5G: ARE WE THERE YET?

April 30, 2016

FORTRESS SOLUTIONS

While most of the world is still awaiting 4G to maximize its potential, 5G trials are already well underway, and they're generating some impressive results.

If you fixed, used, or even so much as glanced at a computer in the early 1990's, you will remember Intel's iconic processor numbering schema: 8086, 80186, 80286, 80386, 80486. So when it was time to name the 5th incarnation, we intuitively all knew it was going to be called...a Pentium?

It was a shock, but Intel actually had good reasons to rename its processor line. The Pentiums really jump-started the performance of computers at the time. Within 5 years, CPU speeds went from 33MHz to 333MHz.

It is perhaps serendipity that after cellular data networks have progressed through their 1G - 2G - 3G - 4G evolution, that fifth-generation 5G networks are going to do for mobile devices what the Pentium did for computers.

4G Performance

The 4G network is not based on a single standard. The well-known term LTE (Long Term Evolution) is sometimes used interchangeably with 4G, but it's really just one of its many parts. 4G is an ongoing evolution of new standards and technology, taking advantage of improvements like new frequency spectrum and data compression techniques as they become available. The once competing standards of GSM/EDGE/UMTS and CDMA2000 are essentially merged, albeit with a legacy effect that still prevents many devices from working across all networks. Planned download speeds for 4G have not yet been realized and may never be depending upon where you live, but even today you can still watch a 1080p video on your tablet, smartphone, or wrist watch, and you don't have to be in the middle of a metro coverage area to do so. It wasn't long ago that coverage gaps for plain voice calls was common, yet now you can watch movies.

Theoretical speeds for 4G are still listed to 1Gbps, but actual downstreams are much slower, around 20Mbps, although they will continue to improve. Still, in the US, wireless data speeds are not that far behind average broadband speeds carried by fiber and cable, and are jaw-dropping when compared to previous 3G technology. By the time it's reached final deployment, some late 4G installations might be pushing that original 1Gbps, already being termed "4.5G" to distinguish between the difference in different 4G category levels of performance. If nothing ever came after it, we would be doing pretty well with 4G, even into the 4K video generation.

5G Performance

As you would expect, 5G should improve upon 4G. Current specifications for 5G downstream speeds are anywhere from 1 to 10Gbps on paper, but out-the-gate speeds will probably be closer to 1Gbps in practice. Even that sounds pretty good, and this isn't just wishful thinking -- 5G will have to provide that. A 1080p high-definition video requires around a 12Mbps data stream, but a 4K video will require at least 50Mbps (85% compression assumed for both). If you want to watch and record at the same time, double that. If your video source provides an option for less compression in order to take full advantage of that 4K image with high-dynamic range, double it again. Japan's NTT DoCoMo will be trialing an 8K broadcast for the 2016 Rio Olympics in preparation to air the 2020 Tokyo Olympics in Super Hi-Vision 8K video[1], which can be expected to *quadruple* the bandwidth requirement of 4K to 200Mbps+, per Figure 1. And if you want to tether some nearby devices via your 5G wireless modem, whatever it's form, just keep adding on those megabits.

Users are also going to expect a fast response to whatever they are trying to do. 4G latencies are in the 100ms range today, although they can vary significantly. Several 5G specifications are already calling for 5 ms, and even 1 ms latencies, either of which would provide essentially instantaneous response to the user. That's not going to be easy to achieve, even for just the number of mobile devices out there today. And therein lies another challenge. Because a lot more of those devices are coming...

The Internet of Things

5G is not just about the bandwidth. One of its biggest benefits is the ability to support billions of new devices that will soon connect to the internet. In this way, 5G will do something different that none of the other cellular data standards had to do: Form the backbone of the machine known as the *Internet of Things* (IoT).

Although it's been discussed for some time now, the IoT and 5G are going to redefine the idea of what the internet can be used for. It's already started. Animal trackers, utility power meters, street lights, security systems, medical monitoring,

"5G should provide at least several hundred Mbps. This isn't just wishful thinking -- 5G will have to provide that."

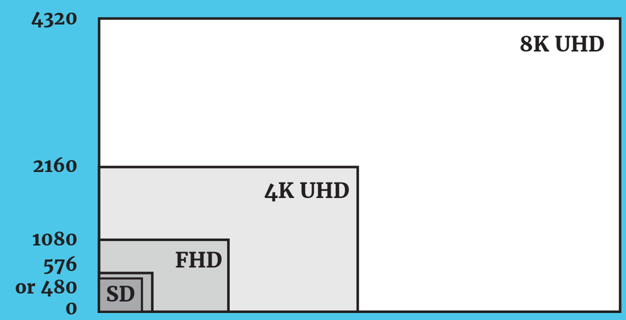


***Figure 1 -** Comparison of resolutions for up-coming video broadcast formats. Bit streams of data will be in proportion to the size of the shaded area. 4K video requires 4 times as much data as Full High-Def (FHD). 8K will use 16 times the data of 1080p FHD.*

and of course your TV and DVR. Some things are wireless, while others are wired, but the latter will still create data that's sent to wireless devices.

And there are a lot more of those "things" coming. Your car. Your porch light. Your microwave oven. Your ID badge. Your valuables. Maybe even your pencil sharpener. If there's a reason to turn it off, turn it on, measure it, view it, or monitor it, you're going to be able to do it wirelessly via the internet. Many of these new devices will also have to communicate amongst themselves, known as machine-to-machine (M2M) or machine-type communication (MTC). Just right now, you might have started thinking about certain movies where computers take over the world, or big-brother is watching your every breath. There undoubtedly are valid concerns over safety, privacy, and interference, but the upcoming deluge of new cellular devices is unstoppable.

As with any population increase, density becomes higher. Bell Labs Consulting predicts that more than 1 million devices per radio cell can be supported[2], while the IMT-2020 5G Promotion Group, which includes companies like China Mobile, Huawei, and ZTE, similarly predict 1 million devices per square kilometer[3]. Several sources outline a connection density of up to 100 cellular devices per square meter. Imagine 100 cell phones (or like transceivers) on a small kitchen tabletop, all actively making calls, sending texts, telemetry, or playing videos. Simultaneously. Without interfering with each other. That's one of the primary visions for 5G.

Of course, no one expects such a dense number of devices to be downloading 4K movies all at the same time. But you might get 5 or 6 mobile devices per square meter within a crowded coffee shop or sell-out football game. The demands upon the system are going to be immense compared to today.

There's also a question of customer expectations, and what customers are willing to pay for the needed bandwidth. A single 4K movie is expected to be at least 100GB in size. Most monthly data plans today don't even go that high. The price of data will have to continue to drop in order for 5G to be adopted. Also, the continuing build-out of fiber-to-the-prem (FTTP) and DOCSIS 3.1 will make gigabit speeds the norm. A wireless speed of 1Gbps sounds fabulous right now, but that will soon be just on par with wired speeds, so wireless will have to provide value when marketed against those other options. 4G has done a pretty good job of staying close to average wired speeds. 5G will certainly be expected to as well.

IoT: Cars and Clouds

Let's look a little more at all those new devices that will be using cellular connections. When we use the term "cellular" we mostly think of phones, and perhaps tablets.

But soon, your car will have a connection (or more likely, several connections) to the internet: for media, engine telemetry, and navigation to allow the car to drive itself, or if you insist on keeping the wheel, to provide you with more accurate directions than GPS can provide now. A little higher up, the use of small drone aircraft for common, every-day commercial purposes seems just about here, and these will require at least one cellular connection, and possibly more for redundancy. Products you buy in a store or have shipped to you might use cellular tracking (as opposed to near-field RFID) as the cost of system-on-a-chip cellular ICs drop, allowing active location lookup anytime rather than waiting to be scanned at some location.

“Computers have a data bus between the processor and hard drive. That bus might soon become the 5G network.”

“Your car is not connected to the internet.
Do you want to diagnose connection problems?”

“QoS is really more a question of high priorities and higher priorities.”

But the really big new user of mobile data is cloud storage. The shift to cloud storage, and even the shift to cloud processing, is well underway. In the days of mainframe computers, it was common to use central storage and processing, where user terminals connected to these central resources through cables. Personal computers made it possible to combine those elements into one enclosure. Now you can de-centralize them again, migrating storage and processing back to central servers. Of course, this will impose a burden on wireless networks, especially since we have become so accustomed to transferring huge amounts of data with our PCs, and doing so in real time. Personal computers have an address and data bus between the processor and hard drive. For many, that bus might soon become the 5G network.

Just as important as bandwidth is quality of service or QoS. You may be annoyed to see your 4K movie stutter, but a self-driving car won’t do well with latency problems and out-of-order packets.

QoS typically assigns priority to voice calls, financial transactions, emergency services, etc., but let’s face it: Everything is high priority to the end-user. It’s really more a question of high priorities and higher priorities. You don’t want your self-navigating car to stop getting its directions at 65 MPH, nor do you want a drone flying into your kitchen window. But slow and choppy videos are not going to be acceptable either.

Also not to be underestimated is the myriad of new, low-bandwidth devices and M2M/MTC applications that will send a small but steady stream of data. Has the mail arrived yet? Do your water filters need changing? Should stock quotes be pushed every 1/10th of a second or every 1/100th? How far is your car from that right turn you need to make? How far is it now?

All of these new applications will have a constant drip-drip-drip effect on the network, billions of times over, with each network-access “drip” needing its own set-up time and routing instructions. Bandwidth may not be the problem so much as processing time. Depending upon the application, some latency will be acceptable, but those packets will still have to be processed quickly and reliably, because new “drips” will be arriving all the time.

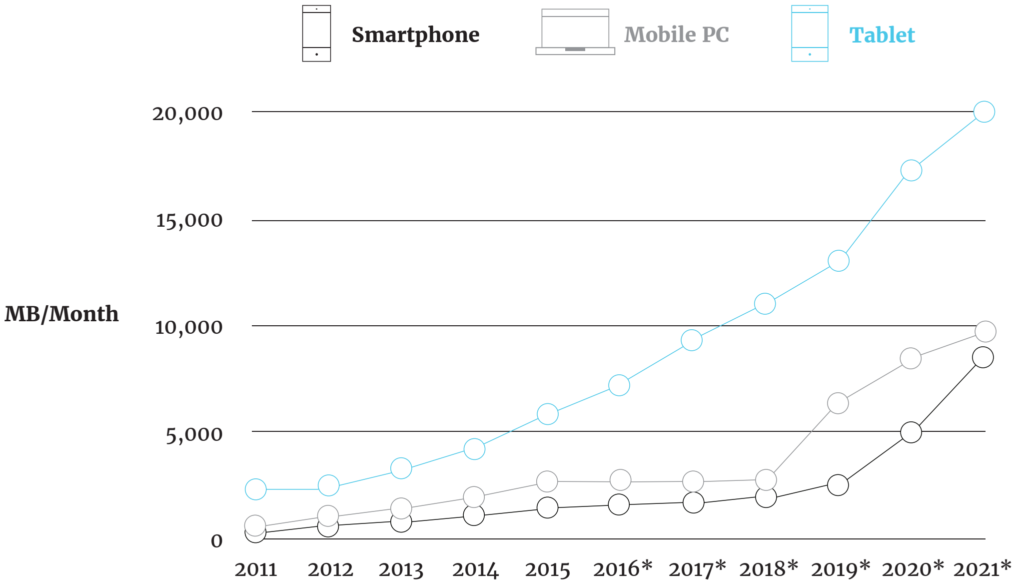
Big Numbers

To get the most out of the still-evolving 4G and upcoming 5G networks, new millimeter wavelength frequency spectrum is being allocated in various radio bands, such as the 28GHz Ka band, to as high as the 100GHz W band. We didn't even know there was a W band. Practical use of such dizzying frequencies is a good example of some of the research going into 5G, as are advanced MIMO (multiple-in, multiple-out) antennas that can be dynamically phased to form spot beams targeting specific users, or to increase omnidirectional gain, or some combination of both.

Google self-driving car

Huge challenges remain. The enormous bandwidth possible at such frequencies also invites major problems with path loss (much shorter overall range), signal propagation through objects or poor weather, and the considerable cost to develop the electronics. Currently, there's nothing cheap about 100GHz.

By 2020, Bell Labs Consulting estimates that up to 4.6 billion IoT devices could be connected to the internet via cellular. Ericsson estimates even more, with up to 26 billion wireless devices[4] (using cellular or Wi-Fi), including phones, tablets, computers, consumer electronics, and machine-to-machine. In mid-2015, it was estimated by Vouchercloud that 2.5 quintillion bytes of data were being created globally every day[5]. As you can see in Figure 2, data use is estimated to rise 4 times from 2015 to 2020, and that doesn't even consider the bandwidth or "transaction" cost for the short but repetitive machine-to-machine devices, which Bell Labs estimates may generate up to 2,500 transactions per megabyte transferred. Bandwidth and real-time processing have a high bar to meet.



Source: Ericsson Mobility Report, 2013-2016
* Estimated

Figure 2 - *Current and estimated device data usage in MB/month over the cellular network, 2011-2021. Machine-to-machine and other new device types are not included. 1MB (megabyte) = 8Mb (megabits).*

2G+3G+4G=5G

By now, you might be wondering how 5G will accomplish all that it promises to do. It's not as easy as slapping on some new frequency spectrum. We all know there are diminishing returns like Moore's Law, spectrum scarcity, RFI, lossy-compression limits, etc. The 3G Partnership Project (3GPP) doesn't even expect to have a formal standard on 5G until 2020. However, that isn't slowing several companies from developing technology for it now.

Nokia has demonstrated in a trial that it can use multiple existing technologies to aggregate bandwidth. It's like system-bonding instead of channel-bonding. 2G, 3G, 4G along with new 5G equipment, and other technologies like Wi-Fi and fiber optic, are used simultaneously to move huge amounts of data over those multiple network technologies. This requires intelligent algorithms to divide and later re-assemble these multiple streams of data, termed by Nokia as a "system controlling systems". In effect, get the data there any way you can, every way you can. Implementing this system-of-systems will require some significant development, but the reward is enticing: Up to 10Gbps download speeds would be possible, says Nokia. There are other challenges, including the question of using common Wi-Fi frequencies for a service provider solution, as some feel that commonly available Wi-Fi frequencies are like the Citizen's Band of domestic wireless radio. Still, there's a lot of new radio spectrum opening up, and 10Gbps does has a nice ring to it. Figure 3 gives an idea of how a 5G radio "pipe" might include some or all of the existing equipment that a provider already uses, plus the new spectrum.

In addition to maximizing the utility of existing network equipment, using multiple streams is inherently more redundant, offers possibilities to load share, and it can easily re-route based on network congestion, all of which are important QoS considerations for higher-priority traffic. The other obvious benefit is the service provider can decide what network equipment to aggregate, whether it's 2G, 3G, 4G, legacy core, and/or customer-facing plant and equipment. Gradual upgrades can be applied to the network, such as by technology or by region or other criteria. The service provider can upgrade what it wants, when it wants.

"Get the data there any way you can, every way you can."

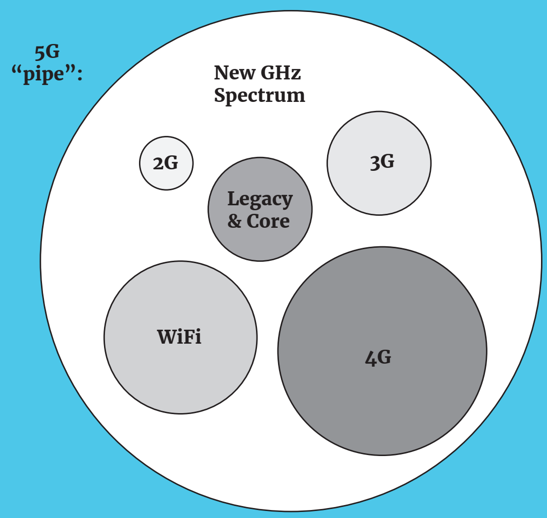


***Figure 3 -** 5G will add new RF spectrum, but it could also aggregate bandwidth from existing network technologies.*

In addition to maximizing the utility of existing network equipment, using multiple streams is inherently more redundant, offers possibilities to load share, and it can easily re-route based on network congestion, all of which are important QoS considerations for higher-priority traffic. The other obvious benefit is the service provider can decide what network equipment to aggregate, whether it's 2G, 3G, 4G, legacy core, and/or customer-facing plant and equipment. Gradual upgrades can be applied to the network, such as by technology or by region or other criteria. The service provider can upgrade what it wants, when it wants.

Japan's NTT DoCoMo has also conducted 5G field trials, where true 3.6Gbps peak download speeds were achieved by multiple participants, who were tasked with trying to mimic real-world mobile scenarios[6]. Equipment used was from a combination of manufacturers including Alcatel-Lucent/Nokia, Ericsson, Fujitsu, NEC, and Samsung. Although it's a little early to know what actual 5G speeds will be available when ready for primetime, just consider that most of us have never even experienced 10% of that kind of throughput through any kind of media. In 1998, we had 56Kbps. By 2018, we might have 10,000 times that for half-gigabit speeds. In another 5 years, 100,000 times that for 5.6 gigabit speed is possible.

Australia's Telstra has aggressively started upgrading its network, installing the latest "category 16" incarnation of 4G, which has theoretical 1Gbps capability, and it wants to trial 5G in time for the 2018 Commonwealth Games[7]. Telstra says they have already achieved 11Gbps in a lab, but no word on whether they are using something like the Nokia system-of-systems bonding technology to do so.

And just in case you thought North America would be last to the 5G party, think again. Verizon is already testing 5G *right now*, and expects to trial 5G in New York, San Francisco and Boston[8] by 2017. There's no word on the exact technology Verizon is employing, but they are part of the 5G Technology Forum which includes heavyweights like Cisco, Ericsson, Intel, LG, Nokia, Qualcomm, and Samsung. There probably won't be many 5G devices by that point, and standards will continue to solidify, but it's clear that 5G isn't going to be another HDTV-in-20-years fiasco.

Conclusions

Like all the wireless generations before it, 5G will bring a huge bump in speed, but it will also provide the backbone for a still-emerging internet that will be comprised of billions of devices, many of which will not directly communicate with a human being. It will be expected to provide nearly instant responses to its human users though, and it will become critical to how businesses and consumers send and receive data, so much so that delays or outages will be intolerable. Absolute prices for data will drop, but the quantity of data used will skyrocket. Watching video in 1080p will be standard, and 4K will be common. 8K video will likely be widely available too, and it might possibly even leap-frog over 4K, putting demands on the network which today are unthinkable.

Even without a finalized set of standards, we already know that 5G will bring several big advantages:

- Faster real-world speeds than 4G
- Much higher device density
- QoS - multiple data paths inherently supporting redundancy, load-sharing, congestion avoidance, and traffic allocation, and through these, a self-healing network
- Upgrades to customer-facing plant and equipment can be rolled-out as needed
- CAPEX investment spread over time, while the existing network generates revenue to pay for it
- Existing equipment can be maintained for a fraction of the cost of replacement, yet contributing to the 5G pipe

Like 4G, the benefits of 5G won't occur all at once, but will come as a series of refinements and improvements. The first 5G trials have already started, and real commercial availability for the masses should be here by 2020, even before official standards are completed, as development continues concurrently. How much further is it to 2020?

John Robertson
Research and Development Engineer
Fortress Solutions

[1] NTT DoCoMo website and the "New Initiatives towards Delivery of Medium-Term Targets", April 28, 2015 and CorporateSundae article "Some Olympic events will air in 8K and VR this year", March 8, 2016.

[2] Alcatel-Lucent Techzine, "5G enabled by massive capacity, connectivity", April 20, 2016.

[3] IMT-2020 (5G) Promotion Group, "5G Vision and Requirements", 2014-2015 white paper.

[4] Ericsson Mobility Report, June 2015.

[5] Vouchercloud - "Every Day Big Data Statistics - 2.5 Quintillion Bytes of Data Created Daily" article, April 5, 2015.

[6] Cellular-News, "Japan's NTT DoCoMo to Start Testing 5G Mobile Networks", May 8, 2014.

[7] itnews, "Telstra to deliver 1 Gbps mobile speeds this year", February 22, 2016.

[8] Tech Times, "Verizon 5G Network Would Be As Fast As Google Fiber 1Gbps Internet Service: Report", December 15, 2015, and the Verizon website, "The 5G future is closer than you think", January 28, 2016.