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The Implications of 5G Networks for Mobile Operators

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ABSTRACT

The purpose of this paper 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 developments.

Keywords: CDMA, WCDMA, 3G, 4G, 5G

I. INTRODUCTION

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.

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 an order of magnitude reduction in end-to-end latency. However, these definitions are often discussed together, resulting in sometimes contradictory requirements.

Sub-1 ms 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-1 ms 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-1 ms latency is a hugely exciting challenge that will define 5G.

Delivering 1 ms of 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 1 ms latency.

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:

- 1–10 Gbps connections to end points in the field
- (i.e., not the 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 a 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, while these eight requirements are often presented as a single list, no use case, service, or application has been identified 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 apparitional 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 Availability: 99.99% and 100% Geographic Coverage

These are not use case drivers or 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 of preparing 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.

While a new generation of mobile network technology may shift the values that go into 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 5G 'qualifying criteria', no network would achieve 5G status until such time as 100% coverage and 99.999% availability were achieved.

Connection Density: (1000 × bandwidth per unit area, 10 - 100 × 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 from 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 to this ecosystem should not be seen as an end solution, but just one additional piece of a wider evolution to enable the 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 more bandwidth per unit area is not dependent upon 5G but is the cumulative effect of more devices connecting with higher bandwidths for longer durations. While 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 networks will also be key to 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 backhaul.

Reduction in Network Energy Usage and Improvement in 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.

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-1 ms latency and >1 gbps downlink speed.

II. METHODS AND MATERIAL

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 that meets the 5G requirements listed above that is not currently possible on an existing network?

b. How could these potential services be profitable?

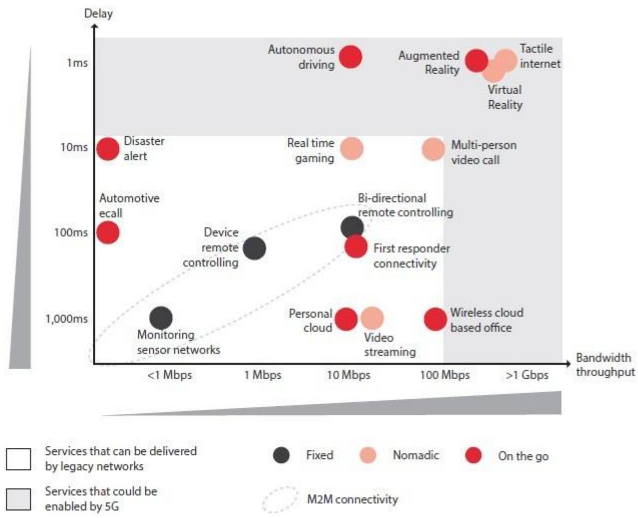

Figure 1 : Bandwidth and latency requirements of potential 5G use cases

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

Virtual Reality / Augmented Reality / Immersive or Tactile Internet

These technologies have a number of potential use cases in both entertainment (e.g., gaming) and 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.

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.

Wireless Cloud-Based Office / Multi-Person Video Conferencing

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, 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 that 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.

The implications of 5G for mobile operators

The progress from initial 3G networks to mobile broadband technology has transformed industry and society by enabling an unprecedented level of innovation. If 5G becomes a true generational shift in network technology, we can expect an even greater level of transformation.

There are varying implications of providing an increased level of connectivity, developing a new radio access network (RAN) to deliver a step change in per-connection performance, or a combination of the two. This means that the final design of a 5G network could be any one of a range of options with differing radio interfaces, network topologies, and business capabilities.

While a shift to 5G would be hugely impactful, the industry will need to overcome a series of challenges if these benefits are to be realised, particularly in terms of spectrum and network topology.

5G spectrum and coverage implications

While there are a number of spectrum bands that could potentially be used to meet some of the 5G requirements identified to date, there is currently a substantial focus on the higher-frequency radio spectrum. As discussed in Appendix A, operators, vendors, and academia are combining efforts to explore technical solutions for 5G that could use frequencies above 6 GHz and reportedly as high as 300

GHz. However, higher frequency bands offer smaller cell radiuses, so achieving widespread coverage using a traditional network topology model would be challenging.

It is widely accepted that 'beam-forming'—the' focussing of the radio interface into a beam that will be usable over greater distances—is an important part of any radio interface definition that would use 6 GHz or higher spectrum bands. This, however, means that the beam must be directed at the end-user device that is being connected. Since the service being offered is still differentiated from fixed line connections on the basis of'mobility', the beam itself will have to track the device. This is an innovation that could make 5G an expensive technology to deploy on a large scale, since each cell may have to support several hundred individual beams at any one time and track the end users that are connected via these beams in three-dimensional spaces.

High-order MIMO (multi-input, multi-output) is another method for increasing bandwidth that is often discussed. This is where an array of antennae is installed in a device and multiple radio connections are established between the device and a cell. However, high-order MIMO can have issues with radio interference, so technology is required to help mitigate this problem. This tends to focus on a need.

for the radio network to adjust its beam to take into account the specific orientation of the antenna at any given time.

All of this is incremental research and development over and above that currently being conducted for 4G. The use of bands higher than 6 GHz will likely require operators to invest in an entirely new RAN since it will have fundamentally different masthead requirements. Given the level of infrastructure required to achieve the desired network topology, operators may be forced to rethink their existing business models. New technology is rarely a cheap option, and the nature of the new technology that is required in the radio network makes it very power-intensive, hence counter to the stated requirement for a significant reduction in overall network power consumption.

That said, vendors are researching ways to include beam-forming and MIMO technology in mobile devices. As a result, the process of identifying and aligning internationally around common bands for 5G will have a clear dependency on the technology that can be identified to overcome band usage at high frequencies for wide area coverage.

Can 1 millisecond latency be achieved?

Achieving the sub-1 ms latency rate identified as a technical requirement for 5G necessitates a new way of thinking about how networks are structured and will likely prove to be a significant undertaking in terms of technological development and investment in infrastructure.

Despite the inevitable advances in processor speeds and network latency between now and 2020, the speeds at which signals can travel through the air and light can travel along a fibre are governed by fundamental laws of physics. Subsequently, services requiring a delay time of less than 1 millisecond must have all of their content served from a physical position very close to the user's device. Industry estimates suggest that this distance may be less than 1 kilometre, which means that any service requiring such a low latency will have to be served using content located very close to the customer, possibly at the base of every cell, including the many small cells that are predicted to be fundamental to meeting densification requirements. This will likely require a substantial uplift in CAPEX spent on infrastructure for content distribution and servers.

If any service requiring 1 millisecond delay also has a need for interconnection between one operator and another, this Interconnectivity must also occur within 1 kilometre of the customers. This could well be the case for a service such as social networking content pushed into augmented reality. Today, inter-operator interconnect points are relatively sparse, but to support a 5G service with a 1 millisecond delay, there would likely need to be

Interconnection at every base station, thus impacting the topological structure of the core network. Roaming customers would need to have visited networks with contextual roaming capabilities and have content relevant to their applications available directly from the visited network, posing challenges for the existing roaming model.

In the most extreme case, it would make sense for a single network infrastructure to be implemented, which would be utilised by all operators. This would mean all customers could be served by a single content source, with all interaction and interconnect with localised context also being served from that point at the base station. This would also imply that only one radio network would be built and then shared by all operators.

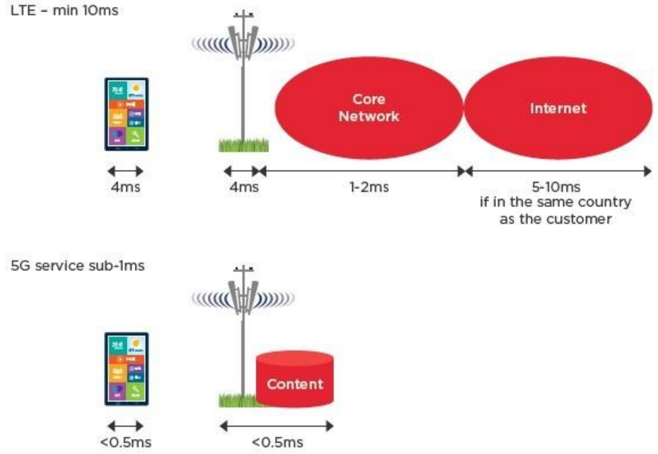

Figure 2 : Latency performance for LTE compared to the latency requirement for 5G

Such a model would considerably reduce CAPEX in the network build (since rather than say four operators building four parallel networks, only a single network would be built) but would require unprecedented levels of co-operation between operators. It would also impact the nature of inter-operator competition, shifting focus to services rather than data rate and coverage differentiation. It would also make spectrum auctions somewhat irrelevant, since only one radio network being built would mean there would only be one bidder and one license per market.

Once this is all realised, it is likely that requirements for sub-1 ms delay will be relaxed or possibly removed entirely from 5G, rather than industry committing to the massive upheaval and resource acquisition that would be implied. If this were to happen, it may draw into question the viability of coupling services such as augmented and virtual reality, immersive internet, and autonomous driving with mobility. However, if those services were removed from the expected service set, the justification for the technological view of 5G would also become questionable.

III. RESULTS AND DISCUSSION

Current 5G industry activity

Since 2012, a number of initiatives have been established to define and develop 5G, and there have also been a considerable number of statements from interested parties, such as governments and infrastructure vendors. Having fallen behind Eastern Asia and North America in terms of mobile technological advancement due to a relatively slow rollout and adoption of 4G networks, European governments are particularly keen to get ahead of the curve in the 5G space, and there have been a number of announcements from Neelie Kroes, European Commission (EC) Vice President for Digital Agenda, on the subject going back to Mobile World Congress 2013. The governments of Japan, South Korea, and China have also been particularly active in driving the 5G agenda.

Meanwhile, vendors such as Ericsson, Huawei, NSN, and Samsung all began research and development towards 5G in 2013, and this year mobile operators have also begun making announcements regarding their own 5G laboratory trials. A summary of the key parties, milestones, and targets is below.

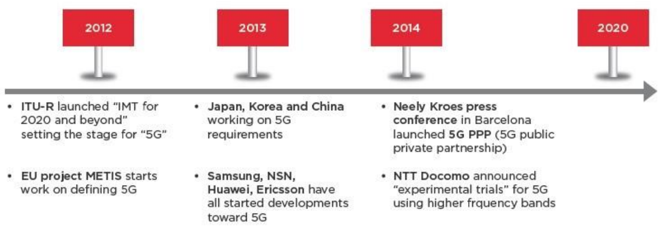

Figure 3 : Timeline of key events in 5G developments

In reality, the adoption of LTE is proceeding at a faster rate than its predecessor technologies (see Figure 4), yet we still do not expect LTE connections to peak until well into the next decade. The technology is still at an early stage in its lifecycle, with networks currently confined to just 110 of the world's 237 mobile markets. Hence, LTE still represents a considerable growth opportunity for the industry; at present, only around a third of the world's mobile operators (293) have live LTE networks. Assuming all known future network launches go ahead as planned, 158 countries will soon have at least one LTE operator, yet this still leaves one-third of the world's mobile markets as untapped territory for LTE services.

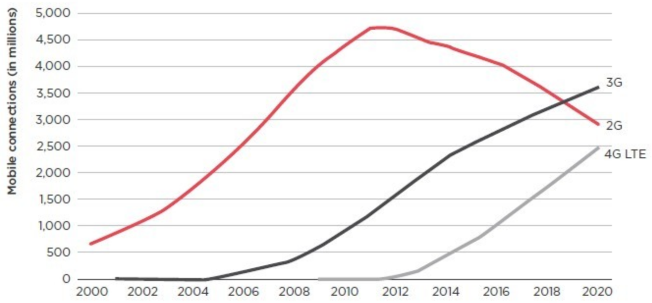

Figure 4 : Total cellular connections, global, by technology generation

IV. CONCLUSIONS: ENABLING INNOVATION THROUGH INDUSTRY-WIDE COLLABORATION

The many initiatives and discussions on 5G going on around the world by governments, vendors, operators, and academia demonstrate the continuing ethos of collaboration and innovation across the industry. In these debates, we must ensure that we continue to coordinate with aligned goals to maintain momentum towards completing the definition of 5G.

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