**Open RAN** – Open Radio Access Network (ORAN) alliance produces specifications that disaggregate the different elements within the Radio Access Network and standardise the interfaces between them. This allows end users to procure components from different suppliers without having to worry about interoperability.

**Orchestration** – The ability to create network services across one or more network domains that meets a specific user group need in terms of performance and quality of service.

## P

**Public land mobile network codes (PLMN codes)** – The unique code assigned to a country and operator for the wireless mobile communications systems offered by a mobile operator within that country.

**Private Network / Non-Public Network (PN/NPN)** – A mobile internet network only intended for use by those permitted by the network owner, often within a geographical site such as within a business, household or worksite. They are intended to offer higher levels of coverage, reduce latency and offer network owners more reliability.

**Point of Presence (PoP)** – The physical termination of a communications service. It could be an access point to the internet.

**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.

## Glossary of commonly used industrial 5G and connectivity terms

### R

**Radio Access Network (RAN)** – The components in a wireless network that implement the radio frequency communications services provided to the network's end user devices. The RAN includes a fronthaul network that interconnects the base stations, or remote radio units, with the base station controllers, termed gNodeBs in a 5G network. The RAN is interconnected by a backhaul network to the mobile network core.

**Real-Time Communication (RTC)** – A quality of communication service that is good enough to allow applications to be operated that typically match or exceed human capabilities for the amount of information processed and reaction speed when doing a certain task. An autonomous vehicle, for example, must be able to perform driving manoeuvres and react to hazards much faster than a human driver could.

**Radio Frequency (RF)** – The oscillation rate of an electromagnetic field from around 0 Hz to around 300.

#### **GHz, (lower limit of InfraRed frequencies)**

– Energy from the field can radiate from a conductor as radio waves. The radio waves can induce energy in a conductor, which enables RF communications – the conductor is the antenna.

### S

**Service Based Architecture (SBA)** – This includes the following component functions that are visible to equipment, applications and services outside the SBA:

**Application Function (AF)** – Internal functional block within a 5G core network that supports application influence on traffic routing, accessing network exposure function (NEF), interaction with policy framework for policy control.

**Network Exposure Function (NEF)** – Part of the control plane of the 5G core network architecture that is based on the Service-based Architecture (SBA). NEF exposes 5G core capabilities and events to external applications, using the Unified Data Repository (UDR) as its data source. NEF also allows third parties to securely provision information to the 5G core (e.g. expected UE behavior) and handles the masking of sensitive network information towards external parties. There are several other functions that provide for (among others) registration and authentication of user equipment and subscribers, management of mobility, charging and connectivity with other systems.

**Stream Control Transmission Protocol (SCTP)** – A connection-oriented protocol used widely in the internet for reliable communication between hosts (computers). SCTP guarantees that the information has not been lost, duplicated or missequenced. It is used in LTE signalling protocols in 4G networks.

**Service Enabler Architecture Layer (SEAL)** – A common service layer to support vertical applications (e.g. V2X applications). It is defined by specifying application plane and signalling plane entities for application-enabling services that can be reused across vertical applications. It provides a set of core service capabilities such as group management, location management, device configuration, network resource management, identity and key management functionalities that are common to different industry verticals.

## Glossary of commonly used industrial 5G and connectivity terms

**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, WiFi and any other wireless service. Spectrum is the lifeblood of digital communications and 5G will require spectrum at several different frequencies.

**Small Cells** – A radio access point with a low radio frequency, range and power output. They are often used in densification, and can be used in several environments including indoor and outdoor usage.

### T

**Transmission Control Protocol (TCP)** – a connection-oriented protocol used widely in the internet for reliable communication between hosts (computers). TCP guarantees that the information has not been lost, duplicated or missequenced.

**Time Sensitive Communication** – TSC is a communication service that supports deterministic and/or isochronous communication with high reliability and availability. It provides packet transport with quality of service (QoS) characteristics such as bounded latency and reliability, where end systems and relay/transmit nodes can be strictly synchronised.

### U

**User Datagram Protocol (UDP)** – A connectionless protocol used widely in the internet for communication between hosts (computers). UDP provides no guarantees that the information has not been lost, duplicated or missequenced. It can be used for gaming, streaming and video conferencing.

**Ultra Reliable Low Latency Communication (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.

### V

**Virtual Network Function (VNF)** – The building block of services and applications in communications services.

### W

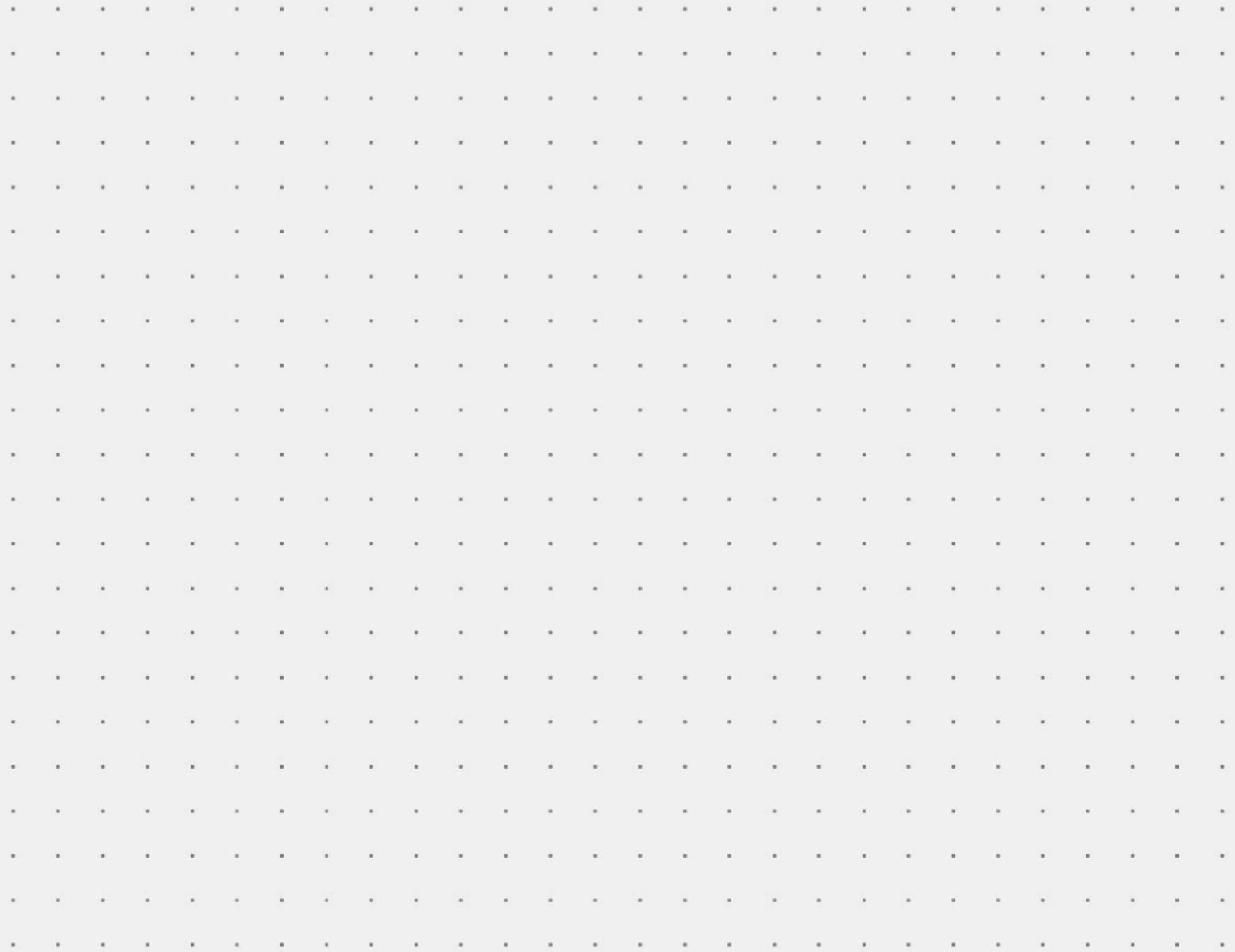
**WiFi** – A RF communications system standardised in IEEE 802.11.

## About the Industrial 5G Testbeds and Trials Programme

Digital Catapult is a delivery partner for the UK Government's Department for Digital, Culture, Media and Sport's Industrial 5G Testbeds and Trials Programme and is helping to drive innovative new use cases of 5G in UK industry sectors by coordinating eight projects including 5G Encode, 5GEM, 5G Factory of the Future, 5G CAL, 5G Logistics, 5G Ports, AMC2 and Smart Junctions.

The Industrial Testbeds and Trials Programme programme sets out to demonstrate the value of 5G beyond enhanced mobile broadband by targeting industry focused use cases in manufacturing and logistics to:

- Explore the potential for efficiency and productivity benefits
- Help make the UK a global leader in the adoption and application of 5G technology
- Help the UK lead the development of the implementation and standards around 5G



## About Digital Catapult

Digital Catapult is the UK authority on advanced digital technology. Through collaboration and innovation, we accelerate industry adoption to drive growth and opportunity across the economy.

We bring together an expert and enterprising community of researchers, startups, scaleups and industry leaders to discover new ways to solve the big challenges limiting the UK's future potential. Through our specialist programmes and experimental facilities, we make sure that innovation thrives and the right solutions make it to the real world.

Our goal is to accelerate new possibilities in everything we do and for every business we partner with the journey – breaking down barriers, de-risking innovation, opening up markets and responsibly shaping the products, services and experiences of the future.

Digital Catapult is part of the Catapult Network that supports businesses in transforming great ideas into valuable products and services. We are a network of world-leading technology and innovation centres established by Innovate UK.

Visit [www.digicatapult.org.uk](http://www.digicatapult.org.uk)

for more information.