Research paper on

UnderStanding 5G wireless Technology:

Perspective on future technology enchancements in mobile.

Submitted by:

Ayush Khandelwal

CS, IV BTech

12ESKCS030

Contents

Executive summary

5G offers enormous potential for both consumers and industry

As well as the prospect of being considerably faster than existing technologies, 5G holds the promise of applications with high social and economic value, leading to a 'hyper-connected society' in which mobile will play an ever more important role in people's lives.

The GSMA will work for its members and with its partners to shape 5G

As the association representing the mobile industry, the GSMA will play a significant role in shaping the strategic, commercial and regulatory development of the 5G ecosystem. This will include areas such as the definition of roaming and interconnect in 5G, and the identification and alignment of suitable spectrum bands. Once a stable definition of 5G is reached, the GSMA will work with its members to identify and develop commercially viable 5G applications. This paper focuses on 5G as it has developed so far, and the areas of technological innovation needed to deliver the 5G vision.

There are currently two definitions of 5G

Discussion around 5G falls broadly into two schools of thought: a service-led view which sees 5G as a consolidation of 2G, 3G, 4G, Wi-fi and other innovations providing far greater coverage and always-on reliability; and a second view driven by a step change in data speed and order of magnitude reduction in end-to-end latency. However, these definitions are often discussed together, resulting in sometimes contradictory requirements.

Sub-1ms latency and >1 Gbps bandwidth require a true generational shift

Some of the requirements identified for 5G can be enabled by 4G or other networks. The technical requirements that necessitate a true generational shift are sub-1ms latency and >1 Gbps downlink speed, and only services that demand at least one of these would be considered 5G use cases under both definitions.

Achieving sub-1ms latency is a hugely exciting challenge that will define 5G

Delivering 1ms latency over a large scale network will be challenging, and we may see this condition relaxed. If this were to happen, some of the potential 5G services identified may no longer be possible and the second view of 5G would become less clear. This paper looks at some of the challenges that must be overcome to deliver 1ms latency.

At the same time 4G will continue to grow and evolve

Technologies such as NFV/SDN and HetNets are already being deployed by operators and will continue to enable the move towards the hyper-connected society alongside developments in 5G. Considerable potential also remains for increasing 4G adoption in many countries, and we expect 4G network infrastructure to account for much of the $1.7 trillion the world's mobile operators will invest between now and 2020. Operators will continue to focus on generating a return on investment from their 4G (and 3G) networks by developing new services and tariffing models that make most efficient use of them.

Introduction

Objectives of this report

The purpose of this report is to take a step toward clarifying what ‘5G’ really means in the technological sense, by: reducing 5G to its fundamental core (including acknowledging what it is arguably not); expanding on some of the use case scenarios that 5G might enable; and discussing conceivable implications for operators in terms of network infrastructure and commercial opportunities. This can only be achieved by framing the discussion around 5G in a broader context alongside existing network technologies and those currently in development.

In summary, there are three key questions that this report will ask:

1. What is (and what isn’t) 5G?
2. What are the real 5G use cases?
3. What are the implications of 5G for mobile operators?

Notes on terminology

GSMA Intelligence’s definition of 4G includes the following network technologies: LTE, TD-LTE, AXGP, WiMAX, LTE-A, TD-LTE-A, LTE with VoLTE and WiMAX 2.

Due to the commonality of operator definitions classifying LTE and TD-LTE as 4G technologies, we follow this convention. This differs from the ITU’s strict definition of transitional versus true 4G. Also, where we use the term ‘LTE’ in this document it incorporates all LTE variants (LTE, TD-LTE, AXGP, LTE-A and TD-LTE-A). Finally, for simplicity we do not consider WiMAX in this analysis, so where the term ‘4G’ is used it incorporates all LTE variants but not WiMAX (a transitional 4G technology) or WiMAX 2 (a true 4G technology). Therefore for the purpose of this report the terms ‘4G’ and ‘LTE’ are interchangeable.

What is 5G?

Evolution beyond mobile internet

From analogue through to LTE, each generation of mobile technology has been motivated by the need to meet a requirement identified between that technology and its predecessor (see Table 1). For example, the transition from 2G to 3G was expected to enable mobile internet on consumer devices, but whilst it did add data connectivity, it was not until 3.5G that a giant leap in terms of consumer experience occurred, as the combination of mobile broadband networks and smartphones brought about a significantly enhanced mobile internet experience which has eventually led to the app-centric interface we see today. From email and social media through music and video streaming to controlling your home appliances from anywhere in the world, mobile broadband has brought enormous benefits and has fundamentally changed the lives of many people through services provided both by operators and third party players.

Generation	Primary services	Key differentiator	Weakness (addressed by subsequent generation)
1G	Analogue phone calls	Mobility	Poor spectral efficiency, major security issues
2G	Digital phone calls and messaging	Secure, mass adoption	Limited data rates – difficult to support demand for internet/e-mail
3G	Phone calls, messaging, data	Better internet experience	Real performance failed to match hype, failure of WAP for internet access
3.5G	Phone calls, messaging, broadband data	Broadband internet, applications	Tied to legacy, mobile specific architecture and protocols
4G	All-IP services (including voice, messaging)	Faster broadband internet, lower latency	?

Table 1: Evolution of technology generations in terms of services and performance
Source: GSMA Intelligence

More recently, the transition from 3.5G to 4G services has offered users access to considerably faster data speeds and lower latency rates, and therefore the way that people access and use the internet on mobile devices continues to change dramatically. Across the world operators are typically reporting that 4G customers consume around double the monthly amount of data of non-4G users, and in some cases three times as much. An increased level of video streaming by customers on 4G networks is often cited by operators as a major contributing factor to this.

The Internet of Things (IoT) has also been discussed as a key differentiator for 4G, but in reality the challenge of providing low power, low frequency networks to meet the demand for widespread M2M deployment is not specific to 4G or indeed 5G. As Table 1 suggests, it is currently unclear what the opportunity or 'weakness' that 5G should address is.

Two views of 5G exist today:

View 1 – The hyper-connected vision: In this view of 5G, mobile operators would create a blend of pre-existing technologies covering 2G, 3G, 4G, Wi-fi and others to allow higher coverage and availability, and higher network density in terms of cells and devices, with the key differentiator being greater connectivity as an enabler for Machine-to-Machine (M2M) services and the Internet of Things (IoT). This vision may include a new radio technology to enable low power, low throughput field devices with long duty cycles of ten years or more.

View 2 – Next-generation radio access technology: This is more of the traditional 'generation-defining' view, with specific targets for data rates and latency being identified, such that new radio interfaces can be assessed against such criteria. This in turn makes for a clear demarcation between a technology that meets the criteria for 5G, and another which does not.

Both of these approaches are important for the progression of the industry, but they are distinct sets of requirements associated with specific new services. However, the two views described are regularly taken as a single set and hence requirements from both the hyper-connected view and the next-generation radio access technology view are grouped together. This problem is compounded when additional requirements are also included that are broader and independent of technology generation.

5G technology requirements

As a result of this blending of requirements, many of the industry initiatives that have progressed with work on 5G (see Appendix A) identify a set of eight requirements:

- 1-10Gbps connections to end points in the field (i.e. not theoretical maximum)
- 1 millisecond end-to-end round trip delay (latency)
- 1000x bandwidth per unit area
- 10-100x number of connected devices
- (Perception of) 99.999% availability
- (Perception of) 100% coverage
- 90% reduction in network energy usage
- Up to ten year battery life for low power, machine-type devices

Because these requirements are specified from different perspectives, they do not make an entirely coherent list – it is difficult to conceive of a new technology that could meet all of these conditions simultaneously.

Equally, whilst these eight requirements are often presented as a single list, no use case, service or application has been identifed that requires all eight performance attributes across an entire network simultaneously. Indeed some of the requirements are not linked to use cases or services, but are instead aspirational statements of how networks should be built, independent of service or technology – no use case needs a network to be significantly cheaper, but every operator would like to pay less to build and run their network. It is more likely that various combinations of a subset of the overall list of requirements will be supported 'when and where it matters'.

Finally, while important in their own right, six of these requirements are not generation-defining attributes. These are considered below:

Perceived 99.999% availability and 100% geographical coverage:

These are not use case drivers, nor technical issues, but economic and business case decisions. 99.999% availability and 100% coverage are achievable using any existing technology, and could be achieved by any network operator. Operators decide where to place cells based on the cost to prepare the site to establish a cell to cover a specific area balanced against the benefit of the cell providing coverage for a specific geographic area. This in turn makes certain cell sites and coverage areas - such as rural areas and indoor coverage - the subject of difficult business decisions.

Whilst a new generation of mobile network technology may shift the values that go in to the business model that determines cell viability, achieving 100% coverage and 99.999% availability will remain a business decision rather than a technical objective. Conversely, if 100% coverage and 99.999% availability were to be a 5G 'qualifying criteria', no network would achieve 5G status until such time as 100% coverage and 99.999% availability were achieved.

Connection density (1000x bandwidth per unit area, 10-100x number of connections):

These essentially amount to 'cumulative' requirements i.e. requirements to be met by networks that include 5G as an incremental technology, but also require continued support of pre-existing generations of network technology. The support of 10-100 times the number of connections is dependent upon a range of technologies working together, including 2G, 3G, 4G, Wi-fi, Bluetooth and other complementary technologies. The addition of 5G on top of this ecosystem should not be seen as an end solution, but just one additional piece of a wider evolution to enable connectivity of machines. The Internet of Things (IoT) has already begun to gain significant momentum, independent of the arrival of 5G.

Similarly, the requirement for 1,000 times bandwidth per unit area is not dependent upon 5G, but is the cumulative effect of more devices connecting with higher bandwidths for longer durations. Whilst a 5G network may well add a new impetus to progression in this area, the rollout of LTE is already having a transformational effect on the amount of bandwidth being consumed within any specific area, and this will increase over the period until the advent of 5G. The expansion of Wi-fi and integration of Wi-fi networks with cellular will also be key in supporting greater data density rates.

Meeting both of these requirements will have significant implications for OPEX on backhaul and power, since each cell or hotspot must be powered and all of the additional traffic being generated must be backhauled.

Reduction in network energy usage and improving battery life:

The reduction of power consumption by networks and devices is fundamentally important to the economic and ecological sustainability of the industry. A general industry principle for minimising power usage in network and terminal equipment should pervade all generations of technology, and is recognised as an ecological goal as well as having a significant positive impact on the OPEX associated with running a network. At present it is not clear how a new generation of technology with higher bandwidths being deployed as an overlay (rather than a replacement) on top of all pre-existing network equipment could result in a net reduction in power consumption.

Some use cases for M2M require the connected device in the field to lie dormant for extended periods of time. It is important that innovation in how these devices are powered and the leanness of the signaling they use when becoming active and connected is pursued. However, this requirement is juxtaposed with 5G headline requirements on data rate – what is required for mass sensor networks is very occasional connectivity with minimal throughput and signaling load. Work to develop such technology predates the current 5G requirements and is already being pursued in Standards bodies.

These six requirements should be and are being pursued by the industry today using a range of techniques (some of which are covered later in the paper) but these amount to evolutions of existing network technology and topology or opportunities enabled by changing hardware characteristics and capabilities. These will in turn open business opportunities for operators and third parties. However, none of these business opportunities exist today – they are constrained by limitations greatly governed by economics, and much of these six requirements are motivated by improving the economic viability of those opportunities, rather than filling technological gaps that explicitly prohibit these opportunities, regardless of the amount they might cost to enable.

Thus in the strictest terms of measurable network deliverables which could enable revolutionary new use case scenarios, the potential attributes that would be unique to 5G are limited to **sub-1ms latency** and **>1 Gbps downlink speed**.

Potential 5G use cases

Imagining the mobile services of the next decade

As with each preceding generation, the rate of adoption of 5G and the ability of operators to monetise it will be a direct function of the new and unique use cases it unlocks. Thus the key questions around 5G for operators are essentially:

a. What could users do on a network which meets the 5G requirements listed above that is not currently possible on an already existing network?
b. How could these potential services be profitable?

Figure 1 illustrates the latency and bandwidth/data rate requirements of the various use cases which have been discussed in the context of 5G to date. These potential 5G use cases and their associated network requirements are described below.

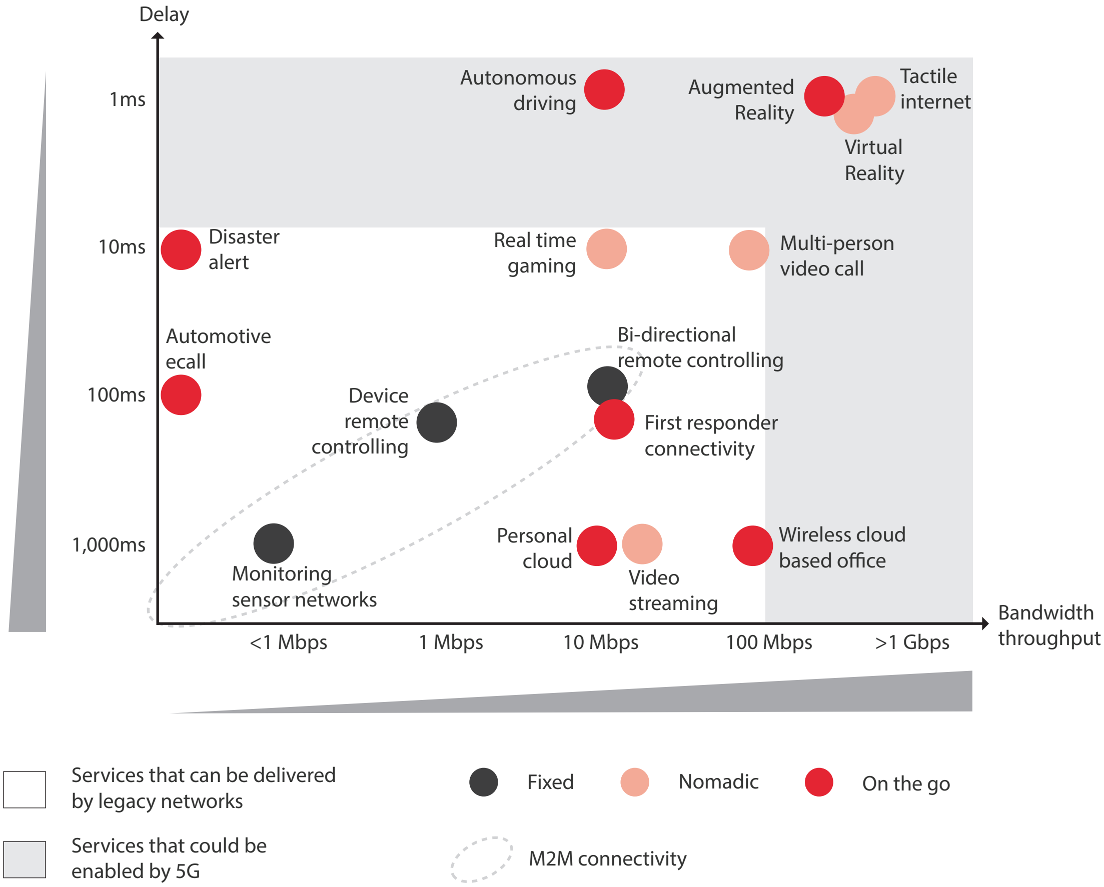

Figure 1: Bandwidth and latency requirements of potential 5G use cases

Source: GSMA Intelligence

Virtual Reality/Augmented Reality/Immersive or Tactile Internet

These technologies have a number of potential use cases in both entertainment (e.g. gaming) and also more practical scenarios such as manufacturing or medicine, and could extend to many wearable technologies. For example, an operation could be performed by a robot that is remotely controlled by a surgeon on the other side of the world. This type of application would require both high bandwidth and low latency beyond the capabilities of LTE, and therefore has the potential to be a key business model for 5G networks.

However, it should be pointed out that VR/AR systems are very much in their infancy and their development will be largely dependent on advances in a host of other technologies such as motion sensors and heads up display (HUD). It remains to be seen whether these applications could become profitable businesses for operators in the future.

Autonomous driving/Connected cars

Enabling vehicles to communicate with the outside world could result in considerably more efficient and safer use of existing road infrastructure. If all of the vehicles on a road were connected to a network incorporating a traffic management system, they could potentially travel at much higher speeds and within greater proximity of each other without risk of accident - with fully-autonomous cars further reducing the potential for human error.

While such systems would not require high bandwidth, providing data with a command-response time close to zero would be crucial for their safe operation, and thus such applications clearly require the 1 millisecond delay time provided in the 5G specification. In addition a fully 'driverless' car would need to be driverless in all geographies, and hence would require full road network coverage with 100% reliability to be a viable proposition.

Wireless cloud-based office/Multi-person videoconferencing

High bandwidth data networks have the potential to make the concept of a wireless cloud office a reality, with vast amounts of data storage capacity sufficient to make such systems ubiquitous. However, these applications are already in existence and their requirements are being met by existing 4G networks. While demand for cloud services will only increase, as now they will not require particularly low latencies and therefore can continue to be provided by current technologies or those already in development. While multi-person video calling - another potential business application - has a requirement for lower latency, this can likely be met by existing 4G technology.

Machine-to-machine connectivity (M2M)

M2M is already used in a vast range of applications but the possibilities for its usage are almost endless, and our forecasts predict that the number of cellular M2M connections worldwide will grow from 250 million this year to between 1 billion and 2 billion by 2020, dependent on the extent to which the industry and its regulators are able to establish the necessary frameworks to fully take advantage of the cellular M2M opportunity.

Typical M2M applications can be found in 'connected home' systems (e.g. smart meters, smart thermostats, smoke detectors), vehicle telemetric systems (a field which overlaps with Connected cars above), consumer electronics and healthcare monitoring. Yet the vast majority of M2M systems transmit very low levels of data and the data transmitted is seldom time-critical. Many currently operate on 2G networks or can be integrated with the IP Multimedia Subsystem (IMS) – so at present the business case for M2M that can be attached to 5G is not immediately obvious.

A true requirement for a generational shift?

Thus many of the services that have been put forward as potential 'killer apps' for 5G do not require a generational shift in technology, and could be provided via existing network technologies. Only applications that require at least one of the key 5G technical requirements – sub-1ms latency and >1 Gbps downlink speed – can be considered true next generational business cases.

Of these two requirements, reducing latency to sub-1ms levels may provide the greatest technical challenge (see page 12). Meanwhile, as discussed in more detail in Appendix B, operators are already making a considerable amount of progress in increasing the data speeds of their existing networks by adopting LTE-A technologies (see Figure 2). While it is important to note that although many of the use cases and services discussed in this section do not strictly require 5G, they could offer an enhanced user experience on a 5G network. However this amounts to an incremental benefit that is more difficult to market than a genuine new service, and not a core component of any 5G business case.