Creating a Gigabit Society – The role of 5G

A report by Arthur D. Little
for Vodafone Group Plc

Contents

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By Richard Swinford, Partner,
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Foreword

Creating a Gigabit Society – the role of 5G

by Markus Reinisch,
Group Public Policy Director, Vodafone Group

In 2016 we commissioned a study that examined how the availability of fibre direct to homes and businesses (FTTH) would help Europe become a Gigabit Society: one where citizens and businesses benefit from widespread connectivity of 1 gigabit per second, low latency and reliable performance[1]. This study builds on that report and focuses on the important role that 5G mobile has to play in achieving the Gigabit Society vision.

In carrying out this study, we asked ADL to highlight the consumer and industrial innovations that 5G will facilitate. And it is clear from the 24 case studies included in this report that 5G holds potential for our economy and society. It has the potential to reshape many European industries, because it can dynamically configure networks to address different customer demands, support massive increases in data volumes and provide highly resilient, secure and low latency communications.

We also wanted this to be a practical study, so ADL has examined the demand for 5G in a broader social and economic context. This includes helping the automotive sector reduce traffic accidents, increasing efficiency in the healthcare sector, or enhancing productivity in the agricultural sector. This report demonstrates how the continued evolution of mobile technology has an important role to play in addressing these challenges, as well as delivering a variety of social benefits and promoting economic growth.

The emergence of 5G will be evolutionary, because standards co-exist as they evolve over time. It's an efficient way to invest in the future as it allows for new services to be tried and tested and the business case to be built in tandem with an improvement in the performance of networks. It also means that networks are already being enhanced and are likely to bring some of the benefits of 5G sooner than 2020.

The prevailing policy framework should also create an environment that is conducive to fast and ubiquitous network investments. The quality of service demands associated with 5G traffic will be significant and we must avoid a regulatory regime of 'innovation by permission' or consumers, businesses and society as a whole will miss out. Spectrum Policy must facilitate and harmonise, rather than simply extract value.

Additionally, the success of 5G will depend heavily on policies and financial incentives that promote the deployment and availability of fibre. Fibre will be critical for moving the enormous amounts of data generated by 5G connected devices and objects between cell towers. Without fibre, 5G will simply not be able to deliver ultra-fast, reliable, low latency connections on which new applications and services will depend. Considering a physician will rely on a 5G connection to monitor the application of bioelectronics medicine, or a driver will rely on it to be immediately informed of a motorway hazard, it's clear that nothing less than fast and robust fibre backhaul will do. It's also abundantly clear that 5G and fibre are not mutually exclusive technologies, or that 5G deployment should be prioritised before full fibre deployment. The evidence in this report simply does not bear this out.

The decisions we make in the coming years will dictate how and when Europe will start to benefit from the technology.

My thanks to all the companies and organisations that participated in the study. We hope it will contribute to the debate and help further our understanding of what is needed to create a Gigabit Society.

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1 See 'Creating a Gigabit Society', a report by Arthur D Little for Vodafone Group Plc,
   at **http://www.vodafone.com/content/dam/group/policy/downloads/Vodafone_Group_Call_for_the_Gigabit_SocietyFV.pdf**

Executive summary

People love being connected to digital services, demand continues to grow, and the number of services and applications continues to expand. Today's mobile networks deliver greater speed and reliability than ever before, but in the next five years we will see a revolution in the capability and application of high-speed digital mobile services, as telecommunications companies invest in the fifth generation of mobile radio networks.

'5G' as it will widely be known, will be a more inclusive, progressive, proven and capable wireless technology. Whilst we are currently in the midst of technical efforts to design, standardise and trial this next wave of mobile technology, it is clear that 5G will help mobile networks to evolve to meet challenges arising from socio-economic shifts, new emergent applications and increased demand for network capacity.

Yet 5G networks will be about much more than 'more data, at higher speed, for less cost'. Their resilience, reliability, immediacy and their ability to 'specialise' will render them the essential final connection between a plethora of devices and objects, increasingly acting autonomously to work for us as well as to entertain us.

Gigabit networks will deliver benefits to many European consumers and enterprises. In this regard, 5G and ultra-fast fibre networks can be seen as the essential infrastructure that will ensure that Europe remains globally competitive in the future Gigabit Society.

What is so special about 5G in this regard?

- 5G is the first mobile technology extensively designed from the outset both with and by the end user vertical industries, as well as by the telecoms operator, vendor and standards body communities

- 5G is designed to ensure a smooth evolution from 4G that improves customer experience with higher data rates and lower delay

- 5G offers wide-ranging capabilities, and is able to support many applications of use and consumer innovations

- 5G offers the resilience and security that is required to be considered for 'mission critical', 'enterprise control' or 'life supporting' services

- 5G brings the performance and reliability to 'untether' previous fixed assets/equipment and enable new methods of production, with both existing (legacy) and new (for example robotic) tools.

European industries are increasingly ready for this technology. When 3G arrived, many had barely 'mobilised' their workforces, and when 4G arrived many were still in the early stages of 'digitalisation' of their production processes and value chains. Today, many industries are well down the road on their own 'digitalisation pathways', and engaging with their customers and suppliers in real time using new channels and tools that require enhanced and new communications that can underpin and accelerate their productivity whilst keeping data and facilities secure. We see five key policy areas to be addressed if Europe is to capitalise on the benefits 5G can bring:

- **Spectrum policy reform:** investment in 5G will depend on ensuring fair and non-discriminatory spectrum awards, liberalisation, refarming and defragmentation of existing spectrum bands, extending licence terms and ensuring Member States award spectrum licences on a common timescale

- **Improved access to fibre backhaul:** effective regulated access to fixed passive infrastructure will be essential. A well-functioning access regime across Europe will be critically important to avoid bottlenecks

- **Encouraging innovative services:** new applications with specific quality needs and, more generally, network optimisation that can better take account of user and network circumstances will be required. Regulatory policy will have to take this into account

- **Sustainable market investment:** the investment required to deliver 5G across Europe in the coming decade is substantial, and will clearly require investment from private investors, who will seek comfort that the competitive environment will not be unpredictable or exposed to excessive regulatory risk

- **Encouraging digital champions:** governments can play a key role, both in encouraging the public sector to embrace the benefits of 5G-enabled digital technologies, but also helping to coordinate and encourage alignment in sectors that are complex but could realise material gains from 5G, especially connected vehicles (including both road and rail) and the aviation industry, in particular drones/unmanned aerial vehicles (UAVs).

Shaping the environment of future smart cities
5G networks will provide an enhanced 'connectivity fabric' for European 'smart' cities.

- Greater data capacity resources for citizens

- Many millions of simultaneously connected 'Internet of Things' (IoT) sensors, monitoring and controlling the intelligent city infrastructure

- Improved quality and enhancements to enhance existing solutions for emergency service communications deployments to ensure the safety of citizens.

Enhancing our industrial zones
5G networks will bring the 'wireless canopy' connectivity to support economic development, as well as ultra-fast indoor services

- Faster rollout of connectivity for economic regeneration of industrial zones

- Optimised indoor networks within factories and warehouses support 'Industry 4.0', robotics, autonomous pallets, etc.

Accelerating our transport corridors
5G networks will play a key role in ensuring that the key transport arteries of Europe flow efficiently and safely.

- Roads will benefit from 'V2X' connections between cars and roadside infrastructure

- Passengers on high-speed trains will be able to simultaneously connect, whilst safety critical maintenance and control will save lives on rail.

With careful design, large parts of networks can be shared and reused across modes to limit costs.

Fostering growth and inclusion in rural areas
5G networks will extend new service performance levels to remote areas, subject to the availability of low frequency spectrum, enabling for example:

- Environment sensing grids

- Critically secure networks for harvest robotics

- Significantly improved service speeds for rural homes beyond the reach of wired networks (i.e. legacy copper networks, where speed falls with distance).

What are the drivers for 5G?

European citizens already live on a continent covered with mobile networks, able to roam across borders, working collaboratively and enjoying content at home and on the move, all enabled by affordable and reliable telecoms networks. Europe led in the development and commercialisation of many of the underpinning aspects of these technologies, and they are now widespread.

But neither technological and sociological change, nor Europe, stands still. Society and industry is undergoing rapid change. Digital connectivity can play a key role in transforming how these industries improve efficiency and customer experience, how they operate and the benefits they deliver.

Figure 1: Drivers and trends that influence the socio-economic environment for 5G services
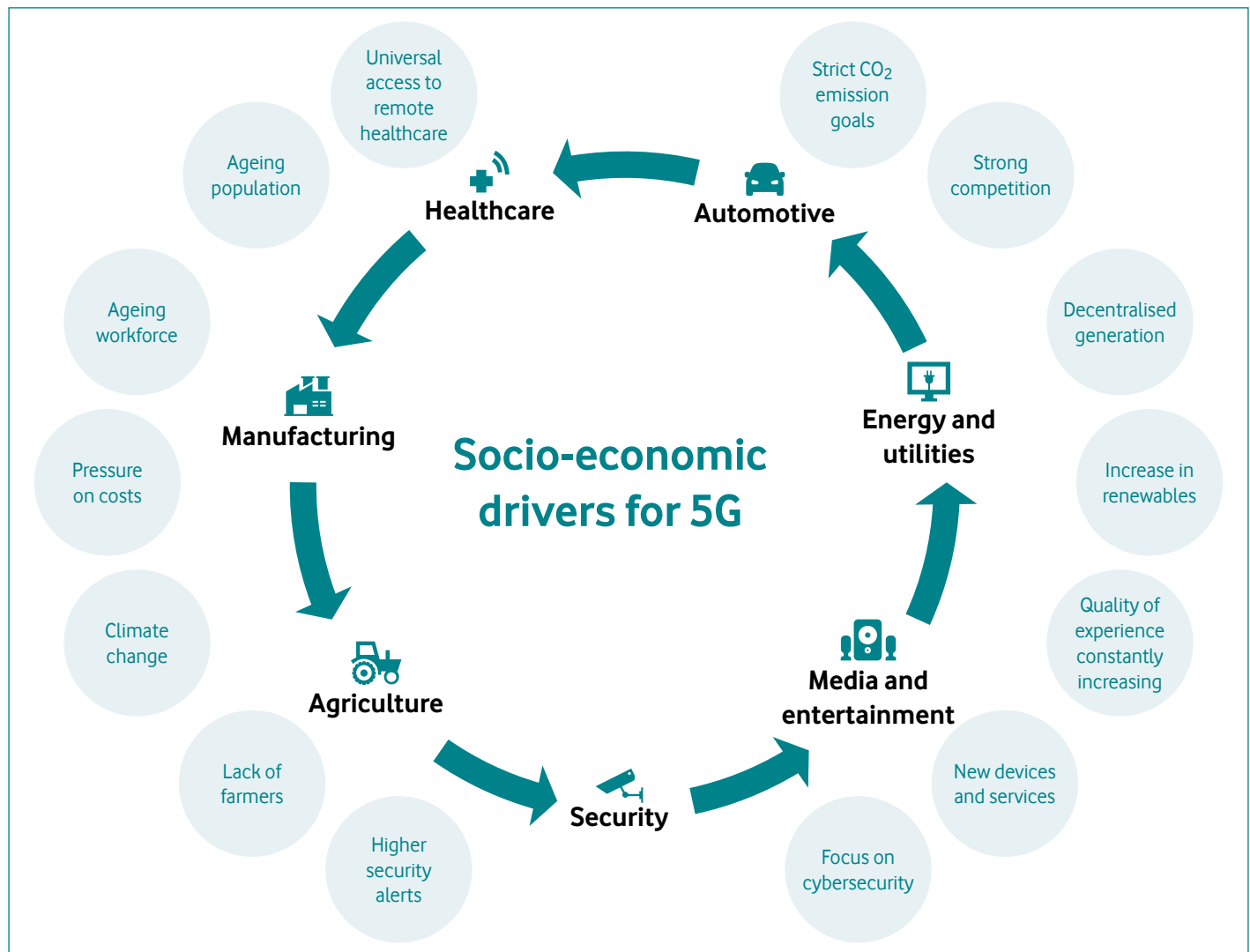
These drivers will prompt socio-economic change that will radically reshape many European industries. To adapt and remain competitive, these industries must innovate their products and their production processes, accelerating the digitalisation.

To support this continued development, we need mobile infrastructure that can deliver:

- Ubiquitous, pervasively ultra-fast gigabit connectivity
- Resilient and secure networks to underpin our societies
- Massive radio resources to accommodate fluctuations in demand and new applications
- Instantaneous connectivity, to satisfy user expectations and new application types

- Support to many connected devices, whether static or moving at high velocity
- Environmental benefits for lower resource consumption
- Economies of scope and scale that achieve the cost requirements, and the global interoperability that meets the user expectations of the citizens of tomorrow's Europe.

What user needs and applications will 5G help to address?

The deployment of 5G networks as enhancements to the established 4G deployments already widespread in Europe will, subject to the availability of appropriate spectrum bands at the right time, allow massive connectivity resources to ensure that user data requirements can continue to be met by licensed mobile network providers. Operators are already planning their networks to be prepared for this evolution.

Beyond this, 5G will support vertical industries across Europe in adapting to a changing economic and social environment, helping with their respective challenges and needs.

Figure 2: Benefits of 5G to industry

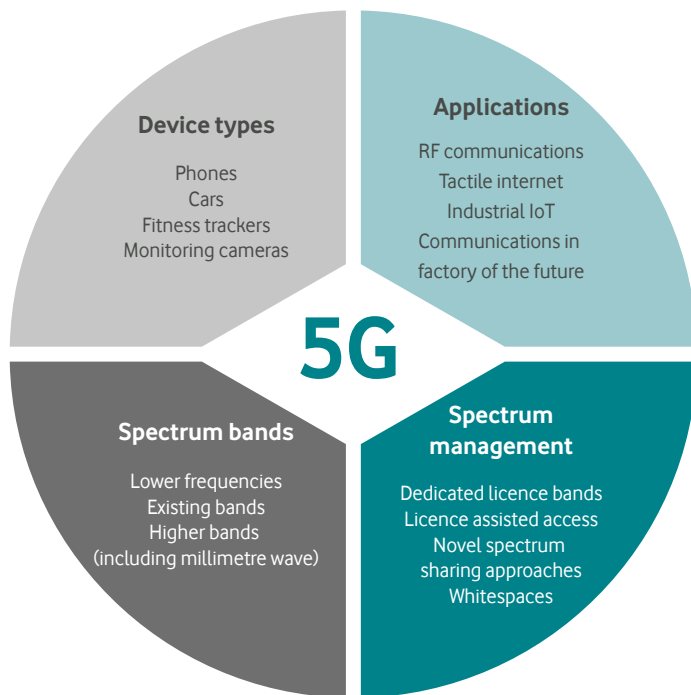|	Challenge	Need	How 5G will help
Automotive	- Strict CO_2 emission goals - Strong competition - Pressure for innovation - Globalisation	- Autonomous and connected cars - Innovative infotainment solutions	- Dynamically configure networks and resources to address different demands
Media and entertainment	- Quality of experience constantly increasing - New devices and services - Explosion of mobile data usage	- Networks which can support new media and entertainment services and devices (VR & AR)	- Support massive increases in data rules - Guarantee a good quality of service
Energy and utilities	- Decentralised generation - Pressure on consumption - Increase in renewables - Fines when outage	- Dynamic smart grids, which can be monitored and controlled remotely throughout the entire network	- Real-time control of grids and remote generators where fibre has not been rolled out
Public transport	- Stronger focus on safety and security - Growing number of passengers - Higher service expectations	- Real-time information and entertainment for passengers - More efficient operations and maintenance of infrastructure	- Provide coverage and bandwidth for infotainment and more efficient operations
Agriculture	- Growing global population - Pressure on use of pesticides - Lack of farmers - Climate change	- Increased productivity and efficiency of farming - Sustainable farming solutions	- Remotely connect and control farming equipment - Provide bandwidth for advanced imagery and use of drones
Healthcare	- Ageing population - Increase in people with chronic diseases - Personalised care expectations	- Affordable healthcare solutions - Personal, wearable devices for monitoring and treatment - Remote patient care and follow up	- Enable mobile remote care solutions through guaranteed and secured connection
Manufacturing	- Ageing workforce - Manufacturing skills gap - Pressure on costs - More environmental concerns	- Robotics and automation inside the factory - Solutions which decrease production costs	- Provide the highly resilient, secure and low latency communication platform in the factory
Security	- Higher security alerts - Increased terrorist threats - Focus cyber security	- More monitoring and screening in public places - Better and faster information to law enforcement agencies	- Support wireless security applications both for monitoring and detection

What kind of technology will 5G be?

Technical characteristics

Various global standards bodies and organisations work to ensure alignment in 5G, in particular the International Telecommunications Union (ITU) which has christened the next global next generation cellular system 'IMT-2020' and the 3rd Generation Partnership Project (3GPP) which unites seven telecommunications standard development organisations.

Figure 3: 5G is 'all inclusive'

Device types
Phones
Cars
Fitness trackers
Monitoring cameras

Applications
RF communications
Tactile internet
Industrial IoT
Communications in factory of the future

5G

Spectrum bands
Lower frequencies
Existing bands
Higher bands
(including millimetre wave)

Spectrum management
Dedicated licence bands
Licence assisted access
Novel spectrum sharing approaches
Whitespaces

5G is expected to meet unparalleled requirements that have been defined through a combination of working user groups, national level committees or consultations and industry associations, as well as significant European, Asian and North American academic research programmes.

In particular, ITU-R IMT-2020 identified three families of usage scenarios and applications beyond the current '4G' technology generation:

1. **Massive mobile connectivity**, which drives the need for Enhanced Mobile Broadband (eMBB)

2. **Connectivity of millions of devices**, which drives the need for Massive Machine Type Communication (mMTC)

3. **Resilient, instantaneous connectivity**, which drives the need for Ultra-Reliable and Low Latency Communications (URLLC).

5G will deliver a faster and more responsive mobile broadband experience to smartphone customers. It should be well placed to support the anticipated growth of new services such as those based on virtual reality and/or augmented reality, and industry-specific services (so-called 'vertical applications') such as autonomous/connected vehicles, control of aerial drones, robotics, mobile healthcare and smart cities.

5G includes a new radio interface specification which will be used to wirelessly connect mobile phones and other devices to networks of base stations — just as with 2G, 3G and 4G. This new interface will deliver higher data rates, near real-time responsiveness and higher spectral efficiency. Unlike previous generational changes, there is no fundamentally new technology being introduced with 5G, and the developments can apply to both an evolved version of 4G and the new 5G radio technology.

When sufficient spectrum is made available, such as those identified as the European pioneering bands, a 10 times increase in user performance may be achievable relative to existing 4G data rates.

Figure 4: 5G technical characteristics[2]

Peak data rate	1–20Gbps		Latency	1–10ms		Availability	Significant enhancement
User experienced data rate	10–100Mbps		Connection density	10k–1m devices/km²		Battery life	10 years
Spectral efficiency	X1–X3		Network energy efficiency	X1–100X		Reliability	Significant enhancement
Mobility	350–500km/h		Area traffic capacity	0.1–10 Mbit/s/m²		Position accuracy	10m–<1m

Network implications

5G will accelerate the ongoing transformation of the look and feel of mobile computing and mobile networks.

Earlier generations of networks (1G, 2G, 3G) relied on relatively consistent and common radio mast designs, large towers, and many connections between them using microwave technologies (which work best with direct line-of-sight, in turn meaning towers would be deployed in high locations and often visually intrusive). These networks were also typically hierarchical, with data travelling long distances to reach control servers and content, even where users were actually close together (perhaps even standing next to each other!).

Mobile networks today are evolving in design in many ways:

- **Flatter, less hierarchical topologies** for network design are already being implemented

- **Network Function Virtualisation (NFV)[3]** is abstracting functionality that was previously rooted in hardware, allowing this to be run in software in a dynamic fashion on servers in a common pool

- **Software Defined Networks (SDN)** enable programmatic control of network resources using application programming interfaces (APIs) to allow flexible network control, optimisation and management.

SDN and NFV together make a more flexible, reactive network: this can be tailored towards various industry and consumer sectors through 'network slicing'. Network slicing allows the allocation of network resources appropriate to the service being consumed and its particular demands on quality of service. Thanks to NFV and SDN, this allocation does not require the addition of new hardware each time a service is brought online, but can rather be rapidly set up and later discarded as required. Thus, a 'slice' operates as a separate logical network. Network slicing can also play a

critical role in energy efficiency – ensuring not only that network resources are tailored to the service using them, but also to avoid 'waking' dormant IoT sensors with a limited battery life, ensuring that they can therefore run for many years without replacement.

The benefits of network slicing are as follows:

1. No discrimination between content providers: all services require a flow of data. For some services it is critical that their flow meet certain requirements, such as latency and resilience – otherwise the service cannot work. So it is not a case of 'discriminating' between providers, customers or even industry sectors, but rather accounting for flow requirements: a flow-centric, service-provider-agnostic approach

2. Energy efficiency: slicing is flexible and rapid, making use of available capacity when it is required, and is hence energy efficient in terms of power and physical resources. This is in contrast to separate physical infrastructures, which would each require a 'static' sizing to their maximum projected capacity – which wastes energy and prevents reuse of physical resources between layers

3. Innovation: the flow-guarantees provided by slicing encourage the development of new and innovative services

4. Flexibility: the design is inherently flexible, allowing new service types to be supported quickly.

Many operators – including Vodafone – are already planning and deploying these technologies, along with the development of Cloud-RAN (C-RAN) technologies and Edge Computing (i.e. the placement of application servers and processing capability closer to end customers within network architectures). Future technologies, including 5G architectures, NFV, SDN, and the use of widespread control APIs and Edge Computing will reinvent the structure of these mobile networks.

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2 Further detail on the technological characteristics of 5G can be found in Annex 1

3 For further detail on NFV and SDN technologies, see **'Reshaping the future with NFV and SDN' – Arthur D. Little and Bell Labs, 2015**

Figure 5: Evolution of mobile networks towards the 5G era

Networks of yesterday

Datacentres, databases (HLR, VLR, etc.)

Core network

Aggregation layer

Source: Arthur D. Little

Networks of today

Application layer

Enabler APIs

Enablement layer

Virtualisation

Infrastructure resource layer

Datacentres

Access nodes

Macro cells — Street level microcells — In building — Direct mode

Hetnets
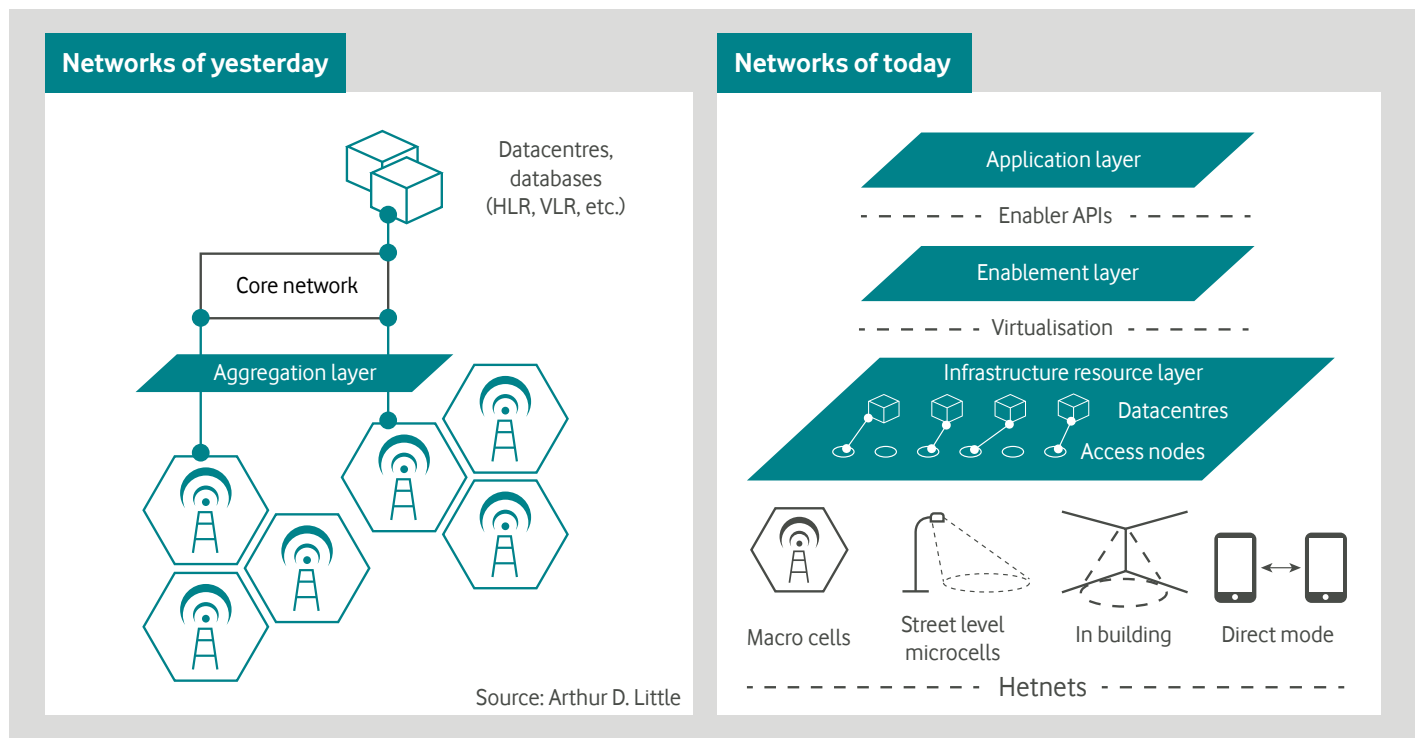
5G will herald the arrival of new challenges in base station design – requiring new types of antennae for some frequencies, as well as leveraging existing and upgraded 4G network assets and C-RAN to provide broad area coverage. For the most dense traffic areas in which it will be necessary to deliver gigabit capacity a new approach to network design will be required:

- Overhaul of network topologies and new requirements for **sharing of passive infrastructure**

- New types of **locations required for antennae/transmitters** (poles, lamp posts, street cabinets, advertising signs, etc.). But these antennae may be **less visually intrusive** than before. This will necessitate a less onerous approach to municipal build regulation

- Ubiquitous and **rapid availability of fibre** to connect these antennae will be required (see below)

- **New approaches to radio planning and network design**, including more granular and 3-D mapping and planning

- **Alignment of licensing**, both the duration of licences to better match the technology lifetime and anticipated period for economic returns on investment, and more generally harmonising spectrum licensing approaches across the European Union

- **Security within the networks**, as well as at the perimeter.

It will take both innovation and investment capital to complete these changes, as well as improved regulation, but the benefits promised are worthwhile:

- **Performance:** these networks will offer unparalleled capacity, speed and reliability

- **Resilience and redundancy:** these networks will offer quality of service levels that critical applications require, in particular in relation to latency, pacing, durability and resilience

- **Flexibility and configurability:** these networks will dynamically offer specialised support to different industries, applications and users, in turn unleashing innovation in product and service design for IoT

- **User centricity:** today's traffic management is focused on efficient and optimal management of limited network resources. 5G is designed to be far more attentive to user demand and responsiveness, whether the user is human or millions of things. 5G networks will utilise cloud, software and 'network slicing' solutions, all of which will drive a more flexible, reactive network and may be managed by both the operator and third parties/providers of content.

Spectrum implications

Rolling out 5G networks, and equipping users with 5G devices will take many years, and it will be necessary for operators to continue to operate and maintain current 4G networks over that period. This means new spectrum bands will be needed to support 5G launch, delivering both coverage and capacity of new high-speed mobile data services.

Within Europe, regulators are planning to offer new spectrum in the 700MHz band and 3.5GHz band to support the launch of 5G services, with further spectrum being planned in millimetre wave bands (26–42GHz bands). Once 5G networks have been rolled out, and customers and traffic are being transferred from 4G to 5G connections, mobile operators expect to be able to operate 5G in some of their bands in place of 2/3/4G.

Whilst mmWave bands show great promise, there are many challenges to address before using them effectively for truly mobile services, given the short range, near 'line-of-sight' requirements. This, coupled with the clear requirement of operators to utilise 5G to add resource to existing 4G networks whilst reusing key elements from them means that many mass

market bands will be in other frequencies below 6GHz – notably 700MHz (for coverage of large areas) and 3.4–3.8GHz (as identified by the RSPG[4] for Europe). Furthermore 5G devices will be able to flexibly use multiple bands (in different modes) at the same time.

Backhaul implications

5G will play a critical role in meeting the bandwidth requirements of tomorrow's customers of mobile networks. In recent years, smartphones have become more common, and are expected to be ubiquitous within a generation. As device capabilities and offered data rates rise (by an order to magnitude per generation), data usage has exploded. Between 2010 and 2016 European data growth was at least 60% year-on-year.

Continuing +60% growth rates implies a six-fold increase in data between 2016 and 2020. This demand must be met through both new spectrum and refarming of legacy technologies.

As the load on the networks rises, backhaul (the connection of the base station to the core networks) must keep pace. This means that 5G networks will preset new backhaul capacity, peak data rate and latency requirements that only gigabit connectivity can deliver, in turn emphasising the need for deep fibre networks.

Figure 6: Increasing fibre backhaul requirements in the 5G era

Year	1990	2000	2010	2016	>2020	Source
Technology	2G	2G/GPRS	3G	4G	5Gw	Vodafone
Typical user data rate	n/a	30kbps	300kbps	3Mbps	10–100Mbps	Vodafone
Cellular penetration of population	1%	70%	120%	125%	>125%	GSMA intelligence
Smartphone penetration	n/a	n/a	10%	65%	>100%	Vodafone
Smartphone data tariff (monthly)	n/a	n/a	1GB	12GB	>20GB	Vodafone
Europe traffic petabytes	n/a	n/a	82	670	4400	Vodafone
Base station backhaul requirement	1.5Mbps	6Mbps	100Mbps	1–10Gbps	>10Gbps	Vodafone

4 Radio Spectrum Policy Group (RSPG), reporting to the Directorate-General for Communications Networks, Content and Technology, EC (Aug 2016)

When will 5G appear?

Mobile technology standards appear in generations, with typical 10-year intervals between each. Intense work on 5G standardisation accelerated with 3GPP study items in 2015, and major radio standards components ready in 2017 (where running in conjunction with existing 4G networks), with subsequent R15 and R16 standards frozen in ~mid 2018 and sometime in 2019 respectively.

Extensive R&D work has continued since ~2012 – both in industry and in academia – including efforts in the UK (5G-IC) and Germany (TU-Dresden) where Vodafone is significantly involved.

Launches of 'pre-5G' technologies – in particular Narrowband IoT (NB-IoT), Cellular V2X and Cloud RAN are already occurring and will proliferate during 2017, prior to 'showcase' deployments of 5G elements in 2018 and thereafter.

Figure 7: 5G timeline

	Prior	2015	2016	2017	2018	2019	2020	...	2025
Design/ Standardisation		3GPP study items		3GPP C-V2X Standard	Key technology freeze **(release 15)** (5G)	Development **(release R16)**	**IMT 2020** specifications		
Launches	**5G (Innovation Centre)** University of Surrey, UK TU – Dresden, Germany **5G lab** **5G tactile internet lab,** King's College Experimental campus network			**NB-IoT launches** in Europe Experimental city networks	PyeongChang showcase **Korea Winter Olympics**	**'5GNR'** commercial launches expected	Tokyo, Japan Summer Olympics: showcase **UEFA 2020** commercial deployments	Release R16 based launches	Widespread urban deployments
Spectrum release		**WRC-2015**	EC/RSPG help identify 'pioneer spectrum bands'	Target for EU harmonised view on initial 5G bands		**WRC-2019** (Agenda item 1.13 on mmWave bands 20GHz to 80Ghz)		**WRC-2023?**	
National policies			**5G Action Plan for Europe** (EC announce-ment)	National 5G roadmaps requested by European Commission UK National Infrastructure Commission, UK Govt 5G strategy			Europe: One network in at least **one EU city** per country by 2020 China plan 10,000 base stations		EU: All **urban areas** and **major terrestrial transport paths**

The expectations for the timing of commercial launches vary, but most operators expect to deploy from around 2019–2020, when standardisation is completed. Initial commercial deployments are – given the key 'enhanced Mobile Broadband' use case – likely to focus on urban centres, high-footfall locations and other 'Gigazones', but there is also an increasing emphasis for policy makers to accentuate the need to address transport corridor connectivity[5].

Given the plethora of spectrum bands, number of sites and small cell locations to consider and the need to leverage existing investments, the rollout of 5G will be progressive, managed hand-in-hand with the evolution and upgrade of 4G networks.

5 See EU, 5G Action Plan and UK National Infrastructure Commission (NIC) papers, both published during 2015

Customer benefits: 5G case studies

In the following chapters we will analyse the opportunities that 5G networks will unlock for customers across each vertical industry. We will discuss potential applications that are already appearing and which require or could benefit from 5G networks throughout Europe.

We do this through illustration with case study examples from third party companies, some of whom are working with Vodafone, and others who are not. Many are already actively involved in the research and development that includes considering the implications of 5G (or relevant pre-5G technologies), wireless technologies on their own product and process roadmaps. Others are developing products and services that would benefit from the capabilities of 5G once both the applications and the technology are more mature.

Figure 8: Case studies per industry

Industry	Illustrative applications	Case studies
Healthcare	- Bioelectronic medicine - Personal health systems - Telecare and telemedicine - Connected ambulance	TIHM for dementia gsk GlaxoSmithKline
Manufacturing	- Remote control and monitoring of stationary and mobile equipment - Machine-to-machine communication - Augmented reality support in design, maintenance and repair	5GEM SKF ERICSSON CHALMERS
Media and entertainment	- Immersive experiences - On site 'stadium' experiences - User/machine generated content - Cooperative media production	TWIN VISION INITION RESOLUTION euro media group
Agriculture	- Distributed soil sensors - Crop monitoring - Drones for farming - Connected farming machinery	vodafone CHAP
Automotive	- Infotainment - Platooning - Autonomous vehicles - Remote monitoring and predictive maintenance	vodafone ROBORACE Audi SCANIA JAGUAR LAND ROVER
Energy and utilities	- Grid monitoring, control and protection - Connecting remote windfarms - Smart electric vehicle charging - Control of edge-of-grid generation	SUN SEED IBERDROLA a2a ESB Scottish & Southern Electricity Networks
Public transport	- Infotainment - Coverage of rail corridors - CCTV for platform clearing - Automatic train operations	NetworkRail icomera
Security	- CCTV systems - Automated threat detection - Facial, iris, fingerprint or palm recognition systems	NEC

Healthcare

Status of the market

The mobile health market has shown significant growth over the past few years with innovative mobile solutions, applications and services being introduced in the market. Globally, the market for mobile health is expected to double to USD 55.9 billion by 2020[6]. Patient care, both monitoring and treatment, is increasingly moving outside the hospital and patients can benefit from personalised treatment plans through new tools and services enabled by connectivity. We also see an uptake in self- and social care supported by ICT.

The introduction of 5G will further accelerate this trend. The lower latency and higher bandwidth of 5G will improve remote care solutions, i.e. by enabling real-time mobile connections between patients and caretakers and the transmission of richer datasets (e.g. test results, CT scans…) and video streams (e.g. consultation). Also the guaranteed and secured connection (e.g. through network slicing) will drive innovation in areas such as bioelectronics where security and reliability is of paramount importance.

Potential applications using 5G networks

- **Smart medication:** real-time collection of personal health data leading to an individual pharmaceutical approach

- **Bioelectronic medicine:** treatment of chronic diseases using miniaturised, implantable device modifying electrical signals that pass along nerves

- **Personal health systems:** wearable systems for monitoring, diagnosis and treatment of chronic diseases

- **Telesurgery:** remote dial-in of expert surgeons to operating theatre through video, using 360° high-quality cameras, to provide guidance and advice

- **Telecare and telemedicine:** remote patient–doctor consultation through a mobile device

- **Mobile delivery of medical files:** exchange of medical data and files over mobile device (e.g. test results, imagery, etc.)

- **Connected ambulance:** real-time connection between hospital, ambulance (and place of incident) to share data and information

- **Assisting service robots:** mobile robots assisting e.g. elderly or disabled people

- **Virtual and augmented reality for medicine:** virtual reality environments with applications across the healthcare sector, from education and training to surgical planning and patients' experience

- **Battlefield medicine:** e.g. through mobile surgical robots.

Challenges for the industry

Moving forward, a number of challenges will have to be overcome to reap the benefits that next generation mobile networks can offer:

- **Pace of innovation:** designing, trialling and adopting new technology whilst remaining compliant with medical association regulation presents a challenge, especially where regulation is old or did not anticipate the technologies now becoming available

- **Willingness to change:** adjusting working practices (of doctors or health providers) can be difficult to achieve in this sector

- **Economic models** (of state healthcare authorities) and politics of infrastructure versus service/employment spending of national healthcare budgets.

6 Arthur D. Little: Succeeding with Digital Health
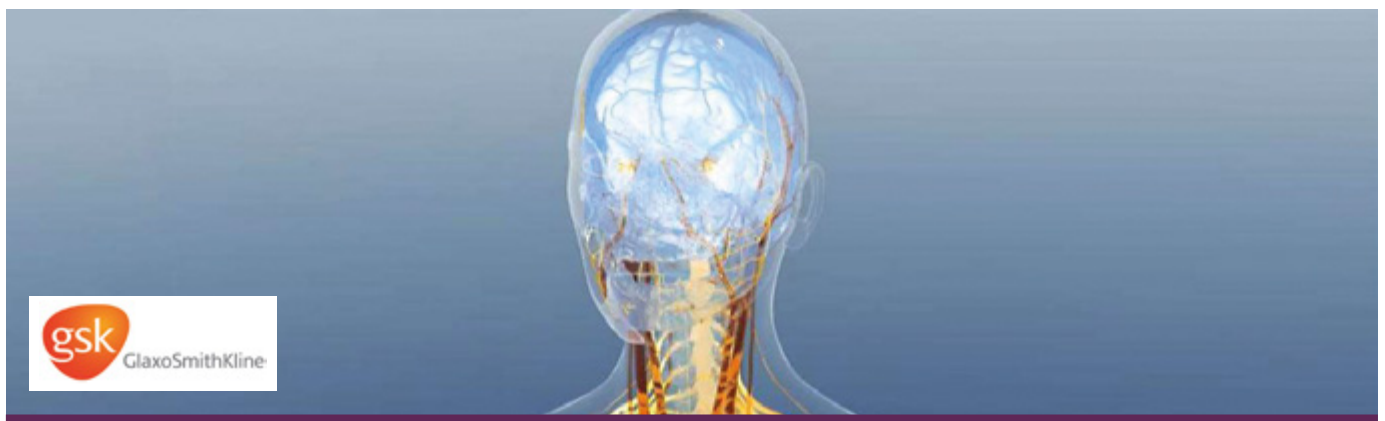
CASE STUDY

GlaxoSmithKline – Bioelectronic medicine

GSK's Bioelectronics unit is developing miniaturised, implantable connected devices to treat chronic diseases such as diabetes or arthritis. As these will rely on mobile networks to communicate back with the physicians for monitoring purposes and to adjust the treatment, having a secure, reliable and dedicated 'network slice' would be a major advantage.

Background information

GSK is a frontrunner in pharmaceutical medicine, vaccines and customer healthcare products. Amongst other research efforts, GSK is committed to advance the field of bioelectronics through its Bioelectronics R&D unit, which is expected to be spun off and become 'Galvani Bioelectronics', a joint venture between GSK and Verily (formerly Google Life Sciences).

Bioelectronic medicine is a relatively new area in healthcare where treatment does not come in the form of pills or injections but consists of miniaturised, implantable devices called 'neuromodulators'. Based on early exploratory work, Galvani Bioelectronics believes that these devices could be programmed to read and correct electrical signals that pass along the nerves of the body, including irregular or altered impulses that can occur in association with a broad range of diseases. By correcting the electrical signals, chronic disorders encompassing a number of inflammatory, respiratory and metabolic disorders could be treated.

The solution

The first generation neuromodulators of Galvani Bioelectronics will transmit data to physicians enabling them to monitor the status of the treatment, e.g. whether the implant has delivered the desired therapy and how frequently it has done so. This data is collected by a telemetry device that is in the same room as the patient which remotely transmits the results to the physician.

The second generation neuromodulators will transmit more advanced measurements (e.g. neuro-recordings, insulin measurements etc.) which will be sent to the physicians over a wide area network, enabling the analysis and adjustment of treatments remotely without the need for a consultation session. These devices will aim to treat more than a dozen therapies, ranging from inflammatory to metabolic disorders.

The implanted devices will communicate with a wearable personal device (over a short-range connection) which will then transfer the data to the cloud and the physicians via wide area networks.

Therefore, a highly reliable and secure mobile network will become very important for the second generation devices. Moreover, a dedicated network slice could be customised and optimised to support these types of applications, which will be possible with the arrival of 5G.

> **Secure, reliable and dedicated next-generation mobile networks such as 5G could become very interesting for bioelectronics medicine as our devices will rely on external networks for real time adaptation of treatments."**

Firat Yazicioglu
Device Engineering Director, GSK Bioelectronics R&D

Challenges

- **Compliance:** bioelectronic devices and their data transmission become part of the treatment and will have to comply with strict regulation (e.g. subject to FDA approval)

- **Long R&D development cycle:** it can take up to seven years for a new bioelectronic device to be developed and commercialised, so it is crucial next generation mobile technologies are understood and incorporated in advance of their release during R&D.

Future

In the longer term, the implantable devices could potentially transmit data directly to the cloud without the need for a mobile phone or a smart wearable. Also, richer data sets could be transmitted, which could be used for research.

CASE STUDY

University of Surrey – TIHM for dementia

The Technology Integrated Health Management project is developing patient and home monitoring solutions for patients with dementia, which could benefit from the increased bandwidth, reliability, security and device-to-device connectivity that can be supported by 5G networks in the future.

Background information

Technology Integrated Health Management (TIHM) for dementia is a research study funded and monitored by NHS England and Innovate UK. The aim of the project is to develop technology solutions which are placed in dementia patients' homes and can be used to help improve the lives of both patient and caregiver.

The project is coordinated by Surrey and Borders Partnership NHS Foundation Trust and led by representatives from Alzheimer's Society, University of Surrey, Royal Holloway University of London, Kent Surrey Sussex Academic Health Science Network, Public Intelligence, six local clinical commissioning groups and nine technology companies (http://www.sabp.nhs.uk/tihm).

By the end of January 2017, 700 patients with an early or medium stage of dementia living in Surrey and north-east Hampshire and their 700 carers were involved in the trial, with half having solutions deployed (and half forming a 'control group' for the research findings).

The new care model

This consists of a combination of devices which collect data from the home (e.g. door locks, activity monitors), the environment of the patient (e.g. room temperature) and from the patient (e.g. blood pressure, fall detectors). The data is collected through devices installed inside the home such as sensors and meters but also wearable devices, which transmit data in a common language to a central monitoring centre with clinical staff within the Trust who monitor patients 24/7.

In this monitoring centre the data is collected in a back-end system where advanced analytics will take place. Alerts will then be issued in case an abnormality is detected (e.g. if door left open, if patient is developing a fever, if patient didn't take medication,

etc.). Clinical staff can then take appropriate action: contacting a caregiver to help resolve the issue, or initiating a consultation, for instance. Some alerts are also automatically sent back to the patient through an avatar (on an iPad) which tells the patient what to do (e.g. take medication), and with whom the patient can interact for daily check-ins.

Currently the different devices are transmitting data over 3G/4G and WiFi networks to the back-end system. Moving forward the researchers will connect more bandwidth-hungry devices (e.g. HD video cameras) but also create systems where any device provider could add compatible solutions. 5G networks would provide the required unified connectivity platform.

In addition, currently the devices transmit data over wide area networks to the back-end system by passing through an intermediary 'bridge' (Bluetooth connection from device to a mobile handset or a gateway) because of reliability and battery life issues with a direct connection. 5G networks can help to eliminate this bridge and gateway requirement.

Ultimately the researchers would like to shift from 'monitoring' to 'actuation' and 'automation' where the back-end system will connect with controllers in the patient's home for e.g. adjusting treatment plans, creating an immersive care environment for the patient, with 'gentle interventions', for which a highly reliable, secure connection will be of paramount importance.

> ❝❝ **We will test our solution on 5G networks when they are rolled out to take advantage of the increased bandwidth, security and reliability."**

Dr Payam Barnaghi
Project Technology Lead at the University of Surrey
(attached to 5GIC Research Centre)

Challenge

Application security: any 'critical to life' application connected via the internet requires substantial security protocols and defences before release.

Manufacturing

Status of the market

Over the past few years the manufacturing industry in developed countries has taken advantage of the benefits that digitalisation and ICT have to offer to deal with important challenges such as the manufacturing skills gap, the ageing workforce (needing help to carry out tasks), traceability of products and increased environmental concerns. Industry 4.0 and related new technologies, such as the 'Internet of Things', 'cyber-physical systems' and 'additive manufacturing' are expected to drive radical performance improvements both in terms of cost and customer excitement.

Research shows that new technologies have actual game-changing potential and that savings of between 15 and 50% per cost line can be achieved on the operations side[7]. A key enabler for these factories of the future is a reliable communication layer which can support new Industry 4.0 functionalities.

5G networks have the potential to become the future communication platform in the factory as they will be able to cope with increased bandwidth requirements coming from more connected equipment and more data being transmitted on the factory floor, as well as the millisecond latency needed for real-time remote control of robotics. Some specific critical applications (e.g. production line robotics) will require highly resilient and secure connectivity, which will be another key advantage of 5G (achieved through network slicing). Moreover, elimination of wiring allows flexible production line configurations instead of linear manufacturing processes.

Potential applications using 5G networks

- **Remote control of stationary equipment:** operator has remote mobile control over fixed manufacturing equipment (e.g. production line robotics) on the factory floor. Typical applications include welding, painting and assembly

- **Remote control of mobile equipment:** operator has remote mobile control over mobile manufacturing equipment (e.g. untethered robots). Typical applications include drilling or forklifts

- **Remote monitoring of equipment:** transmission of diagnostics information so service technicians arrive prepared for successful repairs and updates when needed

- **Machine-to-machine communication:** closed loop communications between machines to optimise manufacturing process

- **Intra/inter-enterprise communication:** for monitoring of assets distributed in larger areas and efficient coordination across the value chain

- **Augmented reality support in design, maintenance and repair:** use of augmented reality to aid in the execution of procedural tasks in the design, maintenance and repair domain (through simulations).

Challenges for the industry

- **Cost:** the manufacturing industry has high cost reduction requirements and will only implement new applications if these have been proven to ultimately reduce costs

- **Safety:** hundreds of connected automated devices on a factory floor can create a hazardous environment for humans

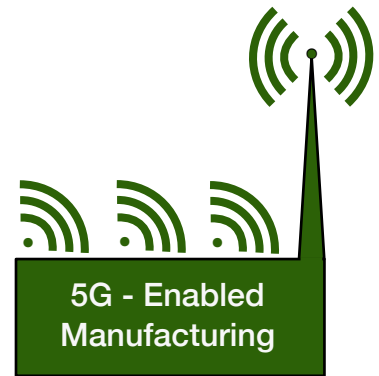- **RF interference:** several objects on the factory floor are already using radio communications.

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7 Future of Operations in the Digital World, Arthur D. Little, 2016

CASE STUDY

5GEM – 5G-Enabled Manufacturing

5GEM is a collaborative research project which aims to create a pilot production system for world- class industrial manufacturing based on wireless and mobile 5G communication.

Background information

5GEM (5G-Enabled Manufacturing) is a two-year demonstrator project which will show how future 5G telecommunication technology can be used with manufacturing technologies to increase sustainable competitiveness of Swedish industry. The digitalisation pilot project is led by Chalmers University of Technology and mobilises resources of the telecom provider Ericsson and SKF, a Swedish manufacturing company of ball and roller bearings, linear motion products, precision bearings, spindles and seals. The project was launched in February 2016, funded by Vinnova, the Swedish governmental innovation agency.

The goal

Through the 5GEM project, Chalmers, Ericsson and SKF are exploring possibilities of future 5G technologies in advanced manufacturing. The four life-cycle phases of a system – design, deployment, operation and maintenance – are used as a generic baseline for innovation and development. The ultimate goal of the project is to demonstrate the capabilities of 5G in world-class manufacturing – such as SKF's production facilities in Gothenburg.

The demonstrators

The project is focused on four demonstrators that improve manufacturing system performance, increase product quality and add manufacturing flexibility. The workplace efficiency and attractiveness of work are also expected to increase.

One of the demonstrators will radically improve connectivity of stationary equipment on the manufacturing floor. This will enable, for example remote control of equipment and monitoring of the status of equipment or the machine environment.

Minimal communication latency is a key requirement in real-time control for process optimisation or for robotics. But bandwidth is also critical when extensive control data, multiple high resolution video streams, etc. have to be transferred to remote operators.

A second demonstrator connects skilled people involved in the manufacturing process. Mobile and handheld devices enable real-time instructions or acquisition of data needed for production.

The third demonstrator provides cloud services, enabling data analytics for e.g. predictive maintenance or decision support purposes. Big data applications will demand 5G, as they may need very high bandwidth.

The fourth demonstrator provides tools for looking at radio space design. Point-cloud scanning and ray-tracing tools are combined to analyse propagation of radio signals in a manufacturing environment in order to identify interference between radio waves and other items (e.g. metallic frames, etc.).

When next generation mobile networks, like 5G, are combined with state-of-the-art connectivity tools, sensors and operator–system interaction, they have potential to greatly improve manufacturing speed and quality. They also lower susceptibility of information flows in an advanced manufacturing system.

" Fifth generation wireless communication technologies offer new means for Swedish industry to achieve radically increased manufacturing productivity, flexibility, and competitiveness."

Johan Stahre
Chair Professor, Head of Division Production Systems, Product and Production Development. Co-Director of Chalmers' Production Area of Advance

Future

The demonstrators are being developed in a multiple stage process. 5G functionality is first tested in Chalmers' Smart Industry Lab for open Innovation and then moved to SKF's pilot plant. As technology readiness increases, Ericsson's 5G technology will be implemented in SKF's operational manufacturing environments.

Media and entertainment

Status of the market

Consumer behaviour in the media and entertainment industry is continuously changing with the relentless adoption of new device formats and services, whilst the quality of the experiences is constantly increasing.

As a result, Ericsson estimates that within Central and Eastern Europe the average mobile data usage will increase from ~2GB per month in 2015 to ~18GB per month in 2021[8] with the number of subscriptions already exceeding the population in several countries today.

HD streaming for both video and music has become the norm on mobile devices over recent years, and with 4K/8K streaming on the horizon, the bandwidth requirements will continue to increase. Moreover, consumers also increasingly upload high-quality video to social media platforms and online video channels through a mobile device, pushing up upload bandwidth requirements as well. Future 5G networks will be able to support this massive increase in data rates enabling new use cases and services.

Several virtual reality (VR) headsets have recently been launched which rely on a mobile device to download content, and market estimates show that large adoption of virtual reality is just around the corner. The latency and bandwidth required for mobile live streaming of VR content, whether it is to watch or participate in sport events or for massive online VR gaming, will require next generation mobile networks such as 5G to guarantee a good quality of service (i.e. continuous image and avoiding motion sickness).

5G networks could also bring a significant advantage for broadcasting companies further up the value chain. Broadcasting companies increasingly move production away from the event site (Outside Broadcast, or 'OB' Units) to a central studio, where video streams gathered from multiple cameras will be edited and compiled.

If broadcasting companies could rely on mobile 5G instead of wired fibre networks (from fixed event sites) or satellite (from dynamic event locations) to transmit the captured video streams back to the central studio, this would open up a whole new way of working.

Potential applications using 5G networks

- **Immersive experiences:** online augmented reality (AR)/VR gaming or experiences. Also includes tactile internet experiences (i.e. recreating sense of touch e.g. bionic suits). With accuracy for voice recognition technology and open-ended dialogue with computers being developed, this could evolve towards voice interaction with virtual characters

- **On-site experiences:** providing additional features to spectators like replay, view from different angle, translation, etc.

- **User/machine generated content:** users or machines recording self-created imagery which is uploaded to social media or online channels

- **Cooperative media production:** content worked upon by different users in multiple locations simultaneously

- **Distributed performance:** creation of content by sourcing content from different locations in real time (e.g. orchestra).

Challenges for the industry

Latency: the quality of the telecommunication connection remains the most important bottleneck for media and entertainment companies who have to transmit large amounts of data and have strict latency and contention requirements, especially when dealing with live experiences.

8 Ericsson Mobility Report 2016

CASE STUDY

INITION – Virtual reality orchestra

INITION is an innovative production company specialised in developing full immersive experiences. Amongst other initiatives, INITION has been looking to move beyond pre-recorded and edited VR experiences and create live 360° 3D virtual reality streams of events such as an orchestra, which could potentially be enabled by next generation mobile networks.

Background information

INITION is a multidisciplinary production company based in London specialising in producing installation-based experiences that harness emerging technologies with creative rigour. With over 13 years of experience and hundreds of installations across the world, INITION is known for leveraging new technologies for creative communications. INITION is involved in augmented reality, 3D printing and virtual reality (VR) experiences.

The solution

INITION partnered with the UK Philharmonia Orchestra and Southbank Centre to create a unique orchestra experience. The production allowed classical music lovers to experience the orchestra performance in a VR world, wearing a Samsung Gear VR headset. The project delivered a 360° 3D video and audio experience, transporting the user into the centre of the orchestra, where they could change position to listen to the music from a different angle.

To produce the video stream, special VR cameras were installed to record 360° 3D imagery of the orchestra. The recorded video stream, which could be up to several hundred gigabytes in size, was then moved to the production studio where it was edited and adapted making it ready for use in a VR experience.

INITION is experimenting with using live 360° 3D video streams of the orchestra which will be used to simulcast the performance in a virtual world in real time. Remote users could then be transported into the virtual orchestra and experience the performance in real time through a VR headset.

Current limitations of the mobile network hinder the creation of such a use case. The bandwidth requirements are significant as 360° 3D live video streams are extremely data intensive. More importantly, delays and lags in the video feed would 'break the spell' and quickly diminish the overall user experience. The higher throughput and lower latency that 5G will bring could potentially solve this issue.

Moreover, next generation mobile networks such as 5G will enable mobile devices to use the processing power of the cloud instead of using internal processing power. This will significantly increase the battery life of mobile devices, which would allow mobile devices to facilitate applications such as 360° VR live streams for an extended period of time.

❝❝ **360° 3D live video streams are very data hungry and require bandwidth well beyond what is offered today in typical media user environments."**

Adrian Leu
CEO INITION

Challenges

* **Battery life:** at present smartphones dedicate significant power to process the tasks on the device itself. This has a negative effect on the battery life of a mobile device and limits use cases such as watching 3D live streams for a longer period of time

* **Bandwidth:** the current mobile network does not provide ample bandwidth for both the upload of recording to the cloud, as well as streaming content to the user's VR device.

Future

In the future, augmented reality is expected to become more important, where the real physical world is combined with a computer generated virtual world enabling the user to take decisions and interact (e.g. make music of their own, as part of the ensemble).

CASE STUDY

TwinVision – Digital Twin

TwinVision has developed a 'Digital Twin' prototype, using IoT sensors to re-create a 3D digital version of a real-life sport event. TwinVision gives the audience the ability to follow the event from a mobile app/VR device, which increasingly requires lower latency and higher bandwidth connectivity.

Background information

TwinVision is an Austrian start-up which has developed a user-centric 'Digital Twin' prototype enabling spectators of major sports events to follow a digital replica of the event on a mobile device, giving them a better experience.

The company is at an early start-up stage but is already engaging with large event promoters and media houses in the sports world.

The solution

Spectators of large sports events often experience limited visibility on what is happening throughout the event. Viewers at home are bound by what broadcasting companies choose to show, whereas spectators that attend the event have limited or occasional visibility.

The TwinVision solution gives the audience an enriched live experience by enabling them to follow a digital replica, i.e. a Digital Twin of the event from a handheld device, and giving them control of what they follow. In a car racing event for instance, spectators could choose to follow their favourite car and see its telemetry versus other cars in the race.

The car racing prototype relies on positioning, acceleration and movement data from existing GPS sensors mounted on the cars and around the tracks, which is processed in a visualisation engine that creates the Digital Twin, i.e. a 3D digital replica of the race in real time. This Digital Twin can then be accessed by spectators who are following the event from their handheld device, where they can choose from what angle they want to follow the race. Most of the large sports events already gather the sensor data that is needed to create this Digital Twin.

In addition to following the event from a different angle, the prototype also offers the possibility to gather statistics (e.g. measure fastest lap), compare cars (e.g. compare race leader with another car) and engage in a chat with other users of the app. Moreover there is also a 'Drive and Play Along' feature providing spectators with the opportunity to drive along in the race in their own car using a VR headset. Finally users can also generate their own content where they can record a part of the race from their desired perspective and then upload this to social media platforms such as 'Twitch'.

To ensure a good experience, it is important that a fast and reliable mobile connection is in place so that spectators can follow the digital replica simultaneously (i.e. very low latency) with the real event. Moreover, TwinVision has the ambition to add real video streams to the Digital Twin which would require significant bandwidth, especially if there are many users of the app in the same place (e.g. around the track), at the same time (e.g. during the race) and different video streams per car have to be transmitted. The low latency and high bandwidth of 5G radio networks would therefore be a key advantage.

> **On-site live experience at major sports events will increasingly require a reliable and high-bandwidth connection as more functionalities are added to give the audience a better experience."**

Olivier Jauschowetz
CEO TwinVision

Future

As a next step other sports will be addressed such as skiing events, air races or cycling events. Moreover, completely different business segments like aviation are thinkable. Using the Digital Twin combined with augmented reality could be a great tool for flight controllers. They get a better overview and more information on all the airplanes moving around the airport.

CASE STUDY

Resolution Games – Mobile multiplayer VR gaming

Resolution Games is an innovator, developing virtual reality games for mobile headsets such as Google Daydream. Although currently many VR games are single player games, Resolution Games is focused on incorporating online multiplayer functionality into their games.

Background information

Resolution Games is a gaming studio located in Stockholm, focused on mobile VR games. As one of the first studios in the world that solely works on virtual reality, they aim to go further when it comes to both innovation in technology as well as in gameplay. Their core proposition is to design games that make the user forget that they are actually inside a VR world.

The solution

Towards the end of 2016 Resolution Games released their first mobile game 'Wonderglade'. Wonderglade is a carnival-themed game that allows users to teleport into a world of wonders to play new takes on traditional carnival games through VR. Two of the mini-games that users can play in Wonderglade are Tip-N-Tilt Racing and Tiny Tee Golf. Tip-N-Tilt Racing is a fast-paced game where users race against the clock with ball-shaped animals on a tilt-board maze. Tiny Tee Golf is the VR version of the classic mini golf game. Wonderglade will be played through a VR headset that uses a mobile device, such a mobile phone, for its content.

Wonderglade has initially been released as a single player game. However, Resolution Games has anticipated the push for multiplayer games by designing the game in such a way that they can quickly add and enable multiplayer functionality.

The VR multiplayer functionality has a significant advantage over traditional console games. Multiplayer full immersion games will enable users to feel very close proximity to other players and really 'connect' – an experience that is lacking in traditional gameplay.

In order to facilitate a multiplayer gameplay, a continuously secured connection is required that provides both high-quality bandwidth, upload and download, and low latency. Data on the players' movement and actions needs to be collected and processed before the stitching of the virtual world environment can be done and the information sent back to the user devices for rendering. A lag in the gameplay will remind users that they are in a virtual world; it is crucial to have high throughput and very low latency to ensure the customer experience.

> **One of the biggest potentials within virtual reality is multiplayer gaming as VR really makes users feel they are close to each other, even when they are not. To facilitate multiplayer collaborative VR games, the networks need to be able to handle significant throughput with near zero latency."**

Tommy Palm
CEO Resolution Games

Challenges

- **Latency:** in order to offer gamers the idea and feel of being present in another place while playing VR games, it is crucial that latency is reduced to the minimum. Any delay or lag will diminish the customer experience significantly

- **Bandwidth:** as current mobile infrastructure is not strong and consistent enough to facilitate live content streaming for virtual reality, VR games often still have to be pre-installed on the mobile devices and locally rendered. Moving towards online multiplayer gaming, the live streaming of a high-quality virtual world will become essential.

Future

Looking towards the future, the market for mobile VR devices and games will become more mature. Headsets will become more compact and affordable, which will boost the uptake of games such as Wonderglade.

CASE STUDY

EURO MEDIA GROUP – LIVE TV PRODUCTION

For live TV production, Euro Media Group has to send vast amounts of data from event sites to its production studio in real time over fibre networks or rely on mobile production units. 5G networks could replace the use of such units and could enable direct transmission from the cameras to the studio.

Background information

Euro Media Group (EMG) is a leading provider of broadcast facilities and services, active in seven European countries: France, Belgium, Netherlands, Germany, United Kingdom, Switzerland and Italy. The group is headquartered in France and masters the entire broadcasting value chain from image capture and creation to distribution.

EMG is the broadcasting partner for major international sports events (e.g. football and car or bicycle racing events) as well as live shows (e.g. music festivals) and owns the largest range of studios as well as the greatest fleet of mobile facilities in Europe.

Live TV production

For live TV production, broadcasting companies such as EMG rely on high-performing networks to send captured video streams back to the studio. For a large football match for instance, several cameras placed around the stadium each transmit a live video stream to the central studio, where they will be compiled into one final stream that will be used for broadcasting to the general public.

The bandwidth required to send live video back to the studio for production will depend on factors such as the number of cameras, the video quality and the compression technique applied, but will often be in the range of gigabits per second. Latency is also very important for EMG as they want to be able to switch from one camera to another instantly (e.g. during penalties or goals).

For events in stadiums or arenas, EMG usually relies on fixed fibre networks to send the video streams back, as these venues are already connected by fibre and current mobile networks do not have the required bandwidth and latency.

However for many one-off (e.g. concert) or outdoor events (e.g. marathons, cycling) current connectivity solutions are not sufficient and the broadcasting company has to work with mobile production units who will edit and compile the final video stream on-site, which is then transmitted over a satellite connection for broadcasting.

Next generation mobile networks such as 5G could replace the use of mobile units, as they will provide the necessary bandwidth and latency, and facilitate remote production. Moreover network slicing will enable a high quality of service and a guaranteed connection which is extremely important for a company like EMG as they directly lose revenues if even a second of video is missing.

For broadcasting of some outdoor events such as long bicycle races EMG currently relies on a solution where motorbike-mounted cameramen are capturing the video stream and transmitting it via a helicopter to the mobile unit for production. 5G networks could replace this (very expensive) process and enable direct transmission from motorbikes to a central production studio.

> **If bandwidth, latency and quality of service of 5G networks meet our requirements this would open up a whole new way of working as we are currently constrained by the amount and speed of data we can send back to the central studio."**

Ronald Meyvisch
CTO, Euro Media Group

Benefits

- **Cost reduction:** direct transmission of video streams over a mobile network reduces the need for a mobile production unit (with crew) and also eliminates the need of helicopters which will have a positive impact on costs and environmental impact

- **Richer production:** production of live TV can happen in the studio using a larger number of video streams and tools compared to on-site mobile production.

Agriculture

Status of the market

Next generation mobile networks such as 5G will help to address some of the pressing issues that the agriculture industry faces. Amongst the greatest challenges is the rapidly growing global population, from 7 billion in 2015 to an estimated 9.7 billion in 2050[9], with 70% of this population living in urban areas by 2015[10]. This creates the need for agriculture to satisfy an increasing demand, through increased productivity and efficiency. Sustainable farming (e.g. reducing net carbon emission per unit of food) and reduced use of pesticides are other topics that next generation mobile networks will help to address.

The agriculture industry has already started to embrace ICT and connectivity to increase productivity and efficiency. The current USD 1.27 billion 'Connected Cow and Farm' business is expected to grow eight-fold to USD 10.75 billion by 2021[11]. Farming companies are turning to real-time information systems to monitor the harvest and take informed decisions on treatment (e.g. use of pesticides). NB IoT technology, which is already being launched and will likely integrate into 5G networks, will enable further rollout of millions of connected sensors on a large scale to increase monitoring capabilities of harvest and soil.

Potential applications using 5G networks

- **Distributed soil sensors:** sensors that measure a number of parameters such as moisture or temperature, or identify issues such as diseases or insects and enable informed farming decisions

- **Crop monitoring:** real-time crop vegetation monitoring, which enables tracking positive and negative dynamics of crop development

- **Routing and monitoring of livestock:** real-time management of livestock

- **Smart irrigation:** use of controllers and devices which reduce water usage by using real-time information about the site conditions

- **Connected farming machinery:** automated farming equipment (e.g. smart milking equipment) or vehicles (e.g. harvesting trucks) which can be controlled remotely by a central operator

- **Drones for farming:** use of drones to monitor fields, livestock or autonomous machinery (e.g. driverless harvesting trucks) sending live video streams back to a central control room.

Challenges for the industry

Coverage: for 5G to live up to its potential within the agriculture sector, high coverage in rural areas needs to be achieved. Deployment of smart and precision farming processes, such as autonomous equipment and vehicles, will be hindered if coverage in rural areas is limited.

The bandwidth that 5G networks can provide will become important when these sensor based monitoring systems are combined with advanced imagery from drones or special on-site cameras, and cloud analytics, enabling autonomous adjustments of the farming approach and precision farming.

Farming equipment and machinery are increasingly connected and will become autonomous moving forward, for which a low latency connection and ultra-secure connectivity and control platforms will be crucial.

9 UN world population projections from 2015

10 The Economist: 2050 Mega change

11 Digital Trends: Connected Cows

CASE STUDY

CHAP – Digital farming

CHAP is developing a SMART Decision Support Unit that helps inform farmers about the risks from pathogens, pests and weeds in order to reduce the use of pesticides. This solution could benefit from next generation mobile networks as more data could be included in the analysis, and agricultural machinery could be connected to autonomously take action.

Background information

CHAP (Centre for Crop Health and Protection) is one of the four 'Centres for Agricultural Innovation' created by the UK Government and was launched in 2016. The centre has been established to revolutionise how farmers manage crop threats including pests and disease, both in the UK and overseas.

CHAP and its partners (which include research organisations, food retailers, processors, agronomists and manufacturers) share resources to optimise returns on research and investment, reduce waste and accelerate the deployment of new crop-protection technologies.

The solution

Using the latest technology in remote detection, predictive modelling and in-field data collection, CHAP's SMART Decision Support Unit aims to provide a real-time surveillance and forecasting platform to communicate the risks from pathogens, weeds and pests directly to farmers and agronomists. The key objectives are to reduce the use of pesticides, improve crop yield and quality, reduce costs and waste and increase margins.

In order to better inform farmers on the use of pesticides, relevant data will be collected from automated spore traps (that sample airborne pathogen spores), insect traps and meteorological monitoring stations. The data collected is being analysed using algorithms which generate a localised risk assessment. This assessment is then fed back to farmers through an application on a mobile device. More information on the platform will be available at www.cropmonitor.co.uk in spring 2017.

Currently a proportion of the data is collected through human intervention on a weekly basis but CHAP is planning to automate the collection and analysis of the data by using wide area mobile networks. By automating the solution, real-time updates can be provided to farmers enabling them to take informed decisions about pesticide application.

Next generation mobile networks will advance the solution and facilitate the gathering of significantly more data. In addition, other data sources, such as hyperspectral imagery, captured by drones, or landscape images of the field captured by video or light detection and ranging (LIDAR) equipment mounted on top of farm machinery could be included in the analysis to get better and richer information.

5G networks could also enable further automation within crop protection. As agricultural machinery becomes more autonomous, the information from the SMART Decision Support Unit could be directly sent to agricultural machinery which could then take the required action in real time, without the need of human intervention. A reliable and secure low latency network will be of primary importance for this, when potentially hazardous autonomous harvesting or spraying equipment is involved.

> **5G networks would allow us to expand our SMART Decision Support Unit by enabling the gathering of significantly more data from existing sensors and add on information such as that of high definition imageries."**

Dr Judith Turner
Head of Plant Pathology, Fera

Challenges

- **Battery life of sensors:** as sensors are often placed in very rural areas with no direct electricity source, the battery life limits the effectiveness of an autonomous solution. IoT standards will help address this though.

CASE STUDY

Vodafone – Drones as a service

Vodafone is already able to provide drone connectivity using 4G network capability. Vodafone is also working with partners on the use of 'drones as a service' for future applications, e.g. automatic drones for precision farming or protecting critical infrastructure. Controlling the drones over a 5G network would yield a number of important benefits.

Background information

Vodafone is championing a catalyst project of the TM Forum, which is focusing on how to deliver 'drones as a service'. The TM Forum is a global association for digital business, which provides a platform for companies across a wide range of industries to collaborate on innovative digital services.

Catalysts are proof-of-concept projects developed by TM Forum members looking to create innovative solutions. The drones' catalyst looks at how drones can support precision farming and inspection of critical infrastructure.

The use cases

Initial research of the catalyst focused on precision farming, as this is already an important end market for drones today. Automated drones capture high-quality images of crops which are transmitted to the cloud where advanced analytics will determine where and when the farmers should apply pesticides. With this system pesticides are only applied where needed instead of on the entire field, ultimately reducing costs for the farmer.

The second phase of the research is looking at using drones to inspect the condition of critical infrastructure. Currently companies are forced to send workers or to use helicopters which would capture images and physically bring these back to the control room. These could be replaced by drones transmitting imagery back in real time, leading to important efficiency gains.

Vodafone is currently already relying on commercially available drones for line-of-sight visual inspection of the Vodafone infrastructure.

Today, most drones are controlled using proprietary protocols in the unlicensed 2.4GHz band, and regulation in most countries stipulates that drones have to be in the line of sight of the operator. If the drone were controlled over a 5G network it would be in contact with multiple base stations simultaneously to ensure continuity, and network slicing capabilities of the network would ensure quality of service.

"With a 5G network you could get ultra-high levels of reliability and therefore remove the need to have a human operator within line of sight. If you're going to offer a completely automated service, you can't utilise a best-effort 4G connectivity where the signal is not guaranteed; you need the enhanced reliability of 5G."

Lester Thomas
Chief IT Systems Architect, Vodafone Group

Challenges

- **Safety and security:** emerging regulatory frameworks for drones have highlighted requirements such as drone registration, drone monitoring and drone control. Putting an embedded SIM into drones at manufacture could help with this challenge, for example by providing an automatic and secure registration of the user, as well as constantly updated 'no-fly-zone' information

- **Regulation:** it is important that regulatory policy facilitates the deployment of drones in the existing licensed terrestrial spectrum

- **Battery life of drones:** this can become an issue when travelling over a long distance (e.g. cross-country). They would need to be recharged (e.g. on mobile phone towers).

Future

Vodafone will soon be looking to demonstrate automated air traffic control for drones in conjunction with its partners, operating over a 5G network in a simulated environment.

Automotive

Status of the market

The automotive industry is one of the key vertical industries that could benefit from the arrival of 5G networks. Most car manufacturers are already looking at what the new technology can bring and automotive 5G trials are being conducted around Europe, in collaboration with telecom operators and road infrastructure providers.

The total global revenue for the connected car industry stood at USD 37.5 billion in 2015, and is predicted to increase to USD 151.8 billion in 2020[12], driven by new safety and security features, infotainment and navigation services, relying on or augmented by a mobile connection.

More infotainment applications inside the car (e.g. streaming HD movies, uploading media, etc.) will become possible, especially with autonomy, if higher throughput under high mobility is offered by 5G. The lower latency of 5G networks will help to support the shift to a decreasing dependency on the driver and ultimately fully autonomous driving. For these use cases vehicles must communicate with roadside infrastructure (V2I) – e.g. traffic lights, etc. – but also other vehicles (V2V) – e.g. to signal an obstruction ahead – whilst gathering real-time environment and traffic information that will influence route, braking or speed.

The potential in 5G to dynamically configure networks could effectively address different user demands. For example 'blue light first responders', general road traffic, autonomous trucks, monitoring cameras and maintenance units all have differing needs and requirements, and these can vary based on road conditions (clear, foggy, during an accident, etc.).

These networks will be used in combination with other critical pieces of equipment such as sensors, global positioning systems and artificial intelligence (AI) computers, which can actually operate the car 'autonomously', should the mobile connection fail.

Potential applications using 5G networks

- **Autonomous vehicles:** driverless vehicles enabled by V2I and V2V applications (includes e.g. collision avoidance application, emergency braking, intelligent traffic systems)

- **Driver assistance:** 'see through the front' vehicle, in-dash junction cameras (for HGVs or buses, for example)

- **Infotainment:** streaming HD/UHD movies to tablets/headrests or online gaming in the car

- **Platooning:** convoy of vehicles driving together, connected to a central operator

- **Data collection:** vehicles collecting data on traffic, accidents and road condition. Some maintenance vehicles generate large amounts of telemetry and scan data

- **Intelligent navigation:** using real-time traffic information, computed with data from other vehicles, road authorities, traffic management centres, sensors, cameras and radars, etc.

- **Remote monitoring and predictive maintenance:** manufacturer monitoring condition of car (and sending an alert if faulty) and machine learning maintenance requirements

- **Tele-operated driving:** remote driver assistance to vehicles (e.g. taxi fleets, school coaches), taking control in emergencies.

Key considerations

- **Technology standards:** varying standards hinder global OEMs' decision-making

- **Willingness to change:** widespread autonomous vehicle driving alongside human drivers has not yet occurred, despite trials

- **Harmonised standards:** spectrum that was harmonised for C-ITS applications across the EU (5.9GHz band) should be used by both ITS-G5/802.11p and cellular technologies

- **Government policy:** pro-active government policy (e.g. mandated deployment of safety-related V2X services) can help bring these services to market.

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12 GSMA: Transforming the Connected Car Market

CASE STUDY

Vodafone – A9 testbed in Germany

Vodafone is trialling vehicle-to-vehicle communication as well as geo-messaging solutions for cars along the A9 highway in Germany, between Munich and Ingolstadt, using an advanced version of long term evolution (LTE), as part of a testbed with other partners for future 5G services.

Background information

Vodafone is a worldwide leader in machine-to-machine (M2M) and automotive connectivity, supporting the industry in the transition to connected and autonomous vehicles. Vodafone is now testing new technologies to enable vehicles to talk to each other and to communicate with roadside infrastructure over greater distances and higher speeds in real-world traffic conditions.

The A9 trial

At the A9 testbed, innovative technologies towards 5G form the basis for future mobility evolution. Both vehicle-to-vehicle communication as well as geo-messaging solutions are being trialled on a section of the A9 highway between Munich and Ingolstadt in Germany. The trial is currently running on an advanced version of 4G whilst waiting for the arrival of 5G infrastructure.

The vehicle-to-vehicle communication solution that is being tested enables vehicles to talk to each other and to roadside infrastructure over significant distances using a C-V2X solution.

Messages include, for instance, signals around automatic braking, lane-tracking (i.e. warning that another car will change lanes), blind-spot warning or information from nearby traffic lights (e.g. that they will turn red). Some of these features exist already in new cars but they depend on embedded sensors within the vehicle which have a limited range, and do not enable communication over a greater distance, or with cars or infrastructure that is further ahead.

Whilst the solution is currently being trialled on an advanced version of 4G, Vodafone expects that the introduction of 5G will allow higher terminal velocity support and lower latency will enable real-time communication with the cars (i.e. instant warnings), whilst the higher bandwidth will enable richer information to be communicated (e.g. 3D maps, greater audiovisual entertainment range).

" Achieving reliable communication between vehicles and infrastructure is an important step that will lead to full automation of cars after 2020. We are excited to be trialling the technology that will bring new 5G capabilities to vehicles enabling safer and smarter driving for all."

Dr Ralf Irmer
Chief Innovation Architect, Vodafone Germany

Benefits

- **Less congestion:** the vehicle is told the optimal speed to drive at in order to avoid traffic congestion, and communication between roadside infrastructure (e.g. traffic lights) and cars leads to more efficient traffic flow. HGV platooning is a key example of this

- **Increased safety:** automatic emergency braking systems, visibility aids and hazard warning systems should reduce fatalities

- **New driving experience:** increased driver aids and autonomous driving support frees time for the driver and passengers.

Challenges

- **Coverage:** consistent coverage along the road network will be key to enable connected car solutions

- **Industry collaboration:** many parties must collaborate in order to realise connected car solutions (operators, vehicle and component manufacturers, road infrastructure agencies, emergency services, etc.)

- **Fibre backhaul:** passive infrastructure including ducts is required to ensure traffic is moved from roadside radio to core quickly.
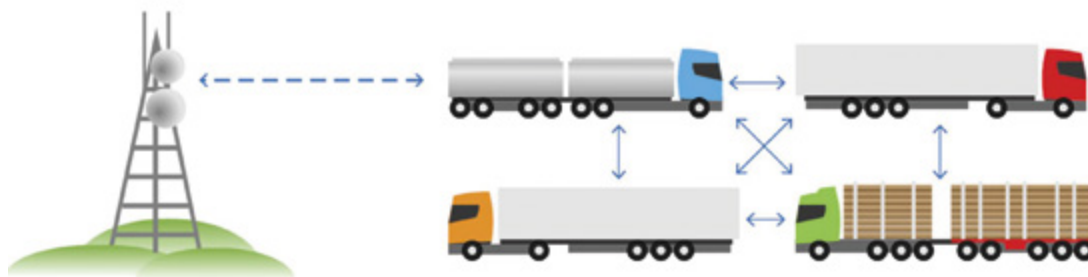
CASE STUDY

Scania – Platooning

Scania is a frontrunner in connected vehicles, having over 200,000 connected vehicles on the road today. Scania has been trialling platooning for several years and has now started a 5G trial to look at the benefits of next generation mobile networks for autonomous driving and platooning.

Background information

Scania is a Swedish automotive manufacturer of commercial vehicles, specifically heavy trucks and buses. The global company has a sales and service organisation in more than 100 countries.

Scania is investing heavily in research and development of connected vehicles and was one of the first heavy vehicle manufacturers to explore platooning. Scania is involved in several European research projects around platooning such as the 'Companion Project' which aims to conduct real-life platooning trials in Spain, where Scania is the lead party.

The solution

Platooning is a driving formation where a group of trucks are driving autonomously in a convoy or 'platoon', i.e. in very close proximity to each other, following a lead truck at constant speed. Platooning is currently already enabled by radar and camera-based systems installed on the trucks permitting trucks to drive at a safe distance from each other.

The main advantages of platooning are lower fuel consumption thanks to the reduced aerodynamic drag and hence reduced CO_2 emissions, as well as improved overall traffic flow.

An even narrower distance between trucks, and hence larger fuel savings, can be achieved by vehicle-to-vehicle communication and interconnected control systems enabling trucks to receive or send messages on e.g. synchronous braking, optimal speed and distance between the trucks. This could be combined with a vehicle-to-infrastructure connection through a wide area network for planning and organisation of the formation and receiving messages on e.g. re-routing or proximity of other compatible trucks or platoons, especially on highways.

Initial platooning research focused on using WiFi for vehicle-to-vehicle communication. Scania has also engaged in a research project in collaboration with Ericsson to test platooning, and eventually autonomous driving, through the use of 4G and future

5G networks. The low latency, higher reliability and network prioritisation features could make 5G a secondary system or part of a redundancy for vehicle-to-vehicle or vehicle-to infrastructure communications in the context of platooning.

❝ Reliable networks are crucial when facilitating solutions such as platooning and autonomous driving. The existing WiFi standard could be complemented with 5G networks for a better experience.”

Karl Håkan Schildt, Director
Strategy and Business Development, Connected Services and Solutions

Challenges

- **Legal barrier:** regulation for wireless access in vehicular environments currently focuses on IEEE 802.11p (i.e. a WiFi standard) and not mobile networks

- **Infrastructure coordination:** European highways are cross border, as are traffic flows, and solutions must reflect this

- **Commercial model:** charging should take into account the fact that trucks and buses cross borders, such that service options in platooning use cases remain feasible

- **Willingness to change:** customers and the general public need to be educated on the advantages of platooning and autonomous driving to achieve widespread acceptance.

Future

Vehicles will increasingly become connected and new and more advanced solutions will be introduced. Solutions such as platooning could deliver significant road safety and environmental benefits to European and global society.

CASE STUDY

Jaguar Land Rover – Connected and autonomous vehicles

Connected and autonomous vehicle technologies are one of Jaguar Land Rover's key priorities, and it is in a suite of research projects including trialling vehicle-to-vehicle and vehicle-to-infrastructure applications based on C-V2X connectivity, which is essentially a precursor of 5G technologies.

Background information

Jaguar Land Rover is the UK's largest automotive manufacturer, built around two iconic British car brands: Land Rover, the world's leading manufacturer of premium all-wheel-drive vehicles; and Jaguar, one of the world's premier luxury sports saloon and sports car marques.

The company is the largest investor in R&D in the UK manufacturing sector. It has invested £12 billion in the last five years and in the current year alone will spend over £3 billion on new product creation and capital expenditure.

Connected and autonomous vehicles

Jaguar Land Rover is trialling several connected and autonomous vehicle technologies which will help improve traffic flow, cut congestion and reduce the potential for accidents. Jaguar Land Rover is looking at both vehicle-to-vehicle communication, enabling cars to send messages to each other, and vehicle-to-infrastructure communication, enabling vehicles to receive and send information to e.g. traffic lights, roadside signs or traffic control centres. This will enable applications such as emergency braking, hazard warning or warning that an emergency vehicle is approaching, and will require robust connectivity with low latency and varying bandwidth by use case.

Jaguar Land Rover is creating a fleet consisting of more than 100 research vehicles over the next four years to develop and test these technologies. The company has already run some C-V2X trials in a dedicated test track in Gaydon, Warwickshire, along with Vodafone and Huawei.

UKCITE trial

UK Connected Intelligent Transport Environment (UKCITE) project is a research project launched in 2016, funded by the British Intelligent Mobility Fund administered by the Centre for Connected and Autonomous Vehicles (CCAV) and delivered by the UK's innovation agency, Innovate UK. It will trial connected and autonomous vehicle technologies along 40 miles of British roads, within Coventry and Warwickshire, on a mixture of road types (on the M40, M42, A46, A45 and an urban route within the city of Coventry).

The initial project duration is 30 months and it is undertaken by a consortium of leading industry, academic and local and national governmental organisations. Along with Jaguar Land Rover, the consortium members are Visteon Engineering Services, Coventry City Council, West Midlands Combined Authority, Coventry University, Highways England Company, HORIBA MIRA, Huawei Technologies (UK) Co, Siemens, Vodafone Group Services and the Warwick Manufacturing Group at University of Warwick.

The project will trial progressive vehicle-to-vehicle and vehicle-to-infrastructure applications, such as in-vehicle variable roadside messages based on the C-V2X technology, and later see-through sensing.

C-V2X will be deployed in a temporary spectrum provided by Vodafone but the aim of the project is to develop learnings on how these applications could work using other frequency bands and later technologies such as 5G.

Benefits

- **Improve road safety**
- **Enhance driving experience**
- **Reduce traffic jams**
- **Improve traffic flow**
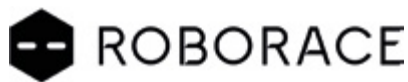
ROBORACE

CASE STUDY

Roborace – Autonomous electric cars

Roborace is currently developing autonomous electric cars that will be used in car racing championships around the world. The solution could benefit from 5G as it would enhance safe operations, create a more dynamic environment and enable new applications within the Roborace experience, such as video broadcasting.

Background information

Roborace is a British self-driving electric car racing concept which was conceived in 2015 by Denis Sverdlov, and backed by the Kinetik fund. The primary aim of Roborace is to provide an open competition platform for the development of autonomous driving (AD) technology.

In 2016 Roborace announced a partnership with the FIA Formula E (i.e. an electric car racing championship) to host events within cities around the globe. Production of the Roborace Ultimate Cars started in 2016 but the company has already conducted a testing programme using development cars nicknamed 'DevBots'. In 2016 these cars completed their first public demonstration at the Marrakech Formula E Championship.

The Robocar

The Roborace Ultimate Car has no cockpit for the driver and as such no traditional control interfaces are required. The cars have more in common with military UAVs than any existing road cars.

The solution is based on a Global Navigation Satellite System, advanced sensors, detection systems and cameras, gathering data on position and environment directly from the car. An artificial intelligence layer built into the cars is then able to interpret this data to control actions of the car and response within the environment. The Roborace Ultimate Cars are hence fully responsible for their technical operation at all times (traditionally steering, throttle and brake inputs).

A mission control centre is located onsite which is connected via a high-speed fibre optic network to several critical infrastructure components. There is also a V2I communications channel which carries real-time telemetry data from each car to a central

processing system. Here it is fused with the data originating from the infrastructure to have global situational awareness of all dynamic objects within the environment. This V2I communication is currently based on a commercially available WiFi standard.

One of the most critical functions is the low latency bi-directional nature of this communication channel which enables mission control to take executive control of the vehicle's operational state to the point of being able to shut down all cars immediately in the event of a serious incident.

Any improvement in the wireless communication layer can be used to immediately enhance safe operations, which would be a key benefit of 5G. Moreover, it would enable a more dynamic environment with a greater potential to interact with the cars at both the tactical and strategic levels by the competing teams.

Next generation mobile technologies such as 5G could also enable more media exposure and entertainment. Enhancing the experience of fans at the events is an essential component for Roborace and the ability for future communication protocols to support low latency, high bandwidth and localised broadcast to spectators' devices will be key.

❝❝ **We are constantly searching for a single communication protocol that combines high bandwidth video, low latency voice and highly reliable packet delivery for critical data. We also need to operate globally and adapt to the available RF spectrum at each city we attend. 5G is perfectly positioned to accommodate all these needs."**

Bryn Balcombe
CTO, Roborace

Challenges

Bandwidth, latency: the wireless communication channel between the cars and the infrastructure is the bottleneck within the communication chain. As soon as there is more bandwidth, lower latency and higher reliability and security, the entire solution could be redesigned enabling more remote control and other functionalities.

CASE STUDY

Audi – 5G technology for automotive

Audi would benefit from the introduction of 5G networks to improve pre-production and production processes as well as post-production maintenance of fleet and vehicles.

Background information

Audi is a German developer and manufacturer of automobiles that focuses on sporty and luxury cars. A large proportion of the production is based at the group headquarters in Ingolstadt Germany, as well as technical development, sales and administration. Audi also has a large network of production sites around the world including Russia, India and China. The company delivered 1.8 million Audi branded vehicles in 2015.

The solution

Audi recognises a number of areas where 5G technology could play an important role, both in pre-production, and post-production (i.e. maintenance and operations) of the vehicles.

When a new car or model is introduced, car manufacturers have to design and plan a new production line system (i.e. pre-production). At this stage it is important to be able to dynamically reconfigure the system and the production line robots to trial and optimise the assembly of the new car as much as possible. Currently car manufacturers have to rely on a cabled fibre network to connect all these robots. A wireless network would significantly increase the flexibility and possibilities for reconfiguration (less restrictions in movement). A very high reliability of the connection is needed for ultra-dynamic reconfiguration, but also for safety reasons when there is human interaction to be able to shut down the system at any time. This quality of service can generally not be offered over WiFi networks in production facilities.

At production stage, car manufacturers like Audi would also welcome 5G networks to support mission critical requirements on the production floor. Thousands of assembly and production line robots generate large amounts of data related to different parts of the car which is uploaded to a central server of the production system. This production system could select and match the most optimal parts (based on specific tolerances) and sends the information back to the production floor to complete the build. Together with fibre communications a 5G network with the ability to support high data rates in Uplink and Downlink direction together with guaranteed quality of service and reliability would introduce flexibility and further optimisation potential in production.

Post-production, 5G networks could also bring significant advantages to support vehicle and fleet maintenance. Audi collects data from test cars over time in their fleet to monitor performance and gather feedback. This enables Audi to identify opportunities for improvement in existing cars (e.g. with automatic lane assist or other driving assistance systems), which they can translate in software updates that are distributed back to all relevant cars in the field. Because of bandwidth limitations, only a limited amount of data can be gathered and returned today. 5G networks could even take this a step further and enable dynamic reconfiguration and update of cars (for which high bandwidth of the connection is paramount).

Finally, Audi also believes that 5G could play an important role to support the introduction of cooperative and autonomous driving. 5G networks could be used both for direct car-to-car communication (e.g. for collision avoidance) and car-to-infrastructure communication (e.g. to enable remote control of cars through edge-computing), where the latency and reliability will be critical for safety reasons.

> **We would welcome 5G networks to support our fleet and vehicle maintenance, for production optimisation and evaluation and to support the future introduction of cooperative driving."**

Jörg Plechinger
Development Mobile Communication

Future

Car manufacturers like Audi are joining forces with the telecom industry to discuss the requirements for next generation networks to ensure alignment. Audi together with other leading automotive and telecommunication industry partners, including Vodafone, is a key founder of the 5G Automotive Association (5GAA) that aims to develop, test and promote communications solutions for the automotive industry.

Energy and utilities

Status of the market

Electricity grids are becoming increasingly complex and have to manage a growing proportion of decentralised electricity generation applications both coming from renewables and edge-of-grid generation. From a consumer perspective, smart meters will become the norm. The EU aims to replace at least 80% of electricity meters with smart meters by 2020. Potentially, this will reduce emissions and household energy consumption by up to 9%[13].

Future 5G networks could be used to enable real-time control of the smart grid, deeper down the network (i.e. low voltage section of the grid, which is often left unmonitored today) and further to the edges of the network (e.g. connecting remote windfarms and edge-of-grid generation points). For several protection and control applications, a latency of only a couple of milliseconds is required, which will be a key advantage of 5G.

5G networks can be used for monitoring and control of the grid in places where fibre networks have not been rolled out yet or where this would be too costly (e.g. rural areas). The resilience and reliability of 5G will give utility providers the confidence to push the technology deeper into the generation and distribution networks. It is also expected that the benefits of more control deeper down the network will trigger efficiency gains.

Potential applications using gigabit networks

- **Grid monitoring:** advanced monitoring systems of the grid (e.g. through sensor network and high-demand capacity imaging) for predictive maintenance or immediate fault location

- **Grid control:** real-time dynamic routing of electricity flows for power flow optimisation (depending on generation and consumption) and ability to restore faults remotely

- **Grid protection:** mobile control of surge arresters which protect low-voltage systems against e.g. over-voltages and high currents (i.e. fault isolation)

- **Connecting remote windfarms:** connecting wind power generated from remote windfarms to the central grid

- **Smart electric vehicle charging:** near real-time communication with charging stations and e-cars, indicating the optimal charging points to keep the grid in balance

- **Control of edge-of-grid generation:** turning generation on and off depending on load of the grid and consumption

- **Accurate forecasting of generation and consumption:** the optimum prediction of the amount of energy created and consumed.

Challenges for the industry

- **Willingness to change:** the energy industry is generally considered as being risk averse and conservative, meaning 5G will have to be stable and technology proven before take-up

- **Willingness to change:** utilities often rely on their own (fibre or copper) networks rather than public networks. This may change with 5G, but will require a shift in business models

- **Harmonised standards:** network control systems are currently not designed to handle large amounts of data which would be generated with more 5G monitoring systems, presenting IT integration challenges.

13 European Commission: Smart Grids and Meters

CASE STUDY

A2A – Smart grids

A2A, a major Italian multi-utility company, is looking to implement solutions for monitoring and control of their substations and for monitoring and real-time control further down their distribution network. Next generation mobile technologies such as 5G could be an important alternative, or complement, to rolling out fibre for these types of applications.

Background information

A2A Group is an Italian multi-utility company which operates in the energy, environment, heat and networks sectors. A2A generates energy from both traditional and renewable sources and operates some of the largest distribution networks for electricity, gas and water in Italy.

Furthermore, the company is involved in waste management activities, including collection and street cleaning, treatment, disposal and recovery of materials and energy.

The commitment of the Group to research and innovation in collaboration with leading research organisations has driven the development of A2A's activities and services. In addition to Italy, the Group has activities elsewhere in Europe, including Spain, France, Montenegro and the UK.

The solution

A2A has commenced with a large programme dedicated to the automation of substations in their electricity grid. Power from generation plants is carried through high-voltage transmission systems to substations where the voltage is transformed from high to low, appropriate for distribution systems.

This transformation takes place in two stages at primary stations and then at substations, progressively reducing the voltage. The Group wants to have advanced automation solutions for these substations enabling better monitoring and real-time control of the electricity flows.

Currently most of the substations of A2A are connected through a GPRS or 3G connection (approximately 2,000 of them) but this does not give the latency and reliability required for some critical applications such as network protection, real-time control (of

e.g. the voltage transformer, the circuit breaker and switches) or automatic rerouting of electricity flows, for which a latency of only several milliseconds is necessary.

A2A is considering replacing some of the existing mobile connections with a fibre link to improve the reliability and latency. A 5G connection could be an alternative solution. As reliability becomes ever more important, the company is also considering whether to have both a fibre and a 5G connection for redundancy purposes.

Next generation mobile networks such as 5G would also enable the company to monitor the network further down the distribution network (i.e. low voltage sections) by increasingly connecting sensors and telemetry devices. It would also enable them to monitor the gas distribution network to identify very small leakages which often remain undetected, improving safety and decreasing potential penalty payments.

❝❝ When 5G communications will become available, it could be an important alternative or complement to rolling out fibre to connect and automate our substations, some of which are quite hard to reach."

Matteo Neri
Head of Business Transformation & Development and Sole Director of Unareti Servizi Metrici, A2A

Challenges

- **Regulation:** there are other applications that A2A would like to implement but the existing regulatory framework prevents the company from doing so. E.g. A2A would like to have more control of edge-of-grid generation but this is not encouraged economically by the regulatory framework in Italy.

CASE STUDY

Iberdrola – Supporting smart grids to deliver sustainable energy

The European markets where Iberdrola operates have high proportions of renewables in the generation mix, which has encouraged the company to accelerate investment and innovation in the latest smart grid technologies. Combining these with future wireless networks like 5G should help to address the most challenging use cases, such as teleprotection of high-voltage networks.

Background information

With over 170 years of experience, Iberdrola is today one of the largest electric utilities in the world and a benchmark for renewable energy. The company produces and supplies electricity to around 100 million people in the countries in which it operates including Iberia and the United Kingdom, serving people and society.

The markets in which Iberdrola operates present particular challenges for utility companies, given their vast potential for renewable generation. Spain has more than 4.7 Gigawatts (GW) of solar photovoltaic plant installed, whilst Scotland has more than 8GW of renewable generation capacity (more than half of gross electricity consumption), and a further 13GW in preoperational development stages today.

These sources are a mixture of major sites and distributed, edge of grid generation, and balancing their input and output necessitates active, smart management of the European electricity grid.

The solution

Iberdrola has invested heavily in metering and monitoring, including Project STAR (Network Remote Management and Automation Systems), an ambitious initiative to transform technology in the field of smart networks. By 2018 Iberdrola will have replaced over 10.5 million meters and adapted ~80,000 transformer centres in Spain.

The centre of the networks (between the transformers and the end-user locations) however are hard to monitor with today's communications solutions – the combined challenges of coverage, power autonomy, Quality of Service (QoS) and security are formidable.

5G networks promise to meet some of the most challenging use cases for the industry:

- **Operations management:** teleprotection (using communications to assist infrastructure protection due to faults, wind/tree damage) requires latency inversely proportionate to voltage, as low as ~5ms for high voltage (HV) networks, and also extensive mandatory redundancy

- **Medium and low voltage grid automation:** historically this was unaffordable, given the QoS and safety critical nature, combined with the challenges of coverage

- **Demand Response (DR):** including peak clipping, load shifting and valley filling

- **Distributed generation:** bringing edge of grid elements into control, to ensure grid stability and power quality (i.e. tolerable frequency, flicker, power factor harmonics).

> **A platform to facilitate the European energy market of the future will require extensive digitalisation, including connectivity solutions that bring new levels of critical resilience, as well as speed, capacity and operational flexibility."**
>
> **Miguel Angel Sanchez Fornie**
> Director Global Smart Grids, Iberdrola

Benefits

- **Improved network resilience:** remote switching and the extension of teleprotection services will enhance grid reliability in extreme weather or unexpected events

- **Operational efficiency:** the ability to monitor the low-voltage distribution networks from the centre will allow operational maintenance/repair strategies that will vastly reduce costs.

Challenges

- **Power autonomy:** networks designed for critical utilities applications require power back-up of hours/days, not minutes

- **Coverage:** Iberdrola's control networks extend to many hard to reach locations – from remote areas of the Scottish Highlands to equipment rooms below the streets Madrid.

CASE STUDY
SUNSEED – Smart distribution grid

SUNSEED[14] is a research project which aims to develop an optimal ICT solution for a Wide Area Monitoring System for Distribution Network Operators. 4G cellular networks are currently being tested in field trials but might not meet capacity and latency requirements of the future applications.

Background information

SUNSEED is an EU FP7 funded research project. The consortium, consisting of nine academic and industrial partners – including Toshiba Research Europe Limited and Gemalto (an international digital security company, HQ in Amsterdam) – proposes a converged information and communication solution for a fully observable smart distribution grid.

Distribution Network Operators (DNOs) have seen distributed generation, energy storage and new loads (e.g. electric vehicles) connecting to their infrastructure which result in new operational challenges such as reverse power flows on lines or changing fault levels. The DNOs with limited observability in the medium and low voltage parts of their network will find it difficult to manage and operate their networks reliably.

Network observability could be achieved by utilising a Wide Area Monitoring System (WAMS) which consists of a network of Phasor Measurement Units (PMUs) reporting using a fast and reliable communication network. The PMUs are already used at transmission network level using fibre optic communications. However the number of primary and secondary substations on the distribution network is approximately 200 times more than that of the transmission side. Use of fibre optics for communications in the distribution network area is today financially unviable.

The solution

In the SUNSEED project, a new WAMS device was developed which is capable of providing GPS synchronised phasor measurements with lower production and installation costs compared with current PMU deployments. Cellular technology, in particular long term evolution (LTE), is being used as the primary communication technology for the WAMS devices.

The project aims to develop an optimal ICT solution in terms of capacity, scalability, reliability and cost-effectiveness.

4G cellular technology is currently being tested via field trials in Slovenia covering both city and rural areas. Initial results from the field show the ability of the WAMS devices in producing real-time grid measurement data with round trip delay of approximately 160ms. This can enable a range of applications for medium/low voltage networks such as steady state estimation.

However, the number of measurement devices in the future energy grid is expected to increase which could create significant communications challenges in terms of capacity and latency requirements. For instance, current LTE standards based solutions may not be suitable to support this massive machine-type communications scenario. Furthermore, in the future control applications such as islanding detection will require lower latency than current LTE technology offers (<100ms end to end delays, including the processing and response), and also improve jitter, which impedes some WAMS deployments using current mobile technologies.

> **We believe that the latency and capacity offered by next generation (5G) cellular network will meet demanding communications requirements of future energy grid monitoring and control."**

Dr. Mahesh Sooriyabandara
Associate Managing Director, Toshiba Telecommunications Research Laboratory, Bristol

Future

The partners in the SUNSEED consortium plan to build measurements and ICT technologies with high reliability to support applications such as complete network observability, demand management and flexible control and protection systems for electricity distribution grids.

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14 Project SUNSEED is funded with support from the European Commission under the Seventh Framework Programme (FP7). This publication reflects the views only of the authors. The Commission cannot be held responsible for any use which may be made of the information contained therein

CASE STUDY

SSEN – Advanced monitoring and control of utility networks

SSEN has implemented a number of solutions for monitoring and control of its networks. As requirements to monitor its network constantly increase, it would benefit from stronger wide area radio and fibre networks, which would enable SSEN to further expand network monitoring and enhance network control functionality.

Background information

SSEN (Scottish and Southern Electricity Networks) is part of the British energy company SSE. SSEN is responsible for the distribution and transmission of electricity to over 3.7 million homes and businesses across the north of the central belt of Scotland and also central southern England. SSEN incorporates Scottish Hydro Electric Transmission (SHET), Scottish Hydro Electric Power Distribution (SHEPD) and Southern Electric Power Distribution (SEPD).

The solution

SSEN has implemented a number of solutions and devices which enable active network management, condition monitoring and adaptive power restoration of electricity networks.

Active network management systems help to manage the quality of supply by controlling connections such as energy generators, renewable generation and storage devices.

Condition monitoring systems rely on a range of devices (e.g. meters, sensors, data loggers, etc.) installed on the transmission and distribution network which continually monitor the condition of assets and feed the information back to the control room. These systems can provide alarms which alert SSEN to potential fault conditions before they have occurred, thus preventing outages or reducing time to restoration.

Adaptive power restoration systems aim to create a self-healing power grid enabling remote reconfiguration of the network from the control room instead of having to rely on manual interventions. These systems can reduce the impact of network faults on the customer by re-configuring supply routing in real time.

SSEN is currently looking at a range of connectivity solutions (including fixed, mobile and satellite) to connect remote devices and components, thus enabling the expansion of automation applications.

A 5G network could unlock significant opportunities, as more devices for monitoring and control could be pushed further down the distribution network. Emerging sensor technologies could mean hundreds of thousands of nodes in the future, so scalability is important both in terms of number of connections and data throughput. Some of the critical network protection and control applications require a latency of no more than a few milliseconds, which means high network performance is essential.

Low power consumption of telemetry connections is key, as well as infrastructure autonomy, because during a power outage the monitoring and control devices are still required to operate and rely on limited battery lifetime.

> ❝ **We would welcome a telecom solution which would provide increased geographical coverage for secure and reliable communications with low power requirements and low capex/opex. We see 5G as a future option worth considering, if available."**

Stephen East
R&D Project Manager, Future Networks

Benefits

- **Fewer and shorter power outages:** remote monitoring and control means power outages can be reduced and even prevented

- **Lower penalties:** electricity companies have to pay significant fines when customers endure power outages. Remote control, fault identification and rapid restoration could reduce this risk.

Challenges

- **Cost:** connecting a large number of devices to the network can become very costly

- **Scalability:** the system will need to be able to handle large amounts of data and an increasing number of devices/nodes being connected.

CASE STUDY
ESB – Smart grids

ESB is looking at a range of solutions for better monitoring and (dynamic) control of their electricity network and would benefit from critical communications support from 5G networks in the future.

Background information

Electricity Supply Board (ESB) is a vertically integrated utility operating in Ireland, which was established in 1927. ESB operates across the electricity market value chain: from generation, through transmission and distribution to supply. In addition, ESB is involved in other operations such as supplying gas, using its fibre network for telecommunications and developing electric vehicle public charging infrastructure.

With a holding of 95%, ESB is majority owned by the Irish Government. The remaining 5% is held by the trustees of an Employee Share Ownership Plan. ESB continuously invests in infrastructure and industry initiatives to bring new offerings and developments to market.

The solutions

ESB has implemented or is looking at a range of solutions which rely on connectivity and could benefit from 5G networks in the future.

Monitor and control low voltage section of the network. ESB has around 250 000 nodes in its low voltage section of the network that continuously need to be monitored in the future (as the Smart Grid develops). Unlike the high voltage section of its network, it would not be cost efficient to deploy dual medium fibre to these locations. ESB is considering mobile alternatives. Future 5G networks would offer the required latency and reliability for remote monitoring but also control for e.g. protection or power flow restoration.

Thermal video monitoring of transformer assets. Transformer assets are responsible for increasing or decreasing electrical voltage in a power grid. The heat generated in this operation causes temperature to rise in the internal structures of the transformer, which is the cause of most transformer failures (following a breakdown of the insulation system). Thermal video monitoring of transformer assets can help to identify hotspots

before failure so that they can be replaced. These thermal video monitoring systems could be connected through future 5G networks as they require significant bandwidth and are often in locations with no fibre alternative.

Dynamic line loading. ESB is looking to deploy sensors alongside its electricity grid which measure the load and the environment (e.g. temperature). Information collected by these sensors could then be used to inform the generators on optimal loads that can be transmitted on the network in real-time (e.g. in cold weather you increase loads). These sensors and generators could be connected through future 5G networks with high reliability and low latency. This would enhance Smart Grid designs.

Expert assistance to field force. ESB is looking at solutions to provide real-time support to electricians in the field, which could transmit real-time video through an HD camera mounted on their helmet. Engineers in a central control room could then provide expert assistance for complex operations, potentially even augmented reality data.

> ❝❝ **The availability of better mobile communication services such as 5G would enable us to connect more nodes and devices to realise Smart Grids in Ireland, and also make better macro decisions in terms of maintenance of our network."**

Noel Rushe
Manager, Strategy and Technology, Telecom Services at ESB

Benefits

- **Predictive maintenance:** the above described monitoring techniques will help determine the condition of in-service equipment to predict when maintenance or replacements should take place

- **Fewer power outages:** hotspots and critical condition of assets are identified before breaking down, leading to fewer power outages. Even in the case of failure, more dynamic rerouting would be possible.

🚌 Public transport

Status of the market

The public transport industry is looking at next generation mobile networks both to improve customer experience over the entire journey (i.e. planning and travelling) and to better run their daily operations.

Customers are increasingly relying on better and more data-intensive infotainment services when travelling on (or waiting for) public transport, such as high-quality mobile broadband or video streaming services. Some researchers even found that the promise of better connectivity would encourage people to take public transport[15]. Customers are also increasingly relying on connectivity to plan their journey and take informed decisions on which vehicle to choose.

Public transport operators also benefit from connectivity to improve daily operations such as dynamic scheduling (based on traffic and passengers) or automated operations. They increasingly aim to monitor and control infrastructure remotely (e.g. condition of trains or buses but also track-side infrastructure) through sensor networks or CCTV systems.

Future 5G networks will provide the required coverage and bandwidth to deliver the services described above, both for passengers and transport operators. The more secured nature of the connection will be an important benefit for critical applications such as automated operations or signalling. In addition, there's a particular benefit for railway operators who are currently relying on GSM-R networks (international wireless communications standard for railways). This standard relies on an outdated 2G network which will have to be replaced as it does not deliver the latency and bandwidth requirements, and 5G networks could be a viable alternative.

Potential applications using gigabit networks

- **Infotainment:** access to on-board information, media and entertainment (including WiFi)

- **Coverage of rail corridors (across borders):** consistent high-quality coverage for a high-mobility environment

- **Signalling systems:** mobile control of signalling systems

- **CCTV for platform clearing:** control room checks if platform is clear instead of driver

- **Automatic train operations:** operational safety enhancement device used to help automate operations of trains

- **Asset monitoring:** gathering of data to predict maintenance requirements for in-service assets

- **Direct passengers for optimal loading:** sensors in trains identify empty coaches and send information to the platform to direct passengers

- **Suicide prevention system:** combination of thermal hotspot and high-quality wireless cameras detecting suicide possibilities.

Challenges for the industry

- **Willingness to change:** the rail industry is very conservative and risk averse. Whilst 5G will improve safety, the industry is hesitant to change 'solutions that already work'

- **Harmonised standards:** differences in lifecycles of rail infrastructure (long) and connectivity equipment (short), impact alignment of technology standardisation

- **Pan-European coordination:** the communications standards for rail are highly regulated (at international level), hence operators will have to wait for 5G to be included in the standard (or request a temporary exemption).

15 The Digitally Connected Commuter, DePaul University's Chaddick Institute for Metropolitan Development, 2015

CASE STUDY

Icomera – On-board entertainment

Icomera has developed a wide range of connectivity solutions for both passengers as well as operators of train, tram and bus services, which rely on high-performing mobile connectivity, and would benefit from the widespread availability of 5G networks.

Background information

Icomera is a Swedish company founded in 1999 by four graduates of the Chalmers Institute of Technology in Gothenburg.

Icomera offers a range of connectivity services and solutions to transport companies such as train, tram, bus and boat operators. The company offers services for passengers such as on-board WiFi, passenger infotainment and real-time passenger information as well as services for transport operators such as fleet management, telematics, and safety and security services.

Icomera has strong working relationships with leading telecommunication industry figures and academics, which drives the design and engineering of their systems forwards.

The solutions

Icomera works with a range of partners to develop several connectivity solutions both for passengers and transport operators, which rely on high-performing mobile connectivity.

Passenger WiFi. Icomera has installed passenger WiFi on thousands of buses, trains and boats around the world. The solution is based on Icomera's mobile gateway technology which acts as a bridge between the vehicle and a mobile network, and creates a mobile WiFi hotspot for passengers. Aggregating 1,000+ passengers' data needs drives large real-time data requirements.

Real-time information. Passengers who have access to real-time travel information – either through in-vehicle displays or mobile apps – will have a better travel experience. The solution uses live data feeds from connected on-board devices to update passengers who are on-board or off-board but planning to join the service.

Fleet management is a service for transport operators enabling them to track the location of different vehicles remotely which can be combined with CCTV-based passenger counting systems to optimise availability of vehicles and dynamic timetables.

Eco driving applications measure speed, brake and idle information and combine this with external data such as surface and weather characteristics, enabling drivers to take informed decisions based on real-time information to reduce fuel and maintenance costs.

Telematics is a service for transport operators enabling them to remotely monitor the on-board network for predictive maintenance purposes and to identify faults. Also, configuration issues can be fixed remotely reducing maintenance times.

Safety and security. Icomera's safety and security solutions enable CCTV footage from both trains and lineside infrastructure to be streamed directly to the operating centre of the transport operator to keep journeys as safe as possible.

Icomera's roadmap

Icomera currently utilises advanced versions of 3G and 4G connections to enable their solutions, and will clearly benefit from the higher bandwidth and performance that 5G will bring.

> **5G is part of the Icomera roadmap as most of our research and development projects have a 5 to 10 year outlook. 5G will enable us to continually meet customer expectations."**

Mike Butler
Business Development Director, Icomera AB

Icomera is involved in many research projects amongst others with the Chalmers University in Sweden looking at solutions working on 5G but also to solve some of the issues, e.g. the need to reduce the environmental impact of future mobile communication systems by intelligently deploying new wireless nodes where users are, in order to optimally use energy and equipment.

CASE STUDY

Network Rail – Future connectivity for trains

Network Rail owns and operates a GSM-R network which supports various applications for monitoring and control of the network. This GSM-R network relies on 2G, which will not be able to cope with bandwidth and latency requirements of future applications, but 5G could be a viable alternative.

Background information

Network Rail (NR) owns and manages most of the rail infrastructure in England, Scotland and Wales and works closely with train and freight operating companies who are running on their infrastructure.

NR aims to plan and operate their network as seamlessly and effectively as possible, as the rail network is getting increasingly busy over time. NR is working closely with suppliers and academic partners to develop new technology solutions and improve operations.

The solutions

Mobile communications are increasingly becoming important for railway operators as they enable various applications which improve railway operations and enhance the travel experience for passengers.

NR plans to deploy a Supervisory Control and Data Acquisition (SCADA) system which monitors train performance and enables predictive maintenance. This system will rely on telemetry devices and sensors which pass the information back to a control room. When dealing with safety-critical detection (e.g. obstruction on the track) it is crucial that information is transmitted instantly to enable corrective actions.

The operator has also mounted video systems on trains which monitor infrastructure such as overhead line equipment or track performance. These cameras can also be used to monitor external factors for e.g. vegetation management or suicide prevention. The amount of data that can be transmitted is currently limited by the communications infrastructure.

NR is running a network measurement train (the so-called 'Yellow Train') which carries advanced detection and recording equipment including scanners, lasers and digital video cameras. This train instantaneously measures the condition of the rail assets and faults (with their exact location). This train generates terabits of data, but none of it is currently transmitted (instead it is off-loaded via a hard disk).

Also highly safety-critical applications such as signalling systems can rely on mobile communications. NR is implementing a European Rail Traffic Management System (ERTMS), where a computer in the driver's cab controls the movement of the train instead of lineside signals, increasing capacity and safety on the railway. A highly reliable, secure and low latency connection is key for the ERTMS system to work safely.

Finally, mobile connectivity is also used to provide internet services to passengers on the train, who are increasingly consuming data in transit. The bandwidth requirements are increasing, especially on long-distance journeys, and can no longer be met by current mobile networks, where coverage is available.

NR currently relies on its own GSM-R network for communications between trains, trackside infrastructure and the control centre. However this standard relies on an outdated 2G network, which will not be able to cope with the low-latency, high-bandwidth and high-reliability requirements as described above. 5G could be a viable alternative and would meet the future requirements.

❝❝**We are currently in the process of establishing an industry programme with university partners to look at the advantages offered by 5G for railway operations in many areas."**

Colin Brown
Chief Architect, Digital Railway

Challenge

- **Regulation**: only designed for existing technologies (GSM-R). HS2 has to be designed according to GSM-R and will later have to switch to 5G.

Security

Status of the market

The physical security industry is a constantly growing market and is highly reliant on connectivity solutions. The global market for physical security equipment[16] was estimated at USD 27.25 billion in 2015, of which 54% is video surveillance products, 22.5% access control products and 23.5% intruder alarms[17]. This market is estimated to reach USD 42 billion by 2020, driven amongst others by increased government spending on security applications to deal with the rise of global security concerns and terrorist threats.

The physical security market is increasingly moving to an all-IP business to improve and extend the service offerings. Next generation mobile networks such as 5G will play an important role as security applications are increasingly wireless and require high bandwidth, e.g. for HD CCTV systems.

Also the low latency can be critical when dealing with near-real-time detection systems where a reduction in the latency of the connection of several milliseconds can free time for hundreds or even thousands of additional searches to be performed.

Given the nature of the applications it is of critical importance that a secured connection is in place, where 5G networks will have a clear advantage over WiFi. At the moment physical security companies are relying to a large extent on Bluetooth and WiFi connections (with high level of end-to-end encryption), but they are starting to explore next generation mobile networks for some of their solutions.

Key customer groups that will benefit from these technological advances are government institutions, such as homeland security and public safety agencies (e.g. police and fire brigades), but also corporates who increasingly rely on physical security solutions for access control and monitoring of their critical infrastructure.

Potential applications using 5G networks

- **CCTV systems:** advanced CCTV systems transmitting several HD and 360° video streams in real time to a control room, to monitor public places or critical infrastructure

- **Automated threat detection:** use of mobile HD video cameras and cloud analytics to detect suspicious objects, patterns, anomalies or disturbances in public places

- **Facial, iris, fingerprint or palm recognition systems:** video or scanning systems which match a face, iris or fingerprint with a database in real time.

Challenges for the industry

- **Data encryption:** this is the most important challenge for the security industry and the basis for all applications

- **Industry collaboration:** physical security companies often provide the physical device and rely on other companies for the end-to-end solution (e.g. connectivity providers, biometric technology developers, etc.), hence industry collaboration will be necessary to investigate the advantages of future 5G networks.

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16 Total world production value of security products (video surveillance, access control and intruder alarm systems) at factory gate prices

17 Source: Memoori, The Physical Security Business 2015 to 2020

CASE STUDY

NEC – Smart security video monitoring

NEC has developed a number of smart security video monitoring solutions for recognition and detection of faces, objects or suspicious activity. In the future these could be connected over a 5G network which would bring significant advantages in terms of bandwidth, latency and security.

Background information

NEC, a global multinational, provides information technology and network technologies that promote the safety, security, efficiency and equality of society. NEC's public business provides public safety and critical infrastructure security solutions for government agencies, local authorities and law enforcement agencies.

Identity and multimodal biometric solutions including fingerprint, face and iris recognition systems are one of the areas where NEC is a leading provider and integrator.

The solution

Historically, monitoring security video was an activity conducted by the human eye where a video stream was either monitored live or could be rewound to monitor retrospectively. Over the past decade, companies like NEC have developed smart recognition and detection solutions within video surveillance, where a live video stream is processed and analysed to identify suspicious patterns or activity, for example:

- Object recognition (e.g. face)
- Pattern recognition (e.g. medical condition)
- Anomaly detection (e.g. unattended bag)
- Disturbance detection (e.g. sudden movements)
- Identification of spikes in congregations.

These systems are used to increase security in public areas by alerting security authorities to anomalies or potential threats.

The camera at the front-end of the system is responsible for the acquisition of the video stream but most of the processing and analysis of the video is run in the back-end on central servers or in the cloud.

Currently most smart wireless video surveillance cameras are connected through Bluetooth or WiFi to a local access point which will forward the encrypted video stream over a wide area network (which could be a 5G network in the future) to central servers for processing (e.g. matching identified face with database, or other 'pattern' algorithms).

Highly secure and reliable connections are critical between the front-end and the back-end of such systems. Video streams continuously increase in quality (for example in observing public gathering places or mass transit locations) so higher bandwidth networks will be beneficial, with wireless providing flexibility and/or redundancy.

Also, the lower latency of 5G networks would bring a significant competitive advantage as it would optimise control and leave more time for real-time processing of the video stream. For face recognition solutions clients of NEC typically require a detection response time of 1–2 seconds or less, meaning that a reduction in the latency of the signal from e.g. 100ms to 10ms would give 90ms extra to perform additional searches. This provides a significant efficiency gain (less hardware, more searches or better process time, hence improved experience).

> **In a report from 2014, the U.S. National Institute of Standards and Technology proved that our facial algorithms can match more than 1 million face searches per CPU core per second. Any reduction in network latency would enable us to enhance overall solution performance when dealing with very large datasets of hundreds of millions of faces."**

Benji Hutchinson
Senior Director, NEC North America

Benefits
- **Improved security:** more efficient monitoring with smart video surveillance systems, with better and faster detection.

Challenges
- **Data encryption:** this is a major concern for security video monitoring as the video streams are for national security purposes
- **Fibre backhaul:** for facial recognition to be processed in the back-end on central servers or in the cloud, fibre backhaul will be required.

CASE STUDY

5Groningen project

The 5Groningen project brings together a consortium of organisations which will explore 5G use cases across a range of industries, from 'smart farming' to 'connected ambulances' in a predominantly rural and economically disadvantaged area in the north of the Netherlands.

Background information

The province of Groningen has experienced numerous earthquakes as a result of subsidence linked to past natural resource extraction. As partial compensation, the Dutch government granted the earthquake region €100 million to promote economic growth. Amongst several initiatives, a '5Groningen' consortium was established that will trial 5G wireless applications across five industries. This is an initiative of the Economic Board Groningen, Vodafone, KPN, Huawei, Ericsson, Dutch Telecommunications Agency, TNO, SURF, and the Universities of Groningen and Hanze.

The solution

The 5G trial is designed to test the widespread benefits of next generation mobile networks across five industries. One use case per industry was selected, which will be deployed in 2017.

Agriculture. The agricultural trial will initially focus on the 'Smart Potato', which will enable potato farmers to better understand and monitor soil conditions. Artificial potatoes will be fitted with low cost, long-life sensors which measure soil conditions such as humidity, acid structure and temperature. Big data analytics will assist farmers in making more educated decisions regarding the treatment of their crops.

Energy. The appearance of more local electricity production sites generating their own power makes it difficult for power companies to balance their grid. The 5Groningen trial will focus on enabling smart grid applications that will help balance the grid in real time. Data, which is collected by numerous sensors, will be transmitted to a centralised control centre that can intervene in real time (e.g. by cutting production).

Sustainable environment. Facing the threat of structural damage from more earthquakes, the project will roll out an earthquake detection system. Thousands of sensors will be deployed across villages in Groningen that will gather seismic data. This will register damage for loss adjustment (i.e. insurance purposes) and could potentially be leveraged to create an earthquake prediction system.

Transport and logistics. Groningen has a large concentration of senior citizens who require assistance when using public transport. The 5Groningen project is looking to test autonomous vehicles that can both increase the mobility of senior citizens, as well as lower the overall government expense to provide this service.

Healthcare. Within the healthcare segment the project will focus on 'connected ambulances'. There is a need for better communication with the ambulance from both the accident site as well as the hospital. In order to assess the benefits of increased communication and information sharing, several mobile network subcases will be tested such as drones dispatch and oversight, live streaming through wearable cameras for first responders and telemetry in the ambulance, and an online switchboard platform that allows bystanders at the scene to provide more initial information through their mobile phones.

❝❝ **We are convinced that the 5G fieldlab will boost our regional economy and make northern Groningen a frontrunner in the application of the next generation mobile technology."**

Marco Smit
Managing Director, Economic Board Groningen

Challenges

- **Additional resources:** in order to expand the scope of the trial and to include more applications, there is a need for additional financial resources and governmental support

- **Securing partners:** the 5Groningen consortium is looking for additional partners who can bring the right systems and equipment to move the trials to the next stage.

Future

From 2017 onwards the trial, with the five applications, will be rolled out. Looking ahead, new use cases and trials will be identified, designed and rolled out. The consortium will remain together on an annual rolling basis.

CASE STUDY

University of Surrey – 5G Innovation Centre

The 5G Innovation Centre conducts ground-breaking research on future 5G networks and has already deployed a live outdoor and indoor '5G testbed' on the campus of the University of Surrey.

Background information

The 5G Innovation Centre (5GIC) at the University of Surrey is the largest UK academic research centre dedicated to developing the next generation of mobile communications. It is part of the Institute for Communication Systems (ICS), within the Department of Electrical and Electronic Engineering.

The Centre brings together academic expertise and key industry partners, including Vodafone, to help define and develop the 5G infrastructure capable of meeting the needs of tomorrow's connected society and digital economy.

The 5GIC vision

The 5GIC vision sets an ambition to enable a world where everything is provided wirelessly to the end device by a fixed and mobile infrastructure that functions across the whole geography, including indoors and outdoors, dense urban centres with capacity challenges, sparse rural locations where coverage is the main challenge, places with existing infrastructure, and also where there is none.

5G research

5GIC carries out its work within a framework of seven key work areas, each of which is led by a dedicated research team working in partnership with industry as mentors. These research projects will be supported by the Centre's live outdoor and indoor testbed to test technologies in a real situation. The key work areas are:

- **Content and User/Network Context:** capture, analysis and utilisation of context data related to content objects, end users and devices, and the network itself. This allows intelligent network control and satisfies user-specific Quality of Experience (QoE). In parallel the research is on new flat architectures based on SDN/NFV and autonomic orchestrator solutions.

- **New Air-interface:** focuses on designing an air interface for dense small cells with the focus on higher spectral efficiency, reduced latency, higher energy efficiency, etc.

- **Light MAC (Medium Access Control) and RRM (Radio Resource Management):** aims to maximise the number of users in a resource limited network and satisfying expected QoE per user with reliable connection

- **Multi-cell Joint Processing:** advanced signal processing (detection and estimation) techniques that maximise capacity in a dense network environment through distributed and co-located MIMO architectures

- **Antennas and Propagation:** focuses on designing novel intelligent antennas to assist in meeting the capacity demands of 5G communications, while also characterising the radio propagation environments in which such antennas will need to operate

- **System Architecture and Coexistence:** focuses on defining system architecture and spectrum sharing schemes to enable the coexistence of users supported by different systems and different spectrum bands (including 700MHz, 3.5GHz, 26GHz frequencies)

- **Testbed and Proof of Concept:** carrying out technology implementation and performance evaluation in a real environment.

❝❝ **5G will intelligently understand the demands of users in real time, dynamically allocating network resources depending on whether the connected device needed voice or data connectivity, and the magnitude and criticality of those demands."**

Rahim Tafazolli
Director of 5GIC and Institute for Communication Systems

Recently, the team at 5GIC demonstrated the first orchestrated, NFV based virtualised 'Flat Distributed Cloud' (FDC) 5G core network architecture.

Future

Researchers at 5GIC are planning to test a radio site of 5G New Radio (NR) in 2017 and they expect to have an end-to-end 5G network on campus by Q1 2018. A C-Ran and LTE-A network is already deployed.

How can we ensure the benefits? 5G policy recommendations

Successful launch and adoption of 5G-based services requires critical mass in order to allow investors a commercially viable business case – wireless networks, mobile devices, smart applications and digital services need to be established on a pan-European level, with corresponding investment policies supporting available infrastructures like fibre backhaul. This in turn requires coordinated timing for the launch and rollout of 5G network services across Member States, giving consumers, enterprise users, device manufacturers and integrators confidence that 5G can deliver reliable services everywhere they are needed.

We see five policy areas to address if we are to ensure that 5G yields a positive outcome for Europe.

1. Spectrum policy reform

The emergence of 5G requires a new approach to spectrum policy. This should involve the coordinated licensing of new 5G spectrum across the EU, under predictable and affordable conditions, allowing timely launch in each Member State, and ensuring wide availability of services. Spectrum policy reform should also ensure fair and non-discriminatory spectrum auctions and prevent auction designs that prioritise state revenues over ensuring infrastructure deployment and service availability for citizens.

Policy should focus on the liberalisation, refarming and defragmentation of existing bands to support 5G, extension of licence terms (perpetual licences, or up to 30 years), and a harmonised approach, otherwise pan-European services will be imperilled.

Any 5G coverage obligations should reflect the likely evolutionary approach to 5G as set out in this report, as rollout will be driven by a number of different factors depending on the requirements of the industry and also the underpinning societal drivers of change. The fact that 5G will complement existing technologies and can build upon existing investments means that targets for deployment and incentives should be designed in a manner that reflects the evolutionary nature of the technology, and set at the right level. Initially at least, this is likely to involve targeted 5G coverage plans, such as major cities, industrial zones and transport routes.

Given the need for enhanced coverage, including rural coverage, to support a number of other 5G innovations, reforms to planning or administrative rules to better reflect the small size of antennae will also be needed. Support from local authorities to facilitate the building of denser mobile infrastructure will be required, including access to public buildings and public transport routes.

2. Effective regulated access to fixed passive infrastructure to support fibre backhaul

There is a clear read-across between the increased network demands associated with 5G traffic (both in terms of total traffic but also resilience and reliability) and the need for fibre. Unless mobile operators are able to cost-effectively deploy fibre to backhaul more demanding 5G traffic from radio sites to core networks, the availability benefits of spectrum reform will count for little.

To facilitate fast and cost effective fibre deployment, Europe needs effective regulated access to the passive fixed infrastructure that has already been deployed, such as ducts. A number of important regulatory steps have already been taken to facilitate access to passive infrastructure[18]. However, it is important to build on this to create a well-functioning access regime in practice, with no access bottlenecks. Specifically, national administrations must ensure that duct access is unrestricted, available on a non-discriminatory basis and combined with effective dispute resolution procedures. These are important implementation points if the Gigabit Society vision, which of course envisages low latency and reliable performance delivered by robust, future-proof fixed and mobile technologies, is to be realised.

Governments also have an important role to play in facilitating the deployment of passive fibre infrastructures in the first place. Public subsidies should be primarily directed at rolling out open fibre connections to base stations in unprofitable areas to speed up 5G coverage in less accessible areas.

3. Enabling efficient network management and encouraging the development of innovative services with specific quality needs

As 5G will allow the dynamic configuration of networks and resources to address a wide variety of demands from European enterprises and consumers, a reasonable regulatory approach on how to deal with effective quality differentiation is required. Existing EU regulation in this area (the Open Internet Regulation)[19] does not sufficiently reflect 5G's ability to adapt to the end-user's specific requirements (for example latency, data rate, availability and reliability) and offer enhanced, tailored capabilities. Therefore 5G traffic management will revolve around the needs of the provider and, in a more profound way, the receiver – and should not be agnostic to these requirements.

To fully realise the benefits of 5G, the currently envisaged 'Innovation by Permission' regime requiring case by case regulatory approvals of each new managed service needs to be avoided. The pace of innovation will inevitably be too fast for regulatory regimes to keep up with requirements. National regulatory authorities should therefore adopt a sufficiently flexible interpretation of the 'necessity' of traffic management assessed from the perspective of the needs of the service provider and the end user.

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18 For example, Cost Reduction Directive

19 Regulation (EU) 2015/2120 of the European Parliament and of the Council of 25 November 2015 laying down measures concerning open internet access and amending Directive 2002/22/EC on universal service and users' rights relating to electronic communications networks and services and Regulation (EU) No 531/2012 on roaming on public mobile communications networks within the Union, **http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R2120&from=EN**

An approach reliant on 'assessing sufficient network capacity' in determining whether a specialised service is permissible or not also potentially creates barriers to innovation as there is no regulatory benchmark against which to measure what the general quality should be, or what is sufficient, which is of course an ever changing standard given network investment. A restrictive approach on this point would be at odds with the dynamic ability of 5G network slicing to respond to changes in end-user traffic management requirements.

4. Sustainable market structures

The investment required to deliver 5G but also fibre across Europe in the coming decade is substantial, and will clearly require investment from private investors. In this environment, which will necessitate ever more capex intensive deployment of ubiquitous and dense network architectures, it is important that competition policy is cognizant of the fact that there is even more of a trade-off between the level of investment and the number of operators a market can sustain. Network sharing will not be enough, and major investment commitments will be imperilled by unpredictable market outcomes arising from unstable or unsustainable competitive environments.

5. An innovative government policy to promote the digitalisation of industry sectors

5G will be the first mobile technology that has been developed both with and by the end-user vertical industries. One such example the cooperation between automotive manufacturers and telecommunications operators to achieve widespread rollout of connected car applications[20]. This approach needs to be accompanied by a similarly innovative approach to set government policy which facilitates the digitisation of these vertical sectors. The safety-related connected car applications highlighted in this report may not be realised without government intervention to mandate these services on public safety grounds.

Proactive government policy can also facilitate innovation and investment in the aviation sector, through the integration of beyond visual line of sight drone operations into civil airspace. This will help unlock a variety of new uses for drones, to the benefit of the economy and society as a whole. At the same time, the right regulation can address a number of associated safety and security requirements, such as those related to the identification, monitoring and control of drones. By embedding connectivity into drone operations (via the inclusion of a SIM in the drone) licensed mobile technology has an important role to play. A harmonised pan-European approach to the management of drones in civil airspace is evidently essential for this sector.

Finally, organisations in the healthcare sector adopting 5G-based services can harness the benefits within their organisations and in partnership with private sector partners. A government policy that requires the public sector to harness the benefits of 5G will be instrumental in achieving the Gigabit Society vision.

Conclusion

Europe has much to offer – including leading research institutes, for example Surrey 5GIC, TU-Dresden, King's College, Imperial College and Napier University who all proactively contributed to this study, but also significant equipment vendors and ecosystems of smaller scale innovators.

Europe must act collectively to create the necessary investment incentives and end user demand, and in concert with other regions to ensure interoperability and economic gain through network effects, but must also place itself at the vanguard of 5G to maintain long term technological and economic competitiveness.

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20 See for example the 5GAA (**http://5gaa.org**), a consortium of automakers, information and communication companies and telecommunications operators to develop, test and promote communications solutions, initiate their standardisation and accelerate their penetration to address society's connected mobility and road safety needs with applications such as autonomous driving, ubiquitous access to services and integration into smart city and intelligent transportation.

Annex 1: Technological characteristics of 5G

Characteristic	Explanation of design characteristic	Unit	5G target design value
Area traffic capacity	Total traffic throughput served per geographic area	Mbit/s/m2	0.1–10
Availability	The network availability is characterised by its availability rate X, defined as follows: the network is available for the targeted communication in X% of the locations where the network is deployed and X% of the time	% (of locations and time)	99.999%
Battery life	Battery life of (low power monitoring/M2M) device connected to the 5G network	Years	Up to 10 (For low power IoT devices)
Connection density	Total number of connected and/or accessible devices per unit area	Devices/km2	10k–1m
Latency	The contribution by the radio network to the time from when the source sends a packet to when the destination receives it	Ms	1–10
Mobility	Maximum speed at which a defined QoS and seamless transfer between radio nodes which may belong to different layers and/or radio access technologies (multi-layer/-RAT) can be achieved	Km/h	350–500
Network energy efficiency	Energy efficiency refers to the quantity of information bits transmitted to/received from users, per unit of energy consumption of the radio access network	Improvement over 4G standards	x1 to x100
Peak data rate	Maximum achievable data rate under ideal conditions per user/device	Gbps	1–20
Position accuracy	Ability to determine network based positioning in three-dimensional space	Metres	10 to <1m (in 80% of occasions) <1m (indoor)
Reliability	The amount of sent packets successfully delivered to the destination within the time constraint required by the targeted service, divided by the total number of sent packets. Reliability rate is evaluated only when the network is available	% (of packets)	99.999%
Spectral efficiency	Average data throughput per unit of spectrum resource and per cell	Times 4G value	x1 to x3
User experienced data rate	Anticipated achievable data rate that is available ubiquitously across the coverage area to a mobile user/device	Mbps	10–100

Sources: Recommendation ITU-R M.2083-0; NGMN alliance whitepaper 2015; 3GPP R14 Study item

Annex 2: Glossary

Abbreviation	Definition	Type
4K	Horizontal resolution on the order of 4,000 pixels	Technology/standard
5G NR	5G new radio	Technology/standard
5GEM	5G enabled manufacturing	Service
8K	Horizontal resolution on the order of 8,000 pixels	Technology/standard
AI	Artificial intelligence	Service
AR	Augmented reality	Service
CCAV	Centre for Connected and Autonomous Vehicles	Organisation

Annex 2: Glossary continued

Abbreviation	Definition	Type
CCTV	Closed-circuit television	Service
CHAP	Centre for Crop Health and Protection	Organisation
CPU	Central processing unit	Common industry acronym
CT	Computerised tomography	Technology/standard
CTO	Chief technology officer	Position
C-ITS	Cooperative intelligent transport systems	Technology
C-RAN	Cloud-based radio access network	Technology/standard
C-V2X	Cellular vehicle to everything	Technology/standard
DNO	Distribution network operator	Value chain role/position
DR	Demand response	Service
Durability	The ability for a connection to be long-lived, or dormant and then woken over a multi-year period	Common industry term
eMBB	Enhanced mobile broadband	Service
EMG	Euro Media Group	Company
ERTMS	European rail traffic management system	Technology/standard
Flicker	Voltage drop in an electrical network, generated over the source impedance of the grid by the changing load current of an equipment or facility	Common industry term (measured by international electro-technical standard IEC 61000-4-15)
Gb	Gigabit (1Gb = 1,000Mb = 1000,000Kb)	Unit
GB	Gigabyte (1GB = 8Gb)	Unit
Gbps	Gigabit per second	Unit
GHz	Gigahertz	Unit
GPRS	General packet radio service	Technology/standard
GPS	Global positioning system	Technology/standard
GSK	GlaxoSmithKline	Company
GSM-R	Global system for mobile communications – Railways	Technology/standard
GW	Gigawatts	Unit
HD	High definition	Technology/standard
HGV	Heavy goods vehicle	Common industry acronym
HV	High voltage (electricity networks)	Common industry acronym
Hz	Hertz	Unit
ICT	Information and communication technology	Industry
IoT	Internet of things	Service
IP	Internet protocol	Technology/standard
JLR	Jaguar Land Rover	Company
LAN	Local area network	Technology/standard
LIDAR	Light detection and ranging	Technology/standard
LTE	Long term evolution	Technology/standard
LTE-A	LTE-Advanced (major enhancement of the long term evolution standard)	Technology/standard

Annex 2: Glossary continued

Abbreviation	Definition	Type
M2M	Machine-to-machine	Technology/standard
Mb	Megabit (1 Mb = 1,000Kb)	Unit
MB	Megabyte (1MB = 8Mb)	Unit
MBB	Mobile broadband	Service
Mbps	Megabits per second	Unit
Ms	Millisecond	Unit
MIMO	Multiple-input/multiple-output	Technology
NB IoT	Narrowband internet of things	Technology/standard
NFV	Network function virtualisation	Technology/standard
NR	Network Rail	Company
OEM	Original equipment manufacturer	Value chain role/position
Pacing	Consistency of delivery rate, ensuring that data packets arrive in order	Common industry term
PMU	Phasor measurement unit	Unit
Power factor harmonics	Harmonic voltages and currents in an electric power system are a result of non-linear electric loads, and can cause quality issues in networks	Common industry term
QoS	Quality of service	Common industry acronym
RAN	Radio access network	Common industry acronym
Resilience	Guarantees that packets are delivered within a certain timescale	Common industry term
RF	Radio frequency	Common industry acronym
SCADA	Supervisory control and data acquisition	Technology/standard
SDN	Software defined network	Technology/standard
SEPD	Southern Electric Power Distribution	Company
SHEPD	Scottish Hydro Electric Power Distribution	Company
SHET	Scottish Hydro Electric Transmission	Company
SSEN	Scottish and Southern Electricity Networks	Company
TIME	Telecommunication, information, media and entertainment	Common industry acronym, Arthur D. Little Department
Tolerable frequency	Acceptable range of frequencies in an electricity supply network, defined in standards such as EN 50160 for some European countries	Common industry term
UAV	Unmanned aerial vehicle	Common industry acronym
UEFA	Union of European Football Associations	Organisation
UHD	Ultra-high definition	Technology/standard
UKCITE	UK Connected Intelligent Transport Environment	Organisation
USD	United States dollar	Currency
V2I	Vehicle-to-infrastructure	Service
V2V	Vehicle-to-vehicle	Service
V2X	Vehicle-to-everything	Service

Annex 2: Glossary continued

Abbreviation	Definition	Type
VR	Virtual reality	Service
WAMS	Wide area monitoring system	Service
WAN	Wide area network	Common industry acronym