# 5G Technologies and Test Challenges

5G networks technology and research is now underway, and future 5G networks are expected to provide critical infra-structure for many types of wireless communications. In this paper we will look at the industry requirements and use cases being used to form and define 5G networks and technologies. The industry activities in the areas radio spectrum and standards/technology research will be reviewed and discussed in line with the industry requirements, and the expected schedule of availability reviewed. Finally, we will review the impact, challenges, and some research activities within the test and measurement industry to see how future 5G technologies will affect testing of devices and network equipment, and monitoring of wireless networks.

## 1. Introduction

'5G' has become very quickly the most talked about step forward in mobile communications, with discussion as both evolution and revolution. It is discussed as an evolution as mobile evolves to support a wide range of new use cases, and discussed as revolution as the architecture concept is being predicted to completely transform to enable these new use cases. Thus 5G includes the evolution of existing 4G networks to use technologies such as CRAN and HetNet to increase capacity of existing networks with an affordable cost. But we also see the revolution for core architecture to fully use SDN/NFV and slicing, the use of a new millimeter wave band air interface for higher capacity, and a new architecture/signaling for extreme low latency.

## 2. Requirements

Studies for use cases of mobile communications (e.g. NGMN white paper published February 2015) have identified three priority areas where there is no suitable alternative technology:

- Enhanced Mobile Broadband, more capacity and higher data rates to each user.
- Extreme real time communication low latency (tactile internet, V2V).
- Ultra-reliability and critical communications (includes D2D).

These three use cases have become the initial focus for industry bodies such as NGMN and 3GPP who are contributing to mobile standards process. One area that is not included is "Internet of Things, IoT", which is also a very important topic for mobile networks. The reason for this is that already 3GPP projects such as Machine Type Communications (MTC, eMTC) are developing evolutions for existing networks to support these use cases (massive numbers of users, low data rates, very long battery life, long range, etc.). This is seen in existing 3GPP technology evolutions such as Cat M, NB-IOT, EC-GSM which are all addressing this topic. So we can see that 5G is designed to co-exist with existing 3GPP (4G), Short Range Wireless (Wi-Fi, Bluetooth, etc.), technologies, and the 5G architecture will be designed to also support the use of these different wireless access technologies.

All data capacity predictions point to the need for more spectrum to deliver the increased volume of data. Although new waveforms can improve efficiency and give more capacity within existing networks, it is felt there will not be enough to meet future demand. As all available spectrum below 6 GHz is in use today there is not enough here to meet future demands of data traffic, so we have to look to higher frequency bands to find new spectrum. So the higher frequencies can provide higher data capacity but have comparatively less coverage/propagation than low frequencies. So a careful plan must be put together to maximize the use of below 6 GHz for best coverage, and then above 6 GHz for high data capacity requirements. Heterogeneous Networks (HetNet) is then the architecture "glue" that holds together these different frequencies to give the best possible service/user experience. So the key activities in the industry for the air interface and spectrum use can be seen as:

- Optimize existing spectrum below 6GHz, new waveforms to overcome issues with LTE (OFDMA) but keep the benefits of this technology. Such issues are related to interference management, such as adjacent channel leakage, the need for strict timing control, and difficulties to deploy within HetNet architecture. OFDMA has been proven to be suitable for MIMO deployment, and for flexible spectrum use, and so candidate waveforms are based on further evolution of OFDMA.
- Understand how to use higher frequency (26-86 GHz) bands for mobile communications, through modeling, propagation measurements, and field trials. This is to enable proper design of waveforms, signaling (protocols) including MIMO algorithms, and Radio Resource Management (RRM) that enables these frequencies to be used.
- Build a HetNet architecture that can bring together both the below 6GHz bands and the above 6GHz bands into a single "seamless" network that is based around the user services and quality of experience. This will also need to include 'legacy' 4G air interfaces and networks, as well as Wi-Fi and other commonly used wireless access methods.

## 3. Spectrum

The global allocation/agreement of radio spectrum is agreed by the International Telecommunications Union (ITU) in the sub-group ITU-R. At the latest ITU-R meeting World Radio communications Conference (WRC15) is was confirmed to continue with existing spectrum below 6GHz for global use of bands mostly in use today. There was agreement on global harmonization for the spectrum at 694-790 MHz, 1427-1518 MHz, and 3.6-3.8 GHz. This makes these bands now global mobile communications bands suitable for licensing/deployment in all countries, rather than being just local/regional bands. The key outcome was that no major new spectrum was allocated to mobile, nothing was moved over from either the Satellite or broadcast industries whom also hold spectrum in these bands, and the focus is now on investigation of new higher frequency bands for consideration at WRC19.

So for WRC19 the discussion will focus on new bands, including new methods of licensing and new methods of sharing (e.g. LSA/LAA, Licensed Shared Access, and License Assisted Access). This is in order to use new technologies that allow operators to share specific frequency bands and enable higher efficiency/utilization of the bands, versus the fixed license schemes currently used. These current license schemes allow operators to provide Guaranteed Quality of Service (QoS) due to them having unique license access, but at the cost of potentially not maximizing utilization of the frequency bands. WRC19 will consider 10 sets of frequency bands in the millimeter wave band (mmw) in the range 26-86GHz, and radio wave propagation at mmW is the key issue to understand how it can be used for mobile communications. Millimeter wave has a history in military communications, satellite, and high data rate P2P communications. But these are mostly static channels, not moving effects, and only slowly variable links. For use in mobile communications there is a need to model now for fast/slow fading, and multipath reflection modes for MIMO, and in building penetration. So ITU-R has now set out a plan for these studies and evaluations, scheduled to report the findings into the WRC19 consultation process.

## 4. Standards and Technologies

The current globally deployed 4G/LTE networks are based on standards written by 3GPP (the standards body that previously defined the 2G GSM/GPRS and 3G WCDMA technologies). 3GPP has now released a plan and started activities for developing a 5G set of standards, and currently the first phase is for Technology Research to establish suitable technologies to be used in the 3GPP 5G standards.

The principle for 3GPP is for a divergence of air interface depending on use cases.

LTE-A continues into Release 13, it has an existing wide deployment and is suitable for smartphones and high mobility use cases (700 MHz - 6 GHz bands). New Rel 13 waveforms are evolving from LTE-A for M2M market, so called NB-IOT and CAT M, to give power savings mode, and lower cost of device implementation. NB-IOT is a narrow band technology for easy deployment into any available spectrum (in GSM, in guard bands, in LTE), and Cat M is a direct evolution of current 4G/LTE waveforms.

For the air interface, a 5G new radio access technology is scheduled to be introduced in LTE-A Rel 14 and beyond, (now to be called “LTE-A Pro”). This new radio interface should be addressing the use cases set out under the “Requirements” discussion of this article. The waveforms for 5G are expected to be an evolution of OFDM, to improve carrier leakage (gives better spectral efficiency and higher capacity) as OFDM is favored for MIMO applications. Candidates for such waveforms include FBMC, GFDM, UFMC, and there is significant work to develop and evaluate these so a new waveform to scale for efficient HetNet use, denser spectrum use, and higher order MIMO can be selected. Also there is investigation into new access methods such as NOMA and SCMA to replace the simple OFDMA process currently used, to multiplex different services and requirements onto the network. OFDMA is relatively static and inflexible, and the divergence of use cases will require a more flexible method of managing the access to the radio resources. These new methods should allow high data rate users, low latency users, and IoT devices to share the air interface without significantly degrading the performance.

A further evolution of the access technologies is the use of C-RAN, and the network evolving to more complex HetNet architectures including User/Control plane and UpLink/DownLink separation. These technologies are being introduced into Rel 13 already, but will be further developed in Rel 14 to support 5G networks. This technology also introduces a new definition of network coverage and capacity, as a dynamic and service/context related parameter, as the user can have different connectivity modes for different services being used even if they are physically at the same location in the network. This also introduces the concept of network “anchor” that will be important during the early phases of 5G. The anchor refers to the access/core network that is used to manage the air interface elements. So a 5G waveform can be used with a new 5G ‘base-station’, but connected to a legacy 4G network that provides the routing, mobility etc, and this would be referred to a 4G anchor. It is expected that this architecture will be used in early deployments, as the 5G air interface may be available ahead of the 5G core network services. This will enable existing 4G networks to use new 5G frequencies to expand capacity/data rates, but may not be capable to support other 5G features such as ultra-reliability or extreme low latency that require the 5G core network technologies and hence must use a 5G anchor.

The evolution of Core Network Technologies is based upon SDN/NFV (Software Defined Networks / Network Function Visualization) that enables the network to be built from a system of specific software elements corresponding to network functions, which can be flexibly deployed onto standardized hardware units. This architecture offers cost benefits for capacity expansion as it is based on relatively low cost hardware, and offers flexible deployment and “on demand” network capacity as the capacity/ capability can be flexible configured as software elements to use the available hardware resources. This concept also allows for support of extreme low latency and ultra-reliability as the software resources and hardware resources required can be more flexibly configured to meet the application/service needs, and they are no longer static resources.

## 5. Schedule

From the standards point of view, the two key schedules are those from ITU-R for the selection of new frequency bands for 5G (see previous discussion on WRC19) and selection of suitable technologies to be used in these bands (to fulfil the objectives of IMT2020), and that from 3GPP to create and define a set of standards to meet the objectives if IMT2020 and also the business needs of the industry and telecom operators.

From the market point of view, there are a number of highly visible global public events that are expected to be used to showcase 5G and demonstrate the latest 5G progress and capabilities. These major public events include the FIFA Football World Cup (Russia 2018), Winter Olympics (South Korea, 2018), Summer

Olympics (Tokyo 2020), are all expected to provide a showcase for the technology to be demonstrated to the public/industry, and to be trialled with demanding new applications and services.

Beyond the public showcase events, the industry expectation is that 3GPP standards may be first usable from late 2018, and in a first complete version from late 2019. In parallel, new frequencies from WRC19 will be ratified in late 2019. These two schedules together indicate availability of 5G networks from 2020, but it is expected that in certain markets then an early deployment using partial standards (or only particle functionality), and operating in locally licensed frequency bands (rather than globally standardized frequency bands) could be deployed in the 2018-2020 time period.

## 6. Testing Challenges

### 6.1 OTA connectorless mmW

For cost effective deployment of massive MIMO (small devices, low cost) then the devices (e.g. base stations and "small cells") will not be able to support an array of connectors that give test access to each antenna port, they will need to be in an integrated circuit/device. So there will not be a specific test port available, and an array will need to be testing Over The Air (OTA) test methods, i.e. without a physical contact to the port. Such OTA test methods exist today for mobile devices and networks, but are based on large/expensive RF chambers to provide suitable isolation/coupling, and require long test times as the signal is integrated from all possible directions. This has been acceptable to the industry, as much testing is performed using RF connectors, and only a small amount of testing is OTA/connectorless. For 5G, a more compact, affordable, and faster test method will be needed if all devices are connectorless and must be tested with OTA methods. For this reason, there is research into new OTA test methods to meet the needs of 5G, looking at both power/sensitivity measurements and also MIMO beamforming measurements.

### 6.2 Wide band millimeter wave device characterization

It is expected that mobile broadband will make use of new mmW band frequencies in order to give the user required bandwidth for high data rate services. This will then require that device/component technology is available to support low cost consumer devices in these higher frequencies. To date these frequency bands have been used by high performance and high cost applications, which have accepted high cost device/component technology. To deploy consumer mobile communications in these bands requires lower cost component technology (amplifiers, mixers, sub-systems etc.). So existing low cost technologies will be developed and tested for use in these new bands, and existing high cost technologies may be re-designed for lower cost. This will require new component/device characterization that is able to evaluate the wideband performance, and demonstrate that device technology is able to meet the price/

performance requirements required by the market. Traditional device characterization in lower frequency devices has been limited to narrow band and Continuous Wave (CW) modes, but now it is expected that wide band modulated characterization of devices is required to ensure the device technology is suitable for the new 5G waveforms that will be used. Especially for Power Amplifiers and other active devices/ sub-systems, then the ability to characterize accurately the device behavior under wide band modulated conditions will ensure that low cost technologies can be used for wide band mmW applications.

### 6.3 Interference

Existing/legacy mobile networks are defined in terms of coverage as noise limited, i.e. Signal to Noise Ratio (SNR) defines the maximum cell radius and coverage available. In HetNet then the complexity of connections, the interference of adjacent cells, and interference in the cell will determine coverage, so cell radius and cell capacity are more defined by interference than by propagation and SNR. Hence network planning and modeling must evolve to use interference, and field test tools must measure interference as a primary parameter. The field test tools will need to evolve along the lines of C-RAN, to support the architecture of generic RF transceivers (Remote Radio Heads) together with centralized Base Band Units that carry the necessary protocols using CPRI or future evolutions of CPRI. As HetNets become more complex, the ability to isolate and measure the RRH installation as a stand-alone entity will be required, as the waveforms and protocols being transmitted may be a dynamic and variable parameter.

### 6.4 Wireline networks and SDN/NFV

As the hardware becomes generic, and functionality is software/visualized, this gives high flexibility in the deployment and expansion of the core network. The testing challenge is to ensure enough physical layer performance to provide the visualized service. The functionality, timing protocols, and QoS relies on an adequate underlying physical transport being available and reliable. Capacity, jitter, latency are critical parameters to be measured in the network to ensure correct performance under all different configurations and load conditions. In addition, inter-connect between the different hardware elements is now requiring higher speed data connections, and new optical/digital waveforms for the inter-connect buses and backplanes. Then use of standardized network hardware (essential for the SDN/NFV concept) also requires standardized and modular inter-connect buses and backplanes, but at ever increasing data rates. So there are significant activities in the waveforms and testing methods being developed to support the high speed inter-connect requirements of 5G network infra-structure. As the data rates are increased, then distortion and degraded signal integrity will affect the maximum performance. To ensure reliable inter-connection of standardized network hardware requires that the distortion and degradation is measured and certified in a standardized method, so the industry is defining both the new standards for inter-connect links and the test methods/equipment to ensure the measurements.

### 6.5 Big Data Analytics

5G networks are expected to have a significant impact on network monitoring and analytics requirements, across several aspects. Firstly, the mobile broadband continued increase in both volume of data and diversification of types of data sources (driven by IoT) will increase the overall volume of records to be processed per hour, requiring more efficient filtering, processing and storage methods to manage the increased volume of data. Secondly, the deployment of HetNet and C-RAN technology will require more complex correlation of different network KPI’s to be able to, validate the customer experience KPI’s, as the customer experience may be based on the simultaneous performance of several different network access technologies and networks. Thirdly, to support the ultra-reliable and extreme low latency use cases, then predictive analytics, real time correlation of diverse sources, and new user KPI’s and metrics will be required for these new use cases.

## 7. Conclusions

Demand for 5G networks is driven by two needs, to provide new technologies that can support the expected volume of data together with emerging new ‘use cases’ for enhanced mobile communications, and by the need to provide an affordable network architecture and technology that can scale and expand to meet this whilst maintaining the network operator’s costs (both OPEX and CAPEX) to bring the technology within the price expectations of users. There is now corresponding activity in standards and spectrum groups, setting framework, and technology research providing inputs and solutions to guide the standards and spectrum policies. It is expected that in the 2018-2020 timeframe there will be standards available and trials/showcase networks deployed to evaluate the technology and start the process of commercial deployment.

New waveforms and access methods become a key component for 5G, both below 6 GHz and above 6 GHz, but with different requirements and objectives. There are needs to improve existing waveforms (OFDM) used below 6 GHz in 4G/LTE, and to have new waveforms suitable for mmW and massive MIMO. Industry research is underway to develop these waveforms and techniques, and testing/evaluation of the candidate waveforms is required to support this activity.

Use of 26-86GHz band (mmw) will drive new requirements into the component measurements, to bring the device technology to an affordable price point suitable consumer market application. OTA and connectorless measurement environment is also a feature of mmW, driven by size/cost needs. New test solutions will be required to bring the technology to market with required quality, but at an affordable cost, and the key technologies for such test solutions are being developed for future 5G applications.

The 5G network will be more than a new air interface, more than an expansion to mmW bands, and will require new technologies and measurement tools across the whole network infra-structure. The access network architecture based on C-RAN, and the core network based on SDN/NFV, will require new inter-connect technologies, new network physical layer/transport layer connectivity, and enhanced monitoring / service assurance tools to ensure that the new services and new use cases can be realized and deployed effectively using the 5G set of technologies. So the industry is developing the new inter-connect and transport technologies to deliver this, and the test and monitoring tools to validate and ensure the quality of customer experience.

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