The Road to 5G: Drivers, Applications, Requirements and Technical Development

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November 2015

A GSA Executive Report from Ericsson, Huawei and Qualcomm

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Acknowledgements

This report benefits greatly from the insights and experiences kindly contributed by the GSA's members and community, in particular, the Executive members Ericsson, Huawei and Qualcomm.

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1. Executive summary

Two significant trends are driving the wireless industry to develop a fifth generation of network technology: the explosive increase in demand for wireless broadband services needing faster, higher-capacity networks that can deliver video and other content-rich services; and the Internet of Things (IoT) that is fuelling a need for massive connectivity of devices, and also a need for ultra-reliable, ultra-low-latency connectivity over Internet Protocol (IP).

A number of distinct application areas can be identified where current wireless networks will struggle to deliver: these include vehicle-to-vehicle and vehicle-to-infrastructure transportation systems; industrial automation and utility applications; wireless health services; consumer and business virtual and augmented reality services; some smart city applications; smart homes and a number of uses for mobile broadband, including the delivery of content everywhere, and the use of wireless networks as the primary broadband access service.

Analysis of applications suggests performance criteria for latency, connection and capacity density, system spectral efficiency and peak throughput per connection will need to be addressed through new technologies. In addition, energy efficiency will need to improve in future wireless networks.

To meet these performance criteria, there is ongoing work in many areas of technology, both as continuous enhancement to LTE networks, and to develop a new radio interface. Research and development to create the next generation of “5G” mobile networks are focused around new radio access technology (RAT), antenna improvements (including beam forming and massive MIMO), use of higher frequencies, and re-architecting of the network. 5G networks will inevitably be heterogeneous networks: they will involve multiple modes and a unified air interface tailored to the needs of specific applications. Network slicing (matching resources to applications in an intelligent way) will be a major feature of a 5G network, as will the use of a new air interface design to make use of spectrum more efficiently, and to meet the latency, throughput and capacity requirements of some applications. In addition, approaches to sharing of network assets and operations will need to be considered by operators.

Access to harmonized spectrum and air interface technology standardization will be essential for a competitive, efficient 5G supply ecosystem to develop: however, timetables for international agreement on spectrum allocation and technology standardization mean that some networks will be labelled “5G” at least two years ahead of the specifications for “fully 5G” networks being finalized. In our documentation we are describing these early deployments as “early 5G” networks. The GSA believes that it is important for the industry to have workable definitions.

We forecast that there will be around 10-15 early 5G networks (exhibiting at least one aspect of network-performance-enhancing technology beyond LTE-Advanced), which will become quickly fully 5G once the standardization process is completed from 2020. By 2025, we forecast that there will be over 270 networks worldwide where there are local or regional areas with full 5G capability.

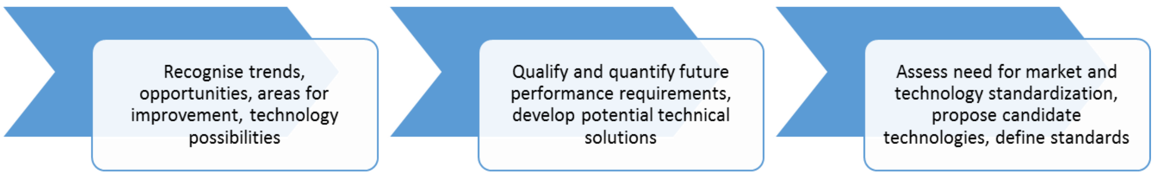
We believe the industry needs to focus between now and 2020 on seeking consensus on approaches to concurrent LTE-Advanced development and 5G radio interface research – in particular demonstrating how assets can be reused. It must also begin to build compelling 5G business models in some specific application areas, focusing on those areas where LTE evolution does not “cut the mustard”.

2. 5G motivations, drivers and opportunities

The telecoms industry is at an early stage in the development of 5G. There is still much life left in LTE networks – with a wide range of standards-compliant network features being developed by vendors and deployed by operators that improve the performance of LTE. But analysis of major trends by many in the industry has led to a consensus that evolution of LTE needs to be complemented with a radical change within the next few years in the fundamentals of wireless networks – a generational shift in technology and architectures and business processes – in order to ensure the industry continues to meet market demand for wireless services as they evolve, and to stimulate new economic and social development.

The three-stage process through which the industry typically progresses can be summarized in the figure below. At present, we are somewhere between the first and second stages. The first stage began in 2012 with the ITU-R's launch of its vision work on "IMT for 2020 and beyond"[1] and the EU's METIS project[2] to begin a 5G definition process, and in 2013 the "5G White Paper" published by NGMA[3].

Figure 1: Three stages of development on the road to a new generation of wireless networks and services



There are two major factors driving the development of 5G: first a need to support increasing demand for broadband services of many kinds delivered over mobile networks, and secondly a desire to support or create services for the Internet of Things (IoT) including for machine-to-machine (M2M) applications. Two classes of IoT-based applications (massive machine-type communication, and mission-critical) can be distinguished. Analysis of these two primary drivers guides service-oriented definitions of 5G, and helps in understanding the technology and other developments that are needed to design, build and run 5G networks.

Mobile broadband

Evolution of cellular network technology has allowed users to experience faster data speeds and lower latency, and has prompted rapidly increasing use of services and applications that are data-heavy. The rapid rise in the volume of data being carried by cellular networks has been driven largely by consumer demand for video and business and consumer moves to the use of cloud services. Many other data-intensive applications – both consumer-oriented and business-to-business – are

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[1] http://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx
[2] https://www.metis2020.com
[3] https://www.ngmn.org/uploads/media/NGMN_5G_White_Paper_V1_0.pdf

also on the verge of emerging. Examples include virtual and augmented reality, 3D and ultra-HD video and haptic feedback applications.

While it has been possible to cope so far with rising data demand (and the industry has been ingenious in dealing with this through traffic optimization and offload on to other networks for instance), it is clear that new capacity needs to be created through use of new spectrum and fundamental improvements to some core wireless technologies, and innovation in the network.

It is important to note that wireless technologies can often more quickly deliver high-speed Internet connectivity to populations currently unserved or underserved by wireline infrastructure; if the economics of future 5G networks can support it, wireless will become the *de facto* means of Internet access for very large numbers of people worldwide – in developing and developed markets.

Internet of Things

The wireless industry has recognized the significance of IoT for some time, and has started work to address the opportunities. Vodafone's work to develop a "Cellular IoT" (CIoT) open standard is one example[4]. A major 3GPP milestone was also achieved in September 2015 with the decision to standardize NB-IoT[5].

Two broad types of IoT application can be identified, with very different characteristics.

Massive machine-type communications (M-MTC)

Applications of this type are characterized by huge volumes of end-points and connections, using low-cost devices and modules for wireless sensor networks, connected home, smart metering and so on. It is possible that applications of this type may start to emerge without a generational change in technology: there is nothing about some of these applications that cannot be handled – on a reasonable scale – by 4G networks. However, it is the ability to handle very much larger numbers of connections efficiently – including in the signalling network – that is prompting development of new networks that will scale more easily. It is generally expected that tens of billions of these devices will be deployed in the next decade, with the number of devices far exceeding numbers of human users of wireless networks. Business Insider's predictions are typical: around 23 billion IoT devices by 2019 [6].

Mission-critical applications

These applications – many of them machine-to-machine (M2M) – are those where high reliability and low latency are essential. Some have been delivered in the past by relatively expensive industry-specific or proprietary networks and IT systems; others are emerging applications, enabled by ubiquitous wireless connectivity, but with stringent requirements for safety or other operational reasons. Examples include connected cars, industrial automation and some applications in health, such as remote surgery.

The potential for cellular networks in these markets is very large if it is possible to meet the performance criteria demanded by potential users.

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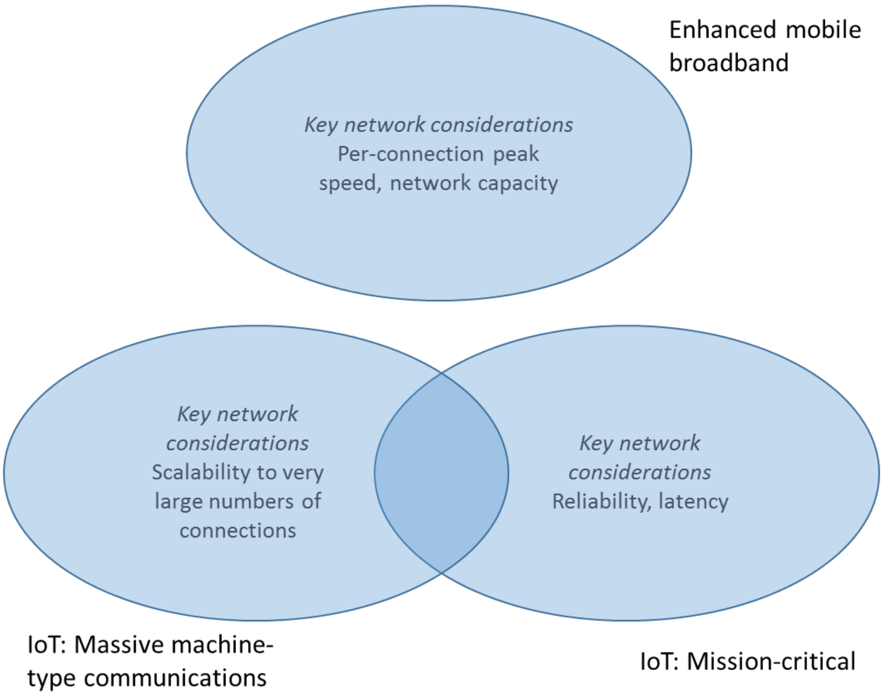
[4] http://www.vodafone.com/content/index/about/what/technology-blog/2015/02/vodafone_extendsits.html
[5] http://www.3gpp.org/news-events/3gpp-news/1733-niot
[6] http://uk.businessinsider.com/how-the-internet-of-things-market-will-grow-2014-10?r=US&IR=T

Other analysis of 5G opportunities

Note that as part of its vision for a future mobile technology, the ITU identifies three broad application areas that closely map on to our analysis – though we consider mission-critical and massive machine-type communications (M-MTC) to be two parts of a broader IoT domain, as many of the vertical-market industrial applications fall somewhere on a spectrum between M-MTC and mission-critical.

Figure 2 shows our classification, which will be familiar to those who have seen the ITU's vision documents referenced earlier.

Figure 2: Classification of 5G applications



3. Why 5G is different

The ubiquity of wireless connectivity, coupled with a standardization on IP as the data protocol, the availability of low-cost and powerful computing resources in the cloud, and increasing data speeds – expected and delivered – are coming together to help shape a vision of 5G.

There is the need to support a clear demand for faster delivery of content to any device, irrespective of location (the heart of the enhanced mobile broadband use cases).

Applications that would have been delivered on specialist networks using dedicated protocols (often in industrial settings) might be delivered using lower-cost ubiquitous cellular networks and with standardized modules and components.

As the benefits of bringing together multiple data sets derived from a deeply connected world become increasingly apparent, for instance, through smart city demonstrators and pilots, data flows of very different characteristics are being brought together and analysed to underpin actions both real-time and offline.

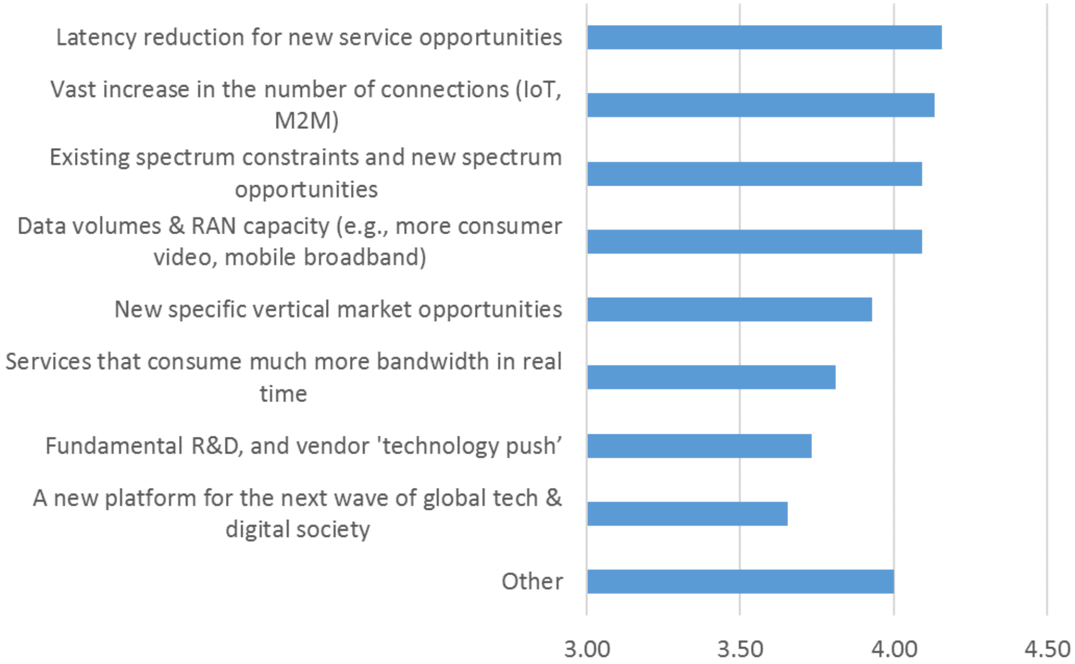
And some completely new applications are starting to emerge to take advantage of advances in technologies of various kinds – including robotics and human-computer interaction.

Some – perhaps most – of the new ideas could be made real using LTE networks, or an evolution of them (the set of technologies known as LTE-Advanced in Releases 12 and beyond of the 3GPP's standards). But some applications require step changes in network performance in certain areas, and many would put a strain even on evolved forms of current networks.

The applications themselves are very diverse, and have different requirements of the network – in particular, in terms of latency, peak data throughput, connection density, throughput density and device power. To maximize its potential, 5G networks will need to meet the varied requirements, and support allocation of resources to different applications in an intelligent way. This is a significant technology challenge, and one we will return to in Chapter 5.

We asked the GSA's online community, through an online survey, to consider drivers of 5G development. Figure 3 indicates how the community rated a number of drivers we proposed in the survey. The "other" category includes the need to increase security, increase ARPU, deliver QoS, improve energy efficiency, provide the user with better usage information, simplify and flatten network architectures, and support increasing customer density in urban areas.

Figure 3: Rate the following drivers of 5G development (5 = extremely important; 1 = not very important). Average scores shown across all respondents (n = 99)



In the rest of this chapter we look at five growing and emerging uses for wireless technology that either cannot be adequately addressed through current cellular technologies, or which require enhancement of current 4G networks. Some have a vertical market focus within which one can identify a number of different specific uses; others are more broadly applicable across consumer and business markets.

We summarize core requirements in graphical form using a radar chart. These requirements form part of a framework for defining 5G that we will return to in Chapter 4.

Transportation

There are multiple types of wireless transportation application being developed, many of them requiring improved performance if cellular networks are to support them.

Vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I) and some other Intelligent Transport Systems (ITS) applications require very low latency – much lower than is currently provided by LTE. Driverless cars and the next generation of driver-assisted cars will need real-time safety systems that can exchange data with other vehicles and fixed infrastructure around them. Alternatives to cellular infrastructure have been proposed, and in the USA the 5.9GHz band has been set aside for the 802.11p standard for dedicated radio spectrum over short range (DSRC)[7]. Collision avoidance systems are expected to require 5ms latency, and 99.999% reliability, according to the EU's METIS project[8]) so current LTE network latency is not good enough. But if the latency issue can be solved, the economies of scale of solutions built on public cellular networks will make V2V, V2I and ITS

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[7] Dedicated Short Range Communication - http://www.its.dot.gov/factsheets/dsrc_factsheet.htm
[8] https://www.metis2020.com/wp-content/uploads/publications/VTCSpring_2014_Shi_etal_SpectrumRequirementForV2VCommunication.pdf

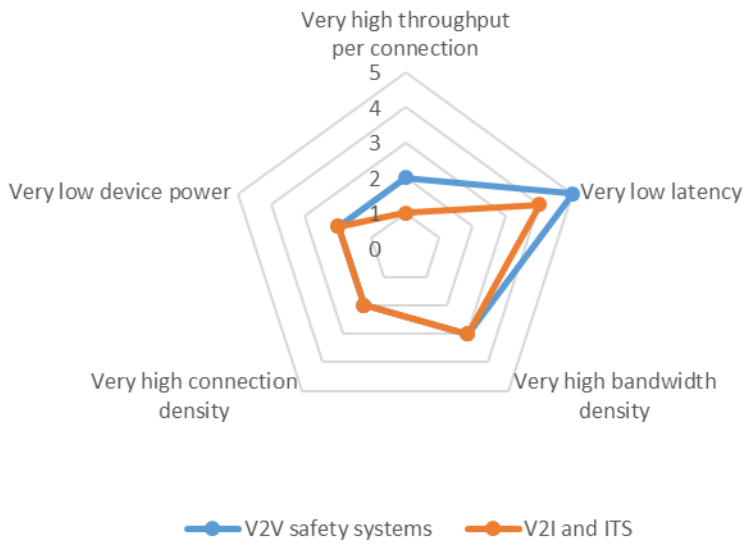
applications much more commercially feasible than using modules and networks dedicated to a single – though large – application area. It is possible that device-to-device (D2D) enhancements to LTE may bring latency down to appropriate values for V2V applications, but baking low latency into the design of 5G networks will help open up this potentially large market for wireless operators.

The connected vehicle market will be extremely large in terms of number of connected end-points and the financial value of the data exchanged with vehicles. Logistics, vehicle telematics and automotive insurance industries using cellular networks as a critical underpinning technology are all well established. Ericsson has a long association with Volvo for the delivery of vehicle telematics and other services, and Verizon and AT&T both have very large telematics divisions. Navigant Research estimated the number of all vehicles on the world's roads in 2014 to be 1.2 billion[9], predicted to rise to 2 billion by 2035; Juniper Research estimates 20% of value of the passenger car market will be accounted for by connected cars by 2019[10] and Analysys Mason predicts that 89% of new cars sold by 2024 will be connected[11]. These vehicles will be concentrated in and around ever-larger cities, so the connection density of connected vehicles is rising and will be an important factor when it comes to dimensioning 5G infrastructures.

In addition to connected vehicles, the transportation sector is a significant market for wireless connectivity in ports, airports, railways and shipping. The applications here, while sometimes industry-specific, include large-file and real-time data exchange, and in the case of passenger terminals, real-time information and entertainment systems and video advertising (digital signage).

Figure 4 summarizes the requirements of two broad areas of transportation applications.

Figure 4: Wireless network requirements for future transportation applications



[9] http://www.navigantresearch.com/research/transportation-forecast-medium-and-heavy-duty-vehicles
[10] http://telecoms.com/424011/connected-cars-forecast-to-be-20-of-car-market-by-2019/
[11] http://www.analysysmason.com/Research/Content/Reports/connected-cars-forecast-Jun2014-RDME0/

Industrial automation and utilities

Industrial automation and robotics is a very active market: the term Industry 4.0 has been coined (initially in Germany, as a government initiative) to define a collection of technologies aimed at improving the efficiency of industry through innovative use of ICT. Three key parts of Industry 4.0 are interoperability and connectedness within and beyond smart factories (an industrial Internet of Things), virtualization (where deep sensor networks monitor physical factories and the resulting data can be used to simulate changes to the physical factory to test new concepts), and real-time capabilities for process control, for instance.

These elements have implications for communications networks, including the end points of the networks. Wireless sensor modules typically need secure, ultra-reliable communication, but must have low power requirements (some are self-powered using energy harvesting). In addition, the greater connectedness of points of the industrial process – both within and beyond the factory, including greater links between digital models, design engineering processes and physical plant, and including the concept of collaborative robotics (human-robot connection at a distance) – mean that communications beyond the factory needs integrating.

Factory automation specialists such as GE, Mitsubishi and SAP have been building industrial IoT platforms (characterized by robustness, and secure protocols developed from traditional automation approaches), but extended to support IP communication over a wider area.

The financial impact of IoT on factories could be huge. A June 2015 report from McKinsey predicts a value from factory IoT applications in areas such as predictive maintenance and operations management of between USD1.2 and USD3.7 trillion in 2025[12].

Within the utility sector, many countries in the world are now moving to a more intelligent power grid (smart grid). Smart grids add the capability to manage power demand more intelligently (both by the consumer and, through tariff incentives, the supplier) – including by reaching beyond the meter or home gateway to devices in the home and consumer apps. Smart grids also enable utilities to deal with distributed generation (often from small-scale renewable energy installations). All this requires two-way communications with very high reliability and very broad coverage at low cost. For protection and control of power grids, very low latency is a requirement.

While existing cellular networks are being used to deliver smart grid connectivity, the extension of the smart grid to more endpoints and to more mission critical applications means that robustness and cost of communication will become an increasingly important factor in the future. Innovation Observatory estimated the value of the advanced metering communications network infrastructure to support smart grid deployments to be around 9% of the total smart grid CAPEX (capital expenditure), and spend on communications services where networks have not been self-built to be USD13 billion per annum by 2025[13].

Figure 5 summarizes the requirements of two broad areas of industrial and utility applications.

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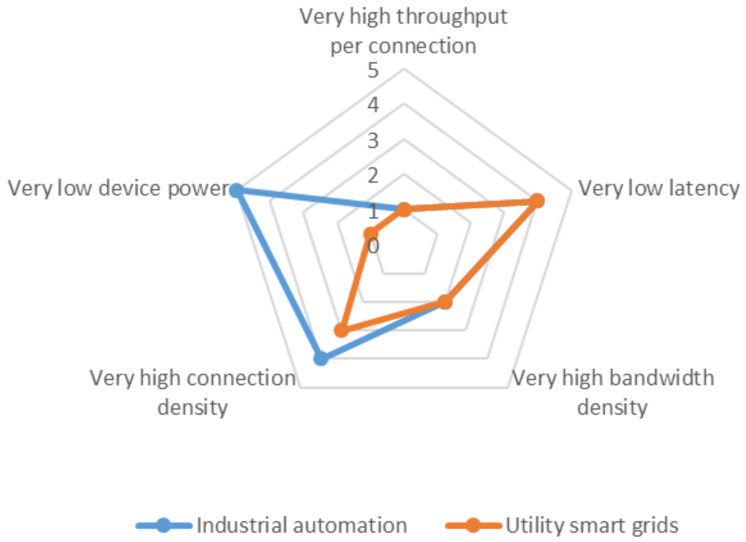
12 http://www.mckinsey.com/insights/business_technology/the_internet_of_things_the_value_of_digitizing_the_physical_world

13 http://www.innovationobservatory.com/content/smart-grid-technology-investment-forecasts

Figure 5: Wireless network requirements for future industrial automation and utility applications



Health

Mobile health application concepts have been developed over many years and some have become widely used. In developed economies, use has centred round personal health records and fitness data, wearable activity tracking, and smartphone-based applications for the monitoring and treatment of long-term medical conditions from mental health problems to diabetes. In developing economies with limited health and wireline telecoms infrastructure, mobile services have enabled the delivery of remote diagnosis and support for paramedics, as well as stimulating new medical devices built on connected mobile platforms. In many countries the mobile network has been a tool to simulate and map disease outbreaks for public health and epistemology research, to assist with asset tracking and to support individuals needing care beyond health service premises.

But faster, more reliable, lower-latency networks open up opportunities not only for wider use of existing applications, and their improvement (for instance through the use of implantable technologies and smart pills, and better visual diagnosis through high-definition video) but the development of new uses such as remote, robotic surgery using VR, AR and haptic technologies and other mission-critical medical interventions. Analysts Technavio forecast the global market for digital health to be growing at around 17% per annum to 2019[14], with growth in the US connected health M2M market even faster at around 29% CAGR to 2019[15]. Analyst estimates of the size of the market for wireless or mobile health globally range from around USD25 billion to around USD60 billion.

Analysts say the market for some types of surgical robots may be nearing saturation in developed markets (though the number of procedures is growing), but advanced communications networks could open up new markets for remote robotic surgery, if network performance is good enough.

Figure 6 summarizes the requirements of wireless health applications.

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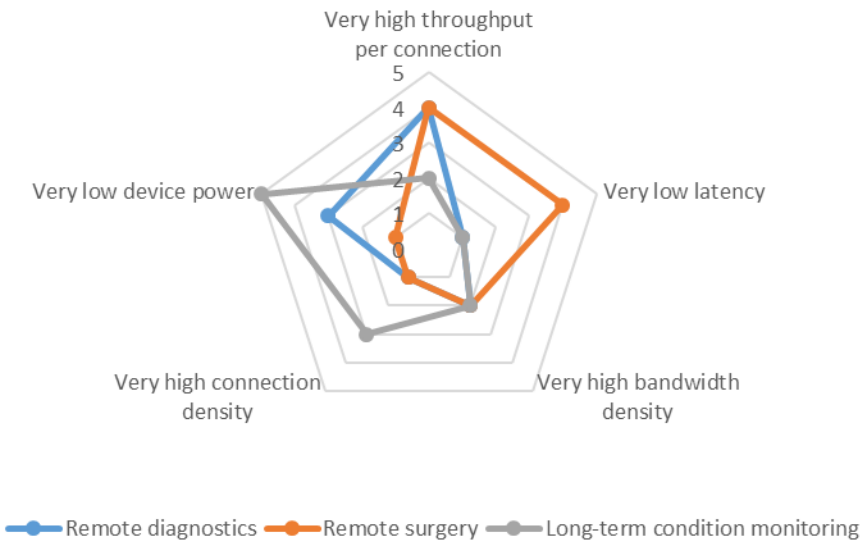
[14] http://www.technavio.com/pressrelease/global-digital-health-market-expected-to-surpass-us-12070-billion-by-2019-says

[15] http://www.technavio.com/report/connected-health-m2m-market-in-the-us-2015-2019

Figure 6: Wireless network requirements for future health applications



Virtual reality (VR) and augmented reality (AR)

End-user devices such as headsets for VR and AR (augmented reality; superimposing a digital view on a physical view), along with haptic sensing and feedback devices (communicating touch from sensors to a user) have been used in the military sector for many years. They are starting to become mainstream in gaming and in other industries where it is important to have a clear, enhanced view of the world around you, or a simulation. The retail sector is once again experimenting with AR and VR virtual showrooms and end-user devices are available at low cost (for example, Samsung's Gear VR headset).

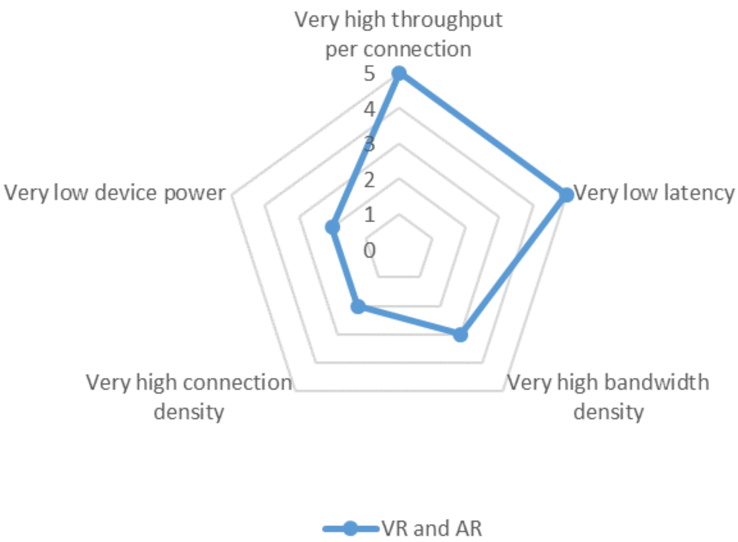
VR and AR require large volumes of data and when headsets and other displays are wirelessly connected networks must support the transport of data with low latencies and high reliability as most of the applications for AR and VR are real-time.

The growth and scale of the opportunity can be judged from assessments made of the games industry: CCS Insight estimated that by 2017, there would be annual sales of VR headsets of 12 million devices, with the value of augmented reality glasses worth USD1.2 billion by the same year[16].

VR and AR devices will mostly be wirelessly connected; there will be a requirement for some uses to be in the wide area. Figure 7 summarizes the requirements of VR and AR applications.

[16] http://www.ccsinsight.com/press/company-news/2251-augmented-and-virtual-reality-devices-to-become-a-4-billion-plus-business-in-three-years

Figure 7: Wireless network requirements for future VR/AR applications



Smart cities

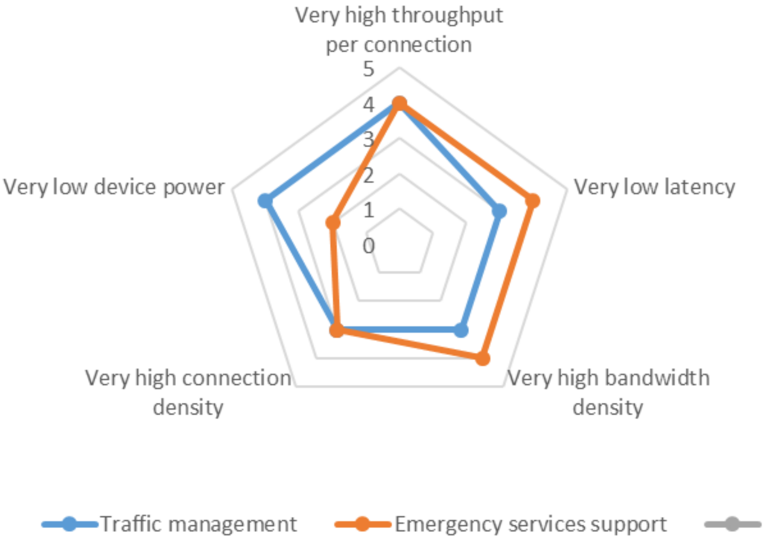
Smart city applications are extremely varied. Indeed, the term smart city is used to describe many different exemplars – though all involve the addition of connectivity and IT to infrastructure, and the development of processes with greater levels of intelligence and automation than previously. In the most compelling examples of smart cities, data from multiple domains (transportation, public administration, emergency services, weather sensing, etc.) are brought together within IT systems that can lead to better planning and better, faster (real-time and automated) responses to changing situations.

Smart cities are generally associated with deep sensor networks – though in most examples these sensor networks have currently been installed to support applications in one or two usage domains only – such as road traffic management and parking. In Santander, a flagship smart city case study in Spain, 20,000 sensors (wireline and wireless) have been installed to support parking and traffic management, energy management, lighting, waste and water services and public information applications. Rio de Janeiro, Brazil, is an example of a city that is (through a long partnership with IBM) attempting to integrate multiple domains of city administration with a highly integrated IT system complemented with deep sensor networks and high levels of automation. Wireless networks lend themselves very well to providing the connectivity needed, especially as installing fixed connections where they do not already exist may be prohibitive in terms of cost and disruption. To support the most ambitious smart city ideas though needs ubiquitous connectivity through a network capable of supporting multiple data flows with varying performance requirements, as efficiently and reliably as possible: some smart city applications are 'mission critical'.

For a brief overview of some smart city projects, see this article http://www.govtech.com/data/The-Rise-of-the-Sensor-Based-City.html.

Figure 8 summarizes the requirements of some individual example smart city applications.

Figure 8: Wireless network requirements for future smart city applications



Enhanced mobile broadband for established applications

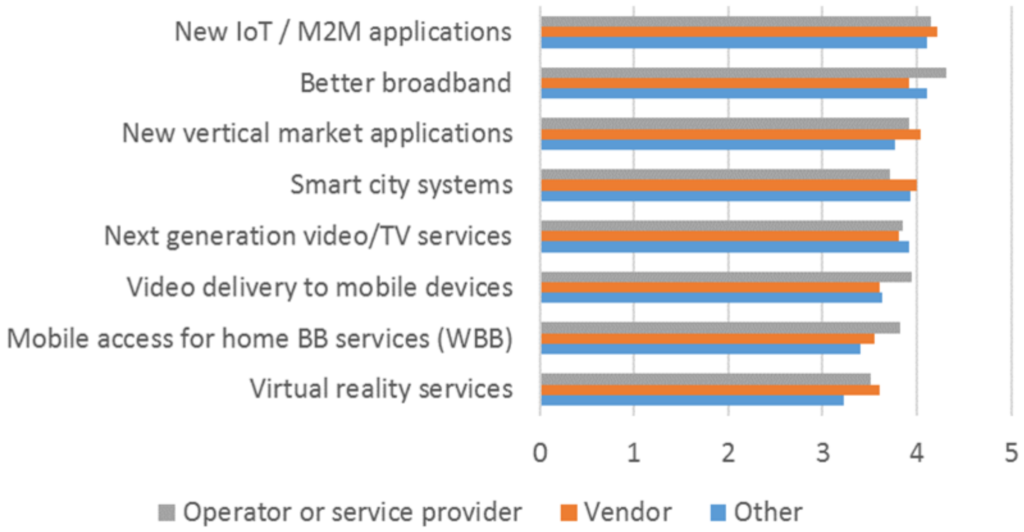
While we see new applications emerging, it is definitely the case that more capacity will be needed in cellular networks to support the continued growth of established mobile broadband services. Experience with LTE networks has shown that the additional cellular connection speed of new mobile networks increases consumption of bandwidth-hungry applications, in particular video (both streaming and download) and other data services. As hand-off between WiFi and cellular data networks become seamless, customer expectations of being able to have a similar experience, irrespective of location, are increasing. Any service delivered over wireline and local-area wireless networks needs to be delivered in the wide area too without deterioration in customer experience.

Ericsson's August 2015 mobility report shows that globally there was 55% data traffic growth year-on-year to Q2 2015 to over 4000 Petabytes per month (uplink and downlink, excluding WiFi, mobile WiMAX or DVB-H); other studies suggest that LTE users consume twice as much data as 3G subscribers[17]. Much of this increase can be attributed to video traffic (both streamed and download).

In our survey of the GSA's online community we tested the relative importance of a number of potential use cases for 5G networks. It was the Internet of Things that topped the list of important use cases for 5G overall, but operators and service providers scored better broadband and video delivery to mobile devices as their top two most important 5G use cases (see Figure 9). There was relatively little difference in the importance of the use cases tested, and little difference between types of respondent. Some additional comments in response to this question suggested a role for 5G in public safety, and to support multiplayer gaming; to create *ad hoc* mesh networks for multiple applications, to slice the network for different uses, and to provide transparent, seamless handover for the user between multiple network types. The ability to use unlicensed spectrum was also mentioned as a driver of 5G investment.

[17] http://www.prnewswire.com/news-releases/lte-subscribers-consume-much-more-data-than-3g-subscribers-264189401.html

Figure 9: How important to you (as an operator) are these potential use cases for 5G (where 5 = will be very important to us and 1 = will not be important to us at all) (n = 27 wireless or converged operators)



As wireless networks increase in capacity and per-user peak-rate and average throughput, the potential for them to provide the primary means of Internet access increases – in particular in places unserved, or underserved, by fast wireline access infrastructure. So when thinking about the potential of future wireless networks it is crucial to consider both mobility and fixed location access.

While 4G networks can and are being used to deliver primary Internet access services (Huawei has made a strong case for using LTE-Advanced for this[18] and Ericsson is using LTE to deliver fixed wireless services in Austria[19]), new technologies will enable greater capacity and the more efficient delivery of services.

[18] http://www.huawei.com/ilink/en/about-huawei/newsroom/press-release/HW_415732
[19] http://www.ericsson.com/news/150716-nbn-and-ericsson_244069645_c

4. Defining 5G

Rigorous definitions of 5G are difficult to make at this stage of the process outlined in Figure 1 earlier, as generational changes in networks have both a technical, network-oriented aspect, and a service and user-oriented aspect. The most appropriate definitions that can be made currently are based on assessment of a set of future service requirements, mapped to network performance parameters. Research and development teams at vendors and universities will then propose ways in which the required performance can be achieved, and the definition will be finally codified in a set of standards agreed by the relevant standardization bodies.

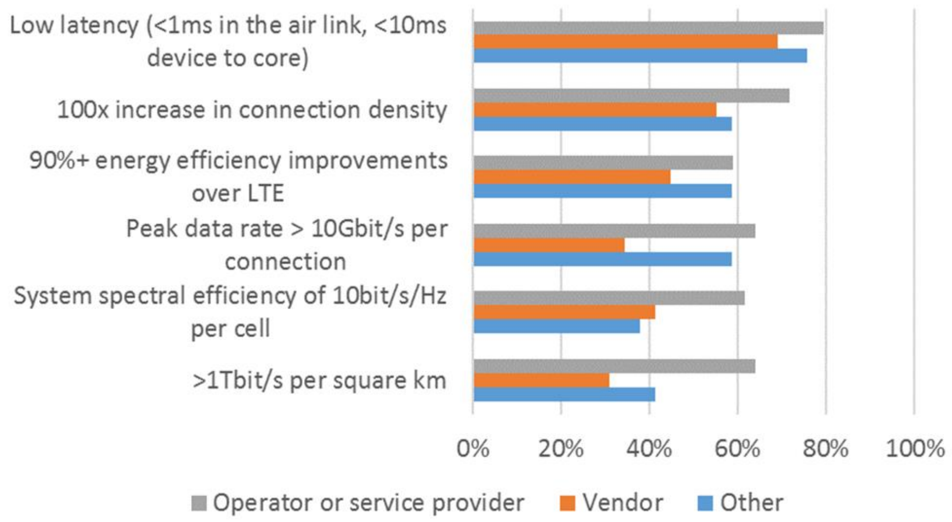
Taking the application requirements outlined in Section 2 as a starting point, the industry has made some progress in discussing network-oriented definitions of 5G, and attaching some initial values to the parameters. Based on discussions with vendors and a review of current discussions on the topic, the GSA considers the values in the table below to be sensible minimum parameters that will define 5G (note that some of these are described relative to LTE network performance, rather than in absolute terms as absolute value will vary a great deal depending on location and network configuration). Many in the industry think 5G will achieve more ambitious values for latency, energy efficiency and perhaps other parameters.

Figure 10: Functional performance criteria for 5G

Parameter	Value
Latency in the air link	<1ms
Latency end-to-end (device to core)	<10ms
Connection density	100x compared with LTE
Area capacity density	1Tbit/s/km^2
System spectral efficiency	10bit/s/Hz/cell
Peak throughput (downlink) per connection	10Gbit/s
Energy efficiency	>90% improvement over LTE

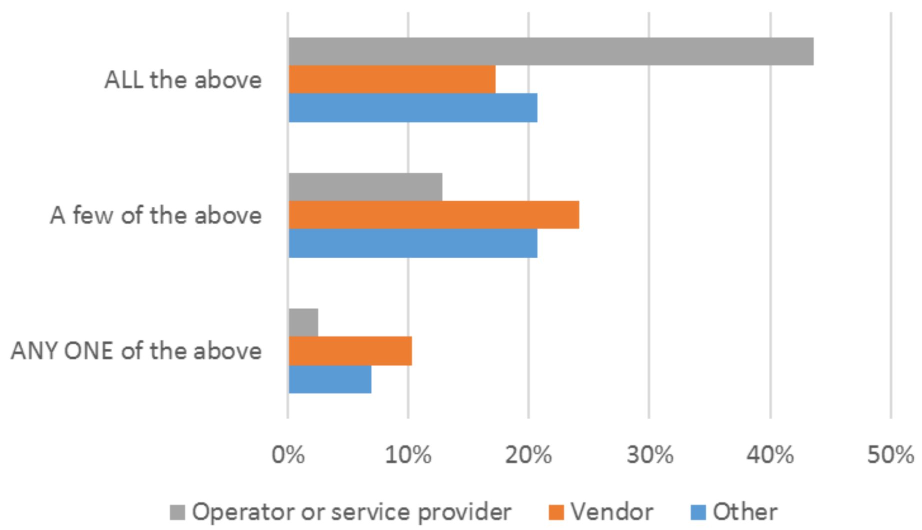
We used these values when testing the relevance of the parameters with our online community. The results are shown in Figures 11a and 11b. The results bear out the belief that latency targets in particular could be more ambitious than those in the table (though it should be noted that latency requirements will vary significantly by application).

Figure 11a: In the coming years, many operators and vendors will claim they have launched or helped to launch 5G networks. Please indicate which of the following you would regard as essential before a network should be considered to be a 5G network. Please choose all that apply (n = 99)



The difference between operators' views of the most important 5G defining criteria and those of vendors and others (regulators, analysts, consultants) is interesting. Many operators believe that networks should deliver against *all* the performance parameters across the board in order to be truly 5G. Other partners in the industry are more relaxed about meeting all the thresholds (see Figure 11b). It is also interesting to note that some operators are happy for the network to meet just one parameter for the network to be 5G.

Figure 11b: In the coming years, many operators and vendors will claim they have launched or helped to launch 5G networks. Please indicate which of the following you would regard as essential before a network should be considered to be a 5G network. Please choose all that apply (n = 99)



If one looks at what has happened with the set of features that are described as LTE-Advanced, it is not necessary for all new features or performance benchmarks to be met in order that the market describes a network as an LTE-Advanced network. Rather, adoption of a few of the key features has come to be equated with LTE-Advanced. The GSA, in tracking LTE market development, takes a pragmatic view of what constitutes an LTE-Advanced network or service, based on operator reporting (typically Carrier Aggregation is a sufficient condition for LTE-Advanced).

This is an important issue. It is worth noting that some of the performance criteria identified in the table in Figure 10 may be achieved through deployment of features of LTE-Advanced: we do not think this would necessarily mean a network was a 5G network.

Performance parameters will not be the only way that a 5G network might be identified. There are two other distinguishing features. First is the step change in heterogeneity that will be apparent. By this we mean that a 5G network is highly likely to encompass multiple frequency bands (as now – but more, including at much higher frequencies), multiple modes (e.g., FDD and TDD) and multiple cell layers. Second, is the development of a new air interface – probably based on OFDM principles, but for which intensive research and development is currently underway.

While various candidate technologies are being proposed to address the performance-based specifications described above, the GSA believes that the two defining characteristics of a 5G network will be:

- the use of a new air interface technology (and associated developments) – using technologies ultimately endorsed by international standards bodies – to achieve one or more of the performance targets in Figure 10, and
- sophisticated network slicing capabilities that match resources to applications in an intelligent way (while this has been started in 4G networks with introduction of SDN and NFV, in 5G networks it will become essential).

In the next section, we look at the progress that has been made as vendors and operators try out potential 5G technologies.

5. Innovation to deliver 5G

There is technology R&D being undertaken to improve all the performance parameters identified in Chapter 4, both as part of an evolution of LTE, and to enable new 5G networks. Examples of LTE-Advanced features that will help achieve the required performance improvements include Carrier Aggregation, Device-to-Device, self-backhauling, Licensed Assisted Access and higher-order modulation schemes (e.g., 64 and 256QAM). “Ultra-lean” radio access design (minimizing transmissions not related to the delivery of user data) is also being applied in LTE networks and will also be important to achieve high efficiency in 5G networks.

In addition, the introduction of network functions virtualization (NFV) in the core and at the edge of the network is helping new architectures to be considered, with operators able to contemplate the dynamic distribution of network functionality to new locations. When coupled with more powerful base station content caching closer to the RAN, this is helping to address some of the most challenging areas of future network performance targets, such as latency.

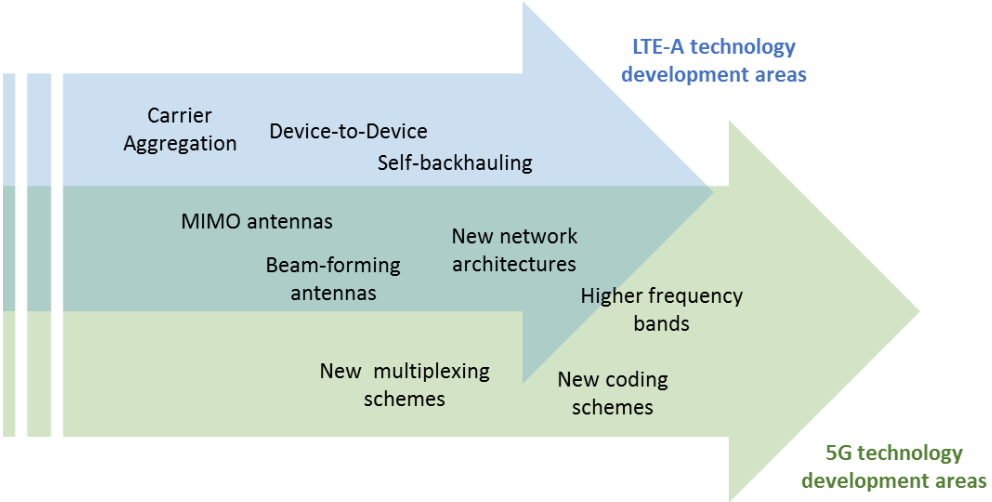
These developments mean that the arrival of 5G *might* not involve a major change in the radio network (a new air interface) – although the consensus among vendors and operators suggests that in order to provide the user experience expected of 5G networks, revolutionary technologies need to be introduced (over and above evolved 4G features) and this *will* require a new air interface. There has been significant R&D effort directed towards the development of relevant technologies such as multiplexing and coding schemes.

5G-specific R&D is focused in a number of key areas: the table in Figure 12 maps these areas to the performance parameters, and Figure 13 shows the inter-relationship between LTE-Advanced development and new 5G R&D areas. In the rest of this chapter we look further at some of the 5G R&D areas.

Figure 12: Research and development technology areas to address 5G performance requirements

Parameter	Technology efforts
Latency in the air link	New multiplexing schemes; new coding schemes, shorter transmit time interval (TTI)
Latency end-to-end (device to core)	New network architectures
Connection density	New multiplexing schemes; new coding schemes
Area capacity density	Higher frequency bands; beam-forming antennas; MIMO antennas
System spectral efficiency	New multiplexing schemes; new coding schemes; MIMO antennas
Peak throughput (downlink) per connection	Beam-forming antennas; higher frequency bands; MIMO antennas
Energy efficiency	New multiplexing schemes; new coding schemes, new control channel structures

Figure 13: Some research and development areas for future wireless networks



Beam-forming and MIMO antennas

Beam-forming antennas, where the radio signal is focused to a narrow beam, help offset the effect of reduced propagation of very high frequency carriers. However, beam-forming antennas at base stations must track the user equipment in order for the device to remain within the beam, and it is likely that RAN CAPEX would be significantly increased if many more antennas were needed to support large numbers of users per cell. Both horizontal and vertical orientations need to be taken into account when designing beams.

In tandem with beam-forming, there has been much work on developing large-scale MIMO antennas. These have the potential to significantly increase the peak throughput per connection in the radio network, as well as increasing coverage. Vendors have demonstrated antennas with 32, 64 and 128 individual antennas per array for instance at Mobile World Congress in 2015 [20].

Signal interference issues with MIMO antennas are being addressed through LTE-Advanced features such as Coordinated Multipoint (CoMP) and Further Enhanced Intercell Interference Coordination (FeICIC).

Use of complementary higher frequency bands and new multiplexing and coding schemes

These two areas are among the most active areas of R&D focus for 5G and together constitute the creation of a new air interface. A great deal of effort is being made to develop the use of frequency bands above 6GHz (including those referred to as millimetre wave, i.e., above 30GHz) because the available spectrum of these bands is greater than those at lower frequencies. High-frequency carriers will help deliver enhanced mobile broadband services to more people.

The use of higher frequencies is closely related to the antenna developments mentioned above, but there is also work on the development of advanced waveforms – based on the familiar orthogonal frequency-division multiplexing (OFDM) but with enhancements such as filtering at the PHY block level to reduce latency and increase capacity. There is also the possibility that non-orthogonal

[20] http://www.ericsson.com/research-blog/5g/massive-beamforming-in-5g-radio-access/

multiple access approaches could be used (NOMA has been proposed by DoCoMo, and Huawei for instance is developing Sparse Code Multiple Access). Though the basic OFDM scheme used in LTE could remain very similar for 5G, a requirement for backward compatibility would put restrictions on full implementation of the enhancements described above, which would ultimately limit the latency, capacity and throughput of the radio network.

Much of the development work on new waveforms is under evaluation in university research labs as well as at technology vendors' and wireless operators' R&D facilities. Future GSA papers will look more closely at this work.

New network architectures

To reduce latency, both the speed of digital processing needs to increase and the distance that signals have to travel through the network and back need to be reduced (as there are limits to the speed of signal propagation). This has implications for where processing takes place (for instance, separation or integration of baseband and radio frequency processing at base stations), and the location of content.

Understanding of use cases is required before appropriate architectures can be drawn up: for instance, extension of traditional broadband services – but faster, and to more people – does not require the same architectural shift as supporting "chatty", connectionless IoT use cases where very low latency and more efficient signaling will be required.

Work underway within LTE networks to introduce network function virtualization (NFV) means that new network architectures can be considered more readily as capabilities can be physically distributed in more locations, including at the base station. NFV (and Software Defined Networking – SDN) will also support the architectural change needed in the way networks are managed: fundamental to 5G will be the need to configure multiple logical networks on the same physical infrastructure so that the different opportunities can be properly and quickly addressed without multiple network overlays needing to be built.

Because there will be a mix of frequencies used for different applications in 5G networks (where those applications and their devices will have very different characteristics), there will also need to be intelligent ways to create application-specific network slices. It is not yet clear where this intelligent control will reside (whether in existing wireless network systems, or in a new management layer).

In part because of the heterogeneous nature of 5G access networks, the concept of distinct cells will disappear, to be replaced by "edgeless connectivity", or a user-centric virtual cell connected simultaneously to other devices, and through multiple hops to different networks. Qualcomm is among the vendors to have neatly articulated this architectural shift in its 5G Vision Paper[21].

[21] https://www.qualcomm.com/documents/whitepaper-5g-vision-next-generation-connectivity

6. Spectrum issues

We have seen above how the use of higher frequencies is a major part of 5G development. However, those frequencies – as with all radio spectrum – constitute a valuable resource over which different competing interests have a claim. The wireless telecoms services community needs to make a compelling case for access to those frequencies in the face of competition from existing users.

It is by no means certain that wireless operators will, in any reasonable timeframe, be given access to enough new spectrum to implement the 5G technologies being developed. Harmonization of spectrum allocation across regions and countries (which is extremely important for the development of technology as it has a large impact on economies of scale, and the incentives for equipment vendors to develop products) is handled by the ITU's World Radiocommunications Conferences (WRC). This year (2015) WRC will consider the use of frequencies up to 6GHz for future wireless networks, but consideration of higher frequencies will not be looked at until 2019.

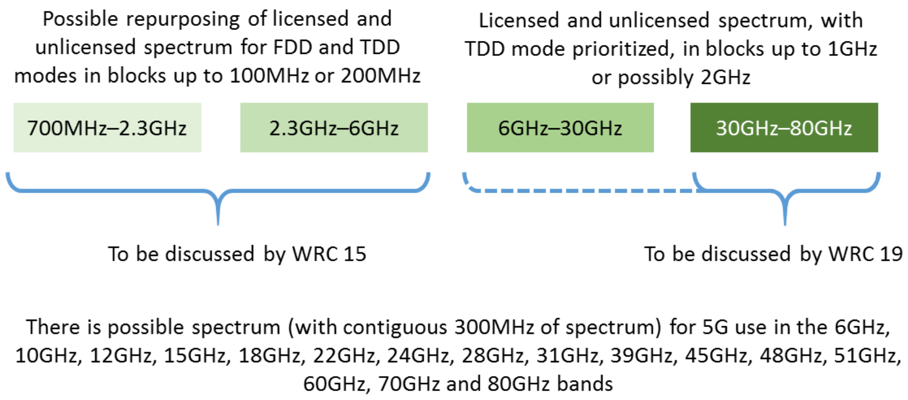
In the run-up to these important events, different national spectrum licensing bodies around the world have been making proposals for how spectrum should be allocated. Details of national proposals is beyond the scope of this paper; however, the GSA is looking into the issue of spectrum for 5G and will publish more information in due course.

While it is widely accepted that 5G networks will make use of spectrum in existing wireless communications networks bands up to 6GHz, and from 30GHz and upwards, one issue to be decided is the use of spectrum bands between 6GHz and 30GHz. Some national bodies (for instance Ofcom in the UK) have suggested considering spectrum from 6GHz as candidate bands for 5G; in the US, the FCC has suggested looking only at frequencies from about 24GHz.

This uncertainty, and the long timescales for agreement on spectrum use, are already having an impact of 5G development: NTT DoCoMo's 5G development plans are focusing in the first instance on what can be achieved with sub-6GHz spectrum. It is progressing research at higher frequencies with multiple vendors.

Based on our understanding of the industry's position on spectrum, Figure 14 illustrates possible spectrum allocations for discussion at the WRC '15 and '19 events. Note that at the time this report went to press, WRC '15 had started but was not completed. The GSA will discuss 5G spectrum issues further in future reports.

Figure 14: Possible scope of WRC '15 and WRC '19 5G spectrum discussions



7. Standardization issues

As we have seen in Chapters 2 and 3, defining 5G is a particularly difficult challenge as it is not yet clear whether an air-interface-based, technology definition or a service-oriented definition makes most sense. As we pointed out in Figure 1, standardization tends to happen quite late in the evolution of a new generation of wireless networks and services once the industry agrees what makes sense to standardize.

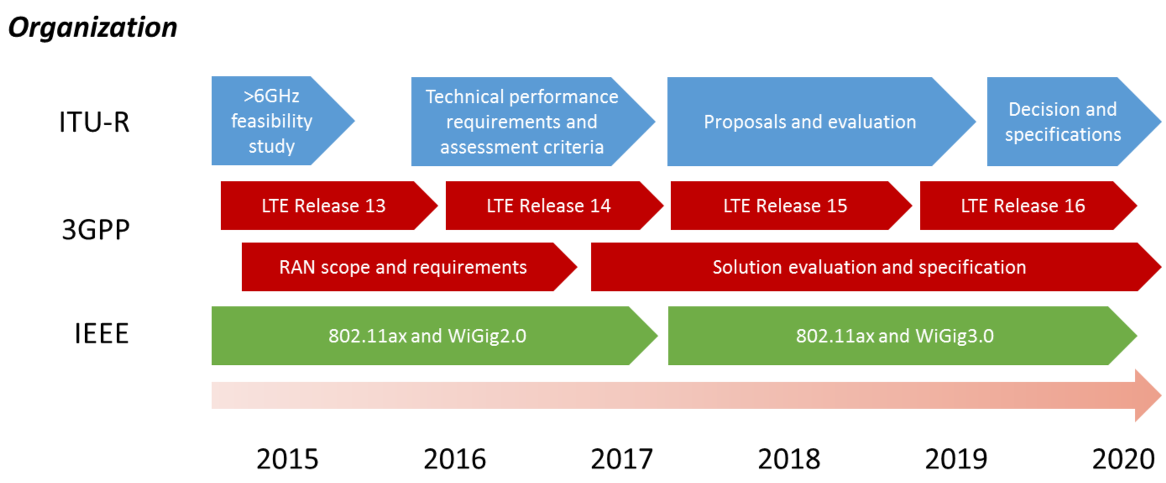
In addition, because several of the technologies that will help wireless networks to achieve the performance targets outlined in Figure 10 are being developed for existing LTE and LTE-Advanced networks, there is a sense that standardization, at least by 3GPP, is a continuous process.

One needs also to consider that as 5G networks are likely to be heterogeneous, the work of standardization bodies other than 3GPP and ITU-T / ITU-R are relevant. For instance, the IEEE sets technical standards for WiFi, and it is quite likely that WiFi could be integrated into a 5G network.

Relevant standards bodies both regional and global have set out timetables for their work, and these timetables are significant in the development of 5G even though the industry is likely to agree working definitions of 5G ahead of standardization. Commercial deployment timetables driven by external events are likely to require some form of industry standards by 2018 ("early 5G") if commercial networks are to be launched by 2020 – which is what several major operators want (particularly in South Korean and Japan; operators may use 5G as a term by this time in any case). The standardization processes of 3GPP and the ITU-R are likely to set the timetable for standardization of "fully 5G" not before 2020 (though it is likely that the 3GPP may not use the term 5G in its standards). The difference in our definitions between early 5G and fully 5G hinges on the use of >6GHz spectrum and all that this entails by way of new RAN technologies.

Figure 15 summarizes some of the progress towards standardization being made by the most significant organizations around the world.

Figure 15: Summary of standards work in 5G



8. Forecasts for 5G

Forecasts for 5G infrastructure need to be looked at in light of the fact that a number of operators and national ministries have committed to deploying networks before the 5G standardization process has been completed. This approach is partly a practical one. Operators anticipating a capacity crunch towards the end of this decade will need to deploy emerging technologies in order to maintain service levels. They cannot wait for the completion of the standardization process. Countries want to position themselves as at the forefront of technology development, and they are introducing showcase 5G networks at major global events that they will be hosting. This means that initial 5G deployments in commercial (or semi-commercial) context may not be fully 5G networks according to our definition as they won't be certified as meeting the 5G standards – that will be impossible, of course.

For this reason, our forecasts include what we have described as early 5G networks and fully 5G networks. Early 5G networks go beyond the capabilities of LTE-Advanced infrastructures, meeting one or more of the characteristics we set out above as being compulsory before we count a network as a 5G network (see Chapter 4). Following the completion of the standardization process (currently anticipated for 2020), we expect these early 5G networks will quickly be certified as fully compliant.

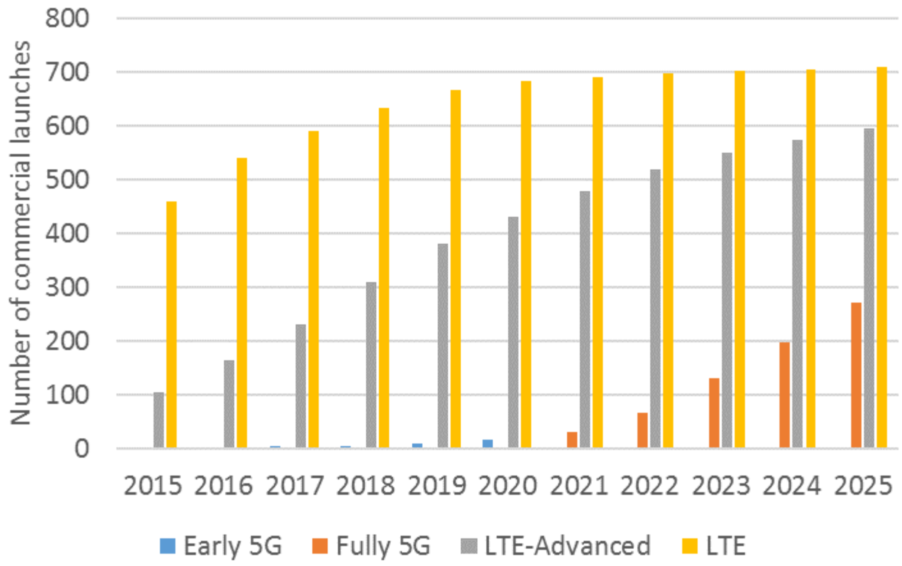
Few operators will launch early 5G networks – we expect only around 10–15 early 5G network commercial launches. The table in Figure 16 below shows those operators that have already made public commitments.

Figure 16: Operator 5G trials and commitments

Operator	Country	Details
Megafon	Russia	Trial 5G networks for eleven cities hosting the Fifa 2018 World Cup. Trial involving M2M and human users
KT, SKT, LG	South Korea	The Ministry of Science, ICT and Future Planning plans to invest up to KRW 68.2 billion to ensure the roll out of a fully commercial 5G service by 2020. Trial services are planned from 2017, with launch of some limited demonstrators services at the Pyeong Chang 2018 Winter Olympics
NTT DoCoMo	Japan	Field trials underway. Commercial launch of 5G for summer Olympic Games in 2020 as first phase (serving stadia and other areas); second phase focused on latency and higher frequencies to follow, potential in 2022/2023 timeframe
Orange	France	Trials in Belfort to end 2016
Softbank	Japan	5G field trials in Tokyo
Verizon	United States	Lab trials underway. Technology field trials to begin in 2016. Possible 5G commercial launch within 2017
Deutsche Telekom	Germany	5G:haus innovation lab launched in March 2015, working with multiple partners
Telstra	Australia	Field trials, proofs of concept and radio test bed initiated in March 2015
América Móvil	Brazil	Test bed announced in October 2015

We forecast that commercial deployment will begin in earnest after the standardization process is completed in 2020. Figure 17 below shows our forecast for the deployment of commercial 5G networks worldwide up to the end of 2025, set against the context of global LTE and LTE-Advanced network deployments. Note that we have assumed a slower adoption rate than for LTE. Our modelling takes into account the responses of operators in our survey to questions about their current plans, and their estimates for when they would begin trialling and deploying 5G networks.

Figure 17: Forecasts for 5G network deployment

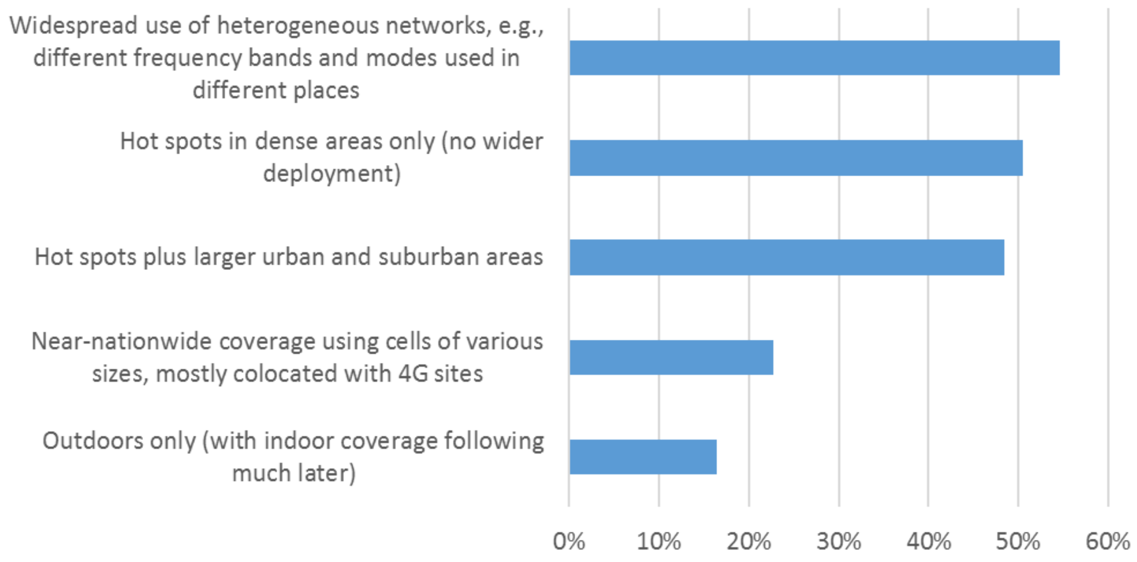


We forecast that by the end of 2025, over 270 operators will have introduced commercial 5G services of some sort, though note that this does not mean those networks will be extensive – coverage may be limited to dense urban areas. We are including in our forecasts only networks using new air interface technologies.

We expect that infrastructure deployment will be focused initially on dense urban areas – using whatever frequencies, modes and technologies make sense to an individual operator in any given location in order to deliver indoor and outdoor coverage – but in particular in hot spot locations where capacity starts to run out. We do not anticipate many widespread 5G network deployments within the forecast period.

Figure 18 shows how the GSA's online community expects 5G networks to be deployed.

Figure 18: Thinking about deployment models for 5G networks, which do you think will be most prevalent for an operator in its first couple of years of commercial 5G operation? Tick any that you think will be widely adopted (n=97)



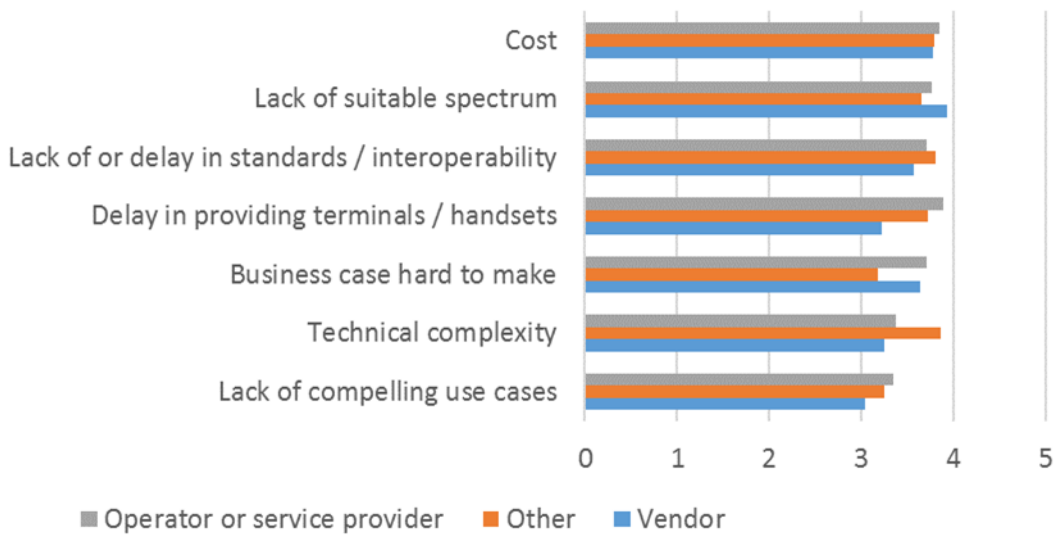
9. What is needed

There is currently little clear consensus on how 5G will be defined, even though work has been progressing on the vision for 5G, the standardization process for 5G, and technologies for 5G for at least three years. We are not yet at the stage that candidate technologies are fully fleshed out for submission to the ITU and 3GPP.

Nonetheless, the industry has a need to come up with some workable concept of 5G (or something close to what 5G will become) because several big players – in Japan, South Korea, Russia and the USA – have already given notice of their 5G plans.

Beyond definition issues, other barriers to 5G development exist: our survey of the industry shows that there is widespread agreement among different parts of the industry about the significance of these. Perhaps surprisingly, lack of use cases is considered (marginally) the least significant of the barriers we tested (see Figure 19).

Figure 19: What do you think are or will be the main barriers to 5G development and deployment? (5 = very serious barrier; 1 = not a barrier at all) (n=97)



We believe the industry needs to focus between now and 2020 on seeking consensus on approaches to concurrent LTE-Advanced development and 5G radio interface research – in particular demonstrating how assets can be reused (to address cost issues). It must also begin to build compelling 5G business models in some specific application areas, focusing on those areas where LTE evolution does not “cut the mustard”. Finally, it must pull together on the issues of spectrum allocation: WRC ’15 and ’19 are critical milestones that will shape how 5G R&D develops.