

The Intersection of HFC and 5G

A Technical Paper prepared for SCTE/ISBE by

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Table of Contents

Title	Page Number
Introduction _____	3
Content _____	3
1. Wireless Mobility Evolution _____	3
2. 5G Timeline and Foundational Pillars _____	4
3. 5G Spectrum and Radio Access Network (RAN) Densification _____	7
4. The 5G PAC (Power, Attachment, Connectivity) Conundrum _____	10
Conclusion _____	12
Abbreviations _____	13
Bibliography & References _____	14

List of Figures

Title	Page Number
Figure 1 – Cellular Standards Timeline. Source: Broadband Advisors Group, LLC	3
Figure 2 – Verizon Wireless and ATT Coverage Map. Source: Engadget.com	5
Figure 3 – Key Capabilities IMT 2020 (5G) vs IMT 2015. Source: ITU-R M.2083.0	6
Figure 4 – 3GPP Release Calendar. Source: 3GPP.org	7
Figure 5 – Spectrum by Carrier US. Source: Sprint	9
Figure 6 – Cellular Block Licenses – top 3 US markets. Source: FCC	10
Figure 7 – 500-foot small cells, 1-mile diameter Macro cell. Source: Broadband Advisors Group, LLC	11
Figure 8 – 500-foot small cells integrated with HFC network. Source: Broadband Advisors Group, LLC	12

Introduction

5G. 5G. 5G. On billboards, in your inbox, at your favorite tech blog:

- 5G - **What** is it?
- 5G- **Where** is it?
- 5G - **WHEN** is it?
- 5G - **How** will it be different for users and the supporting infrastructure?
- 5G - **Why** do we need it?

One of the foundational differences of 5G from the previous mobile communications Generations is its density – perhaps 10x or more than 4G – driving the need for Location, Power, and Connectivity for the Radios that the Hybrid Fiber-Coax (HFC) network is potentially well-equipped to support. This paper will delve into the 5G topology to answer those questions and review performance expectations and how they might map into an HFC network with Data Over Cable Service Interface Specifications (DOCSIS) 3.0 and DOCSIS 3.1

Content

1. Wireless Mobility Evolution

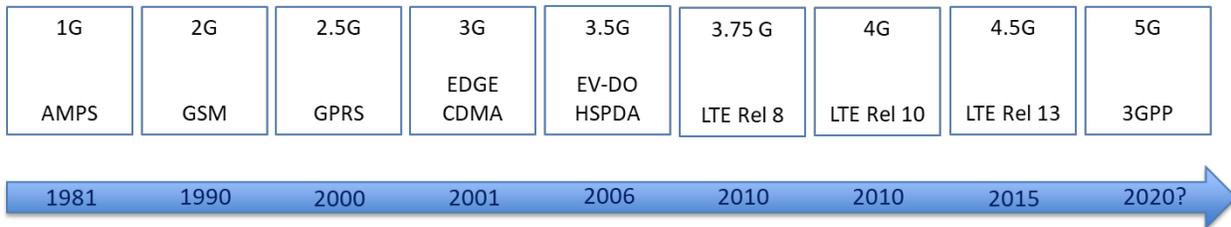


Figure 1 - Cellular Standards Timeline Source: Broadband Advisors Group, LLC

Cellular communications as we know it today began in the early 1980s with the Advanced Mobile Phone System (AMPS), often colloquially referred to as Analog Mobile Phone Standard since the communication was indeed analog and could be listened to (one end of the call) by an eavesdropper with a scanner. The AMPS standard broke the spectrum bottleneck and lowered power requirements for the mobile stations by replicating the spectrum bandwidth through “cells”, radio transmitters/receivers serving a specified geographic area. Adjacent “cells” would use different frequencies to minimize interference, and the key to operational success was the Mobile Switching Telecommunications Office which through telemetry with the handset supported switching from one cell to the next rapidly enough that calls would stay connected and conversations would be able to be conducted normally. AMPS was launched in the 850 megahertz (MHz) spectrum, and was subsequently expanded into reclaimed ultra-high frequency (UHF) broadcast spectrum to add bandwidth.

As mobility technology developed in the late 1980’s, there was an effort in Europe to develop mobility standards that would be digital, work cross-platform, and more importantly enable international roaming between countries, and the Global System for Mobile (GSM) standard set came to life. GSM is a joint

Time Division Multiple Access (TDMA) / Frequency Division Multiple Access (FDMA) modulation schema, and also brought along the Simple Message System (SMS) with its 160-character limitation.

The first packet-switched cellular data service, General Packet Radio Service (GPRS) introduced data service to complement voice and SMS around 2000.

As data use ballooned, GSM continued its development with the Enhanced Data Rates for Global Evolution (EDGE) that was marketed by some operators as 3G for third-generation cellular capabilities. Concurrently a competing standard – Code Division Multiple Access (CDMA) was developed and in the United States some providers chose GSM (AT&T, T-Mobile) while the others chose CDMA (Verizon, Sprint, US Cellular) setting up a handset challenge as for many years handsets only had one chipset or the other in them and could not operate on the other network. Both standard sets supported higher data rates through denser orders of modulation.

CDMA was further enhanced with Evolution – Data Optimized (EV-DO) which introduced a separate data channel that would work in tandem with the voice channel. High-Speed Packet Access (HSPA) was the corollary in the GSM ecosystem.

Recognizing that there was both an insatiable demand for mobile data consumption and that handsets would soon be available with chipsets that could support both GSM and CDMA, the 3 Generation Partnership Project (3GPP), a consortium of international standards bodies charted a path of network development towards the 4th Generation environment, which they named Long Term Evolution (LTE), trademarked by the European Telecommunications Standards Institute – (ETSI) that would provide both platforms with download speeds of up to 300 Megabits per second (Mbps) per cell, along with support for additional frequencies and improved centralized communications management.

Release 8 LTE provided a pre-4G capacity and bandwidth network performance enhancement including carrier-width support from as little as 1.4 MHz to as much as 20 MHz and a much more spectrally-efficient air interface modulation – Orthogonal Frequency Division Multiple Access (OFDMA). The rapid improvement in data performance provided impetus for operators to market these enhancements as 4G though officially 4G was tied to release 10 that included carrier aggregation and Multiple In Multiple Out (MIMO) antenna support. Release 10 is marketed as “True 4G” or LTE Plus in Sprints case.

2. 5G Timeline and Foundational Pillars

As the mobile environment moves towards 5G, it is important to understand that there is are marketing and user-experience components that have driven consumer acceptance and expectations of the performance of the cellular networks. Two main factors have been in play:

1: Coverage – how much of the US the network covered – we all remember the Verizon television commercials with the “Can you hear me now?” guy – giving customers confidence their phone calls would connect and wouldn’t drop.

2: Connectivity – as in to the internet – with increasing performance; 3G, LTE, 4G, LTE-Plus, along with battling maps in TV commercials and on billboards.

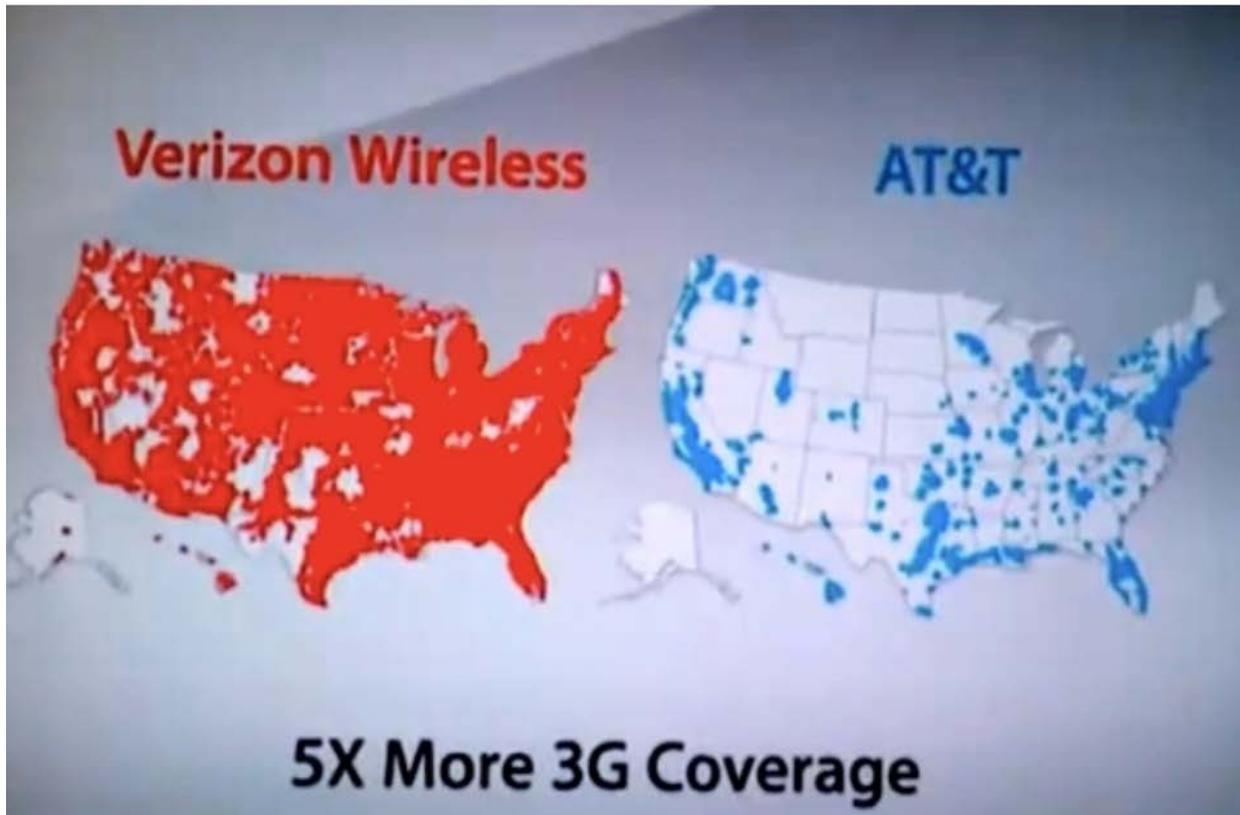
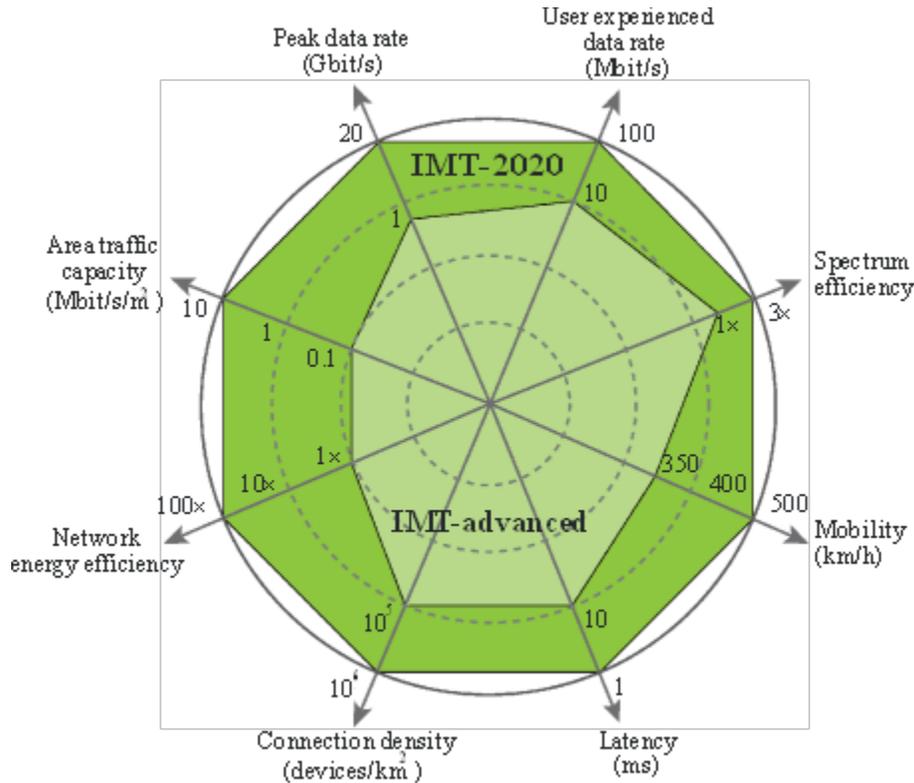


Figure 2 – Verizon Wireless and ATT Coverage Map Source: Engadget.com

What was not messaged, marketed, or even remotely hinted at was the speed/bandwidth of the data connection, contrary to how wireline (or satellite) internet services are sold with claims of “Speeds up to...X Mbps” with the FCC Broadband America report and sites like Speedtest.net validating those claims. There are a couple of key differentiators that drive this dichotomy. First, 4G/LTE handsets and networks under optimal conditions can deliver speeds for a test of up to 100 Mbps, but in reality, given that one phone and user can only do one thing at one time, there is not a practical need for more than a few Mbps for typically video streaming. Second, except for Wi-Fi tethers, only one device, the mobile phone, is consuming bandwidth concurrently, unlike the home environment where dozens of devices may be connected and requiring bandwidth.

The 5G topology is designed to move away from the “Coverage/Connectivity” environment to one where much higher connectivity speeds, much lower latency, and a huge increase in the density of connected devices is expected.

A joint effort is under way led by the 3GPP and the International Telecommunications Union (ITU) to develop and promulgate standards that will support the planned capabilities of the International Mobile Telecommunications (IMT) system 2020, the 5G network we have all been hearing about.



M.2083-03

Figure 3 - Key Capabilities IMT 2020 (5G) vs IMT 2015 Source: ITU-R M.2083.0

The chart above depicts the expected increase in capabilities of the 5G network (IMT 2020) vs the 4.5 G network (IMT 2015). You likely have heard of peak data rates of 1 Gigabit per second (Gbps), along with Internet-of-Things (IoT) connection density, and latency between radio and network in the millisecond (ms) range, there are other key vectors including improved Network Energy Efficiency, Improved Spectrum Efficiency, and increase in Mbps-per-square-meter. The big question is – when will all these new capabilities come to fruition?

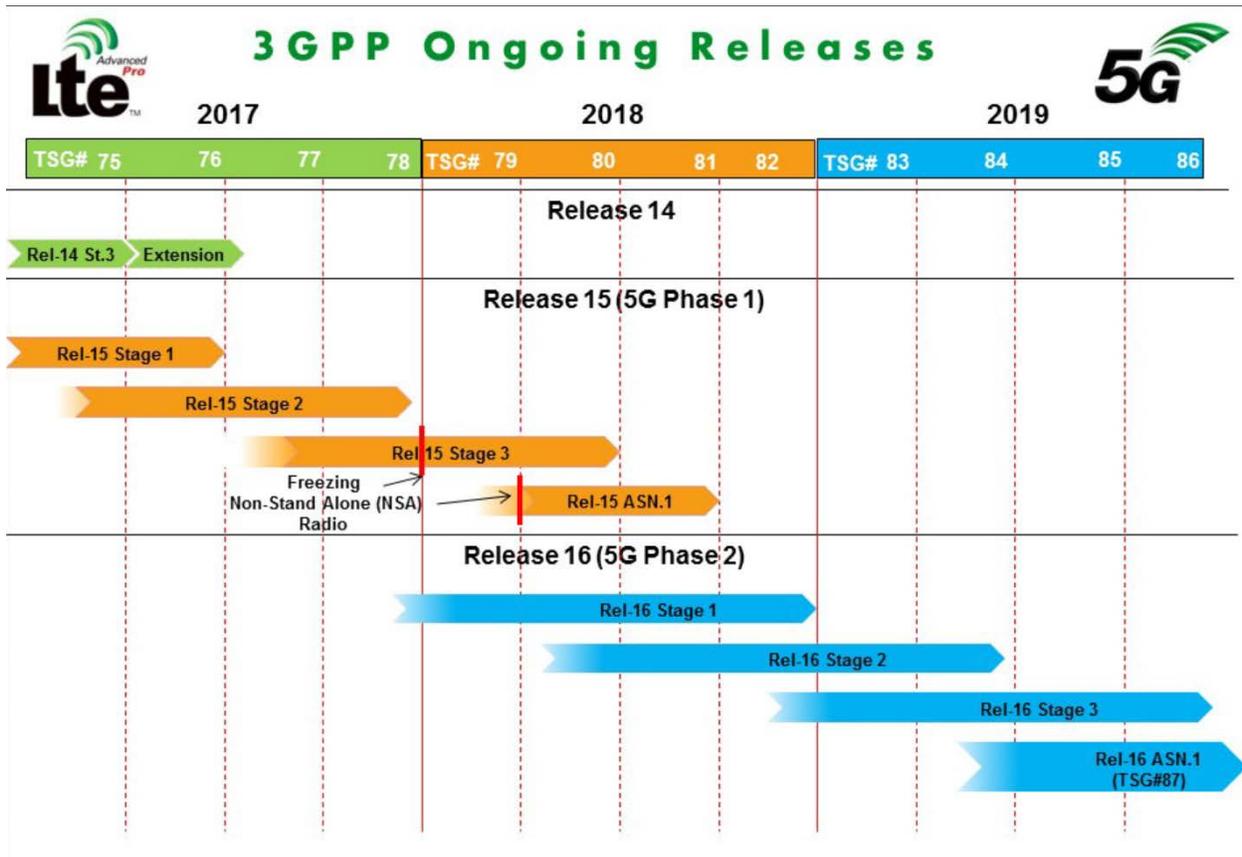


Figure 4 - 3GPP Release Calendar Source: 3GPP.org

To answer that question, we go to the 3GPP Release Calendar, which earlier this year anticipated locking down the 5G Standards in the middle of 2018. However, at the urging of all the large US mobility carriers and others, the 3GPP agreed to accelerate by about 6 month the standards for Non-Stand Alone (NSA) Radios.

This should allow silicon to be developed and integrated for initial deployment of NSA upgrades in 2019, with the remaining standards coming to market in 2020 but likely taking a couple of years to develop scale. One important point to note is that 4/4.5G does not go away in a 5G world, but will both interact with support, and be supported by 5G technologies.

Now that we have reviewed some of the platform expectations of the 5G network, how do we get to Gbps downloads with billions of connected devices?

3. 5G Spectrum and Radio Access Network (RAN) Densification

When more bandwidth is needed in a communications network there are three main levers to pull individually or in combination to develop the increase:

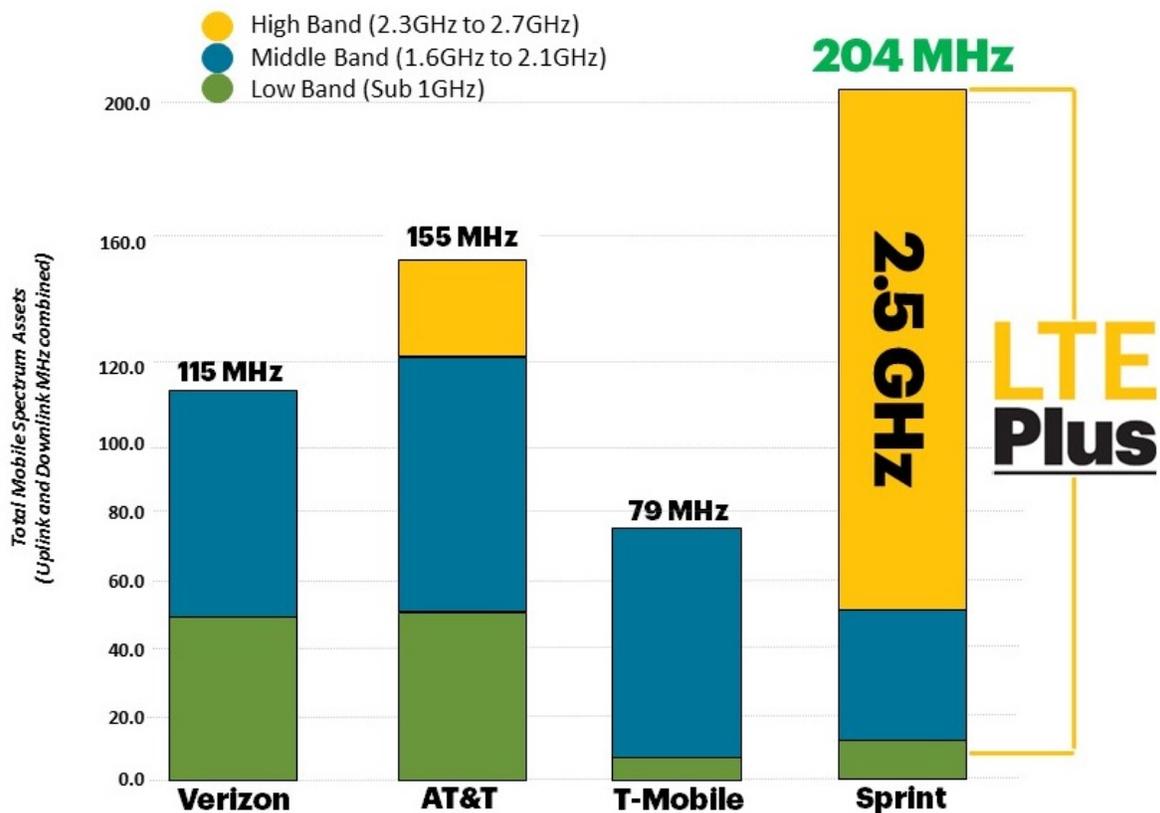
- 1: Obtain more spectrum

- 2: Increase the efficiency through denser modulations allowing the transport of more bits per hertz
- 3: Enable the re-use of spectrum through network densification

The 5G roadmap delivers on all three, all of which the cable industry has employed going from 300 MHz to 1 gigahertz (GHz), moving from Quaternary Phase Shift Keying (QPSK) to 256 Quadrature Amplitude Modulation (QAM) and beyond, and performing node recombines, node splits, and service group splits for spectrum re-use.

On the spectrum front, there are two very significant additions from the legacy cellular world:

- 1: Potentially using unlicensed or shared spectrum such as the 3.5 GHz Citizens Broadband Radio Service (CBRS) in the US.
- 2: Employing hundreds of MHz of spectrum at very high frequencies such as 28 GHz and 39 GHz. It should be noted that these higher frequencies are commonly called “millimeter wave”, however only the 39 GHz spectrum has sub-centimeter wavelength of ~7.6 millimeters (mm).



Nationwide, population-weighted average spectrum assets as of 2/7/17. These numbers are national averages and do not represent the spectrum assets in any specific market.

Figure 5 - Spectrum by Carrier US Source: Sprint

The figure above reflects approximate spectrum of the 4 major US carriers reflecting population-weighting (how much spectrum per average person) versus geographic coverage. Each of the spectrum areas are broken up in a number of blocks/channels, ranging from 10 to 30 MHz in width that are continually reused in alternating cells. Though mileage may vary, for the purposes of providing bandwidth scoping and to make the math easy we will assume throughput on the order of 5 bits per hertz, so a 10 MHz channel would support ~50 Mbps, a 20 MHz 100 Mbps, etc. By aggregating channels together, the carriers are able to deliver higher total throughput, but the challenge for handset manufacturers is adding more antennas and tuners while managing battery life.

The chart below provides the licensee status of the cellular spectrum blocks in the top 3 US Markets.

CHART OF LICENSEES

CMA	CMA Name	Cellular A Block	Cellular B Block	PCS A Block	PCS B Block	PCS C Block	PCS D Block	PCS E Block	PCS F Block	PCS G Block
1	New York, NY	AT&T	Verizon Wireless	AT&T, T-Mobile	Sprint Nextel	Verizon Wireless	T-Mobile	AT&T	Verizon Wireless	Sprint Nextel
2	Los Angeles, CA	AT&T	Verizon Wireless	Sprint Nextel	AT&T	T-Mobile, Verizon Wireless, Metro PCS	AT&T	Verizon Wireless	T-Mobile	Sprint Nextel
3	Chicago, IL	AT&T	Verizon Wireless	AT&T	US Cellular, Verizon Wireless	T-Mobile	Sprint Nextel	Sprint Nextel	AT&T	Sprint Nextel

Figure 6 - Cellular Block Licenses – top 3 US markets Source: FCC

The new cm/mm frequency blocks are where significant bandwidth can be added – the 28 GHz block goes from 27.5 to 28.35 GHz, and the 39 GHz block goes from 38.6 to 40 GHz with some license holders having as much as 600 MHz in certain cities. Though there is a lot of bandwidth in these bands, they are not without challenges. Higher frequency signals do not propagate as far, cannot penetrate buildings well, and are reflected more easily than the lower-band cellular channels. (For you cable folks that remember rain fade on Community Antenna Relay System (CARS) Band microwave links, these cm/mm wave frequencies “enjoy” tree fade and a simple brick/stud/sheetrock wall can introduce ~30dB of attenuation).

Innovative players like Vivint have developed platforms in the 28 GHz spectrum that use a hybrid approach – a high bandwidth point-to-point link is established between a tower or other transmitter location to a rooftop of a “hub” – a home with clear line-of-sight to the tower and an owner willing to allow antennas to be placed on the roof (typically in exchange for free internet) which then can serve as many as 24 other homes via 5 GHz Wi-Fi. This example demonstrates two key concepts in the coming 5G world:

- 1: 5G will serve fixed as well as mobile applications
- 2: Creative uses of multiple frequencies will be commonplace and enabled by the 5G environment. In fact, 5G can and will be used in low, mid, and high band legacy cellular frequencies either in tandem or standalone from the cm/mm bands.

A third concept is important to understand – the “brain” that will allow all these different bands, applications, and systems to interoperate in a sub-millisecond latency environment by definition cannot be back at the core as in the legacy cellular networks connected to the Mobile Telephone Switching Office (MTSO) – it must be near the edge, be able to cache data, and have significant localized intelligence. 5G proposes to solve this challenge with a combination of Software Defined Networking (SDN) and Network Functions Virtualization (NFV). These technologies will enable a multi-level network with autonomous local routing directed from a SDN controller. An example of this would be in a vehicle-to-vehicle communications system instead of the packets having to go from car to tower to MTSO to tower to car,

the Remote Radio Head (RRH) would have the SDN-enabled capability to connect the two vehicles locally.

4. The 5G PAC (Power, Attachment, Connectivity) Conundrum

In the 4G world of 2017 there are 300,000 – 350,000 classic tower/building-top cellular base stations – known in the industry as Macros, and tens of thousands of micro, pico and femtocells. Each cell site could cover as much as several square miles to only a diameter of 1000 feet or so. In the 4G environment absent new spectrum (and at this point not including modulation density improvements) to double the bandwidth would require doubling the towers, but the aspirations of 5G are for a ten-times higher Mbps per square meter – **10X!** The answer is cell-densification, also known as “small cells”. How small? In some proposals only a few hundred feet wide.

To illustrate this the example below shows a 4G “Macro” site with a 1-mile radius, and a subset of 500-foot radius small cells.

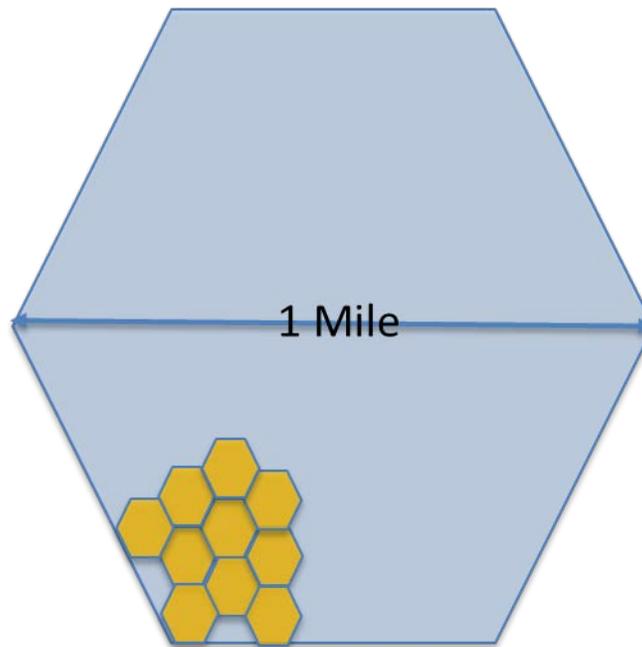


Figure 7 - 500 foot small cells, 1 mile diameter Macro cell

Source: Broadband Advisors Group, LLC

If a 1 square mile macro site (please note a 1-mile diameter hex is not a square mile – illustrative example) was to be fully populated with 500-foot diameter small cells – there would be more than 100 of them, with all the ensuing challenges of power, how/where to attach to light poles, power poles, strand, and how to get network connectivity to them. That’s not the end game for 5G – for one, the Macro site doesn’t go away – it remains serving 4G customer and perhaps enhancing 4G performance and coverage through 5G-enabling technologies such as the dedicated fronthaul/backhaul channel to the Macro site employed by the Sprint Magic Box.

If a cellular operator faces bandwidth challenges in residential areas, there are not many options if additional spectrum is not available – current tower locations are often as close to homes as the municipalities and residents will allow, and adding additional towers, even if a smaller monopole, requires significant time for zoning, permitting, and a fiber extension would be required.

What if an approach modeled after outdoor Wi-Fi networks was taken that could improve bandwidth?

Keeping with our model of a 1 square mile cell, what else is roughly a square mile that the cable industry has hundreds of thousands of? HFC Nodes. Ranging from as small as a couple tenths of a square mile in dense urban areas to several square miles in rural zones, if one looks at road-miles-per-square mile from state and county Departments of Transportation in suburban areas there are 5-7 road miles per square mile – sound familiar? HFC nodes serving 500 homes passed are around 5 strand-miles.



Figure 8 – 500 foot small cells integrated with HFC network

Source: Broadband Advisors Group, LLC

The example above depicts part of node with ~500’ diameter cellular base stations overlaid. Much like outdoor Wi-Fi deployments, these radios could solve the PAC conundrum by obtaining **Power** from the HFC network, being **Attached** via strand mount brackets, and by obtaining **Connectivity** through an embedded DOCSIS modem. Note that the overlays are not ubiquitous – one of the challenges with radio densification is managing interference, so the HFC-connected radios would be designed to cover areas with heavy bandwidth demand (a bus stop for example) or where coverage from the macro base needs to be improved.

For planning purposes, we will assume the radios would be similar to outdoor wireless equipment in terms of space, power consumption, and bandwidth – roughly the size of an amplifier or fiber splice

closure, drawing low tens of watts, and provisioned much like a residential or commercial cable modem with 50-100 Mbps downstream and 3-5 Mbps upstream.

In the power domain, if each radio consumed 20 watts, if 20 were deployed in a node, at 75 volts average input the current draw would increase by 5.3 amps, in most nodes requiring the installation of an additional power supply.

In the Connectivity domain, to make the math easy we will assume the modems are provisioned for 100 Mbps downstream (we will leave upstream out of this scenario as DS/US loads in the cellular domain are very similar those of wireline networks – much lower than downstream) – if the Macro site was congested, a dozen users waiting at the bus stop would have more than enough bandwidth to stream video from the local radio.

A second benefit is Internet-of-Things devices would be able to use dramatically less transmit power as the local radios would be hundreds of feet away versus thousands.

HFC operators would rightly be concerned about overloading their DOCSIS platforms as they were with outdoor Wi-Fi deployments, and certainly extensive traffic analysis and modeling would need to be undertaken prior to deployment. In this traffic modeling, as CEO of Charter Tom Rutledge has noted, more than 70% of the bits flowing down to a smartphone actually do not flow through the cellular network – they flow through the customer's home Wi-Fi network, attached to the cable modem and then through the DOCSIS network. The outdoor HFC-fed radios would only be supporting small volumes of short-duration activity such as a car driving down the street with a child in the backseat streaming video or a jogger streaming Pandora as she made her neighborhood rounds, and likely would consume traffic much like a residential modem – adding another 20 customers in a 500 homes-passed node would not overload a typical DOCSIS Service Group.

If this scenario was deployed, now the operators have another cellular backhaul revenue stream and the improved cellular coverage would provide better experiences for the cable customers TV Anywhere-type streaming via the mobility network.

As cellular densification continues and the need for bandwidth exceeds the evolving capabilities of DOCSIS, (some 5G nodes are postulated to need as much as 80 Gbps), fiber could be extended to the radio for connectivity with power supplied by the coax network – yet another demonstration of the flexibility and capability of the Hybrid Fiber-Coax Architecture.

Some equipment vendors have already implemented LTE-backhaul optical circuits in their optical nodes, and some early DOCSIS 3.1 Remote-Phy Devices (RPD) also have backhaul circuits. The current versions provide 1 to 10 Gbps symmetrical but 80 Gbps or more is on the near-term roadmap. Where these nodes/RPD's are deployed, a more powerful radio consuming more bandwidth could be installed nearby (known in the industry as a Mini-Macro) with little or no outside plant modification.

Conclusion

Now that we have reviewed the evolution of the cellular network, the forthcoming 5G augments to it, and how the HFC network might intersect with it, what have we learned?

- 5G - **What** is it? – an exciting new set of standards for wireless communications, both mobile and fixed, that will dramatically increase connectivity speeds, support much denser end-device connections, reduce latency, and employ new licensed and unlicensed frequencies
- 5G- **Where** is it? – Nowhere, but just wait...
- 5G - **WHEN** is it? – 2020 - with some field trials before and mass scale by 2022
- 5G - **How** will it be different for users and the supporting infrastructure? – Higher connectivity speeds, lower power requirements, better support for machine-to-machine traffic, much denser cellular radio network
- 5G - **Why** do we need it? – to solve the insatiable demand for higher bandwidth for smartphones, overcome cellular spectrum challenges, enable exciting capabilities such as autonomous vehicles, and support the explosion of Internet-of-Things connected equipment

As 5G comes to fruition, cable operators have opportunities to continue to expand the fiber-optic backhaul for macro sites and sites that will be employing large swaths of cm/mm wave spectrum, but also can potentially employ the HFC network for Power, Attachment, and Connectivity for cellular network densification in the legacy cellular radio spectrum.

Abbreviations

3GPP	Third Generations Partnership Project
AMPS	Advanced Mobile Phone System
CBRS	Citizens Broadband Radio Service
CDMA	Code Division Multiple Access
DOCSIS	Data Over Cable System Interface Specifications
EDGE	Enhanced Data Rates for Global Evolution
ETSI	European Telecommunications Standards Institute
EV-DO	Evolution – Data Optimized
FDMA	Frequency Division Multiple Access
Gbps	Gigabit per second
GHz	Gigahertz
GPRS	General Packet Radio Service
GSM	Global System for Mobile
HFC	Hybrid Fiber-Coax
HSPA	High-Speed Packet Access
IMT	International Mobile Telecommunications
IoT	Internet of Things
ITU	International Telecommunications Union
LTE	Long Term Evolution
Mbps	Megabits per second
MIMO	Multiple In Multiple Out
MHz	Megahertz
mm	Millimeter
MTSO	Mobile Telephone Switching Office
NFV	Network Functions Virtualization

NSA	Non-Standalone
OFDMA	Orthogonal Frequency Division Multiple Access
PAC	Power Attachment Connectivity
QAM	Quadrature Amplitude Modulation
QPSK	Quaternary Phase Shift Keying
RAN	Radio Access Network
RPD	Remote Phy Device
RRH	Remote Radio Head
SDN	Software Defined Networking
SMS	Simple Message System
TDMA	Time Division Multiple Access
UHF	Ultra-High Frequency

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