

5G Small Cells and Cable

Realizing the Opportunity

A Technical Paper prepared for SCTE•ISBE by

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Introduction

As wireless networks evolve from 4G/LTE to 5G, small cells will play a critical role in delivering the high bandwidth, low-latency connections required by the myriad potential 5G use cases. With regulators opening up new low, mid and high-band millimeter wave (mmWave) spectrum for 5G, MSOs are uniquely positioned to create ultra-dense 5G wireless networks by leveraging their existing hybrid fiber coax (HFC) networks and emerging technologies such as full duplex DOCSIS (FDX) and distributed access architectures (DAA). This paper examines the drivers for the adoption of 5G and the potential opportunities and challenges presented by 5G small cells based on insights from Shaw Communications’ recent deployments of 4G/LTE small cells, through its subsidiary Freedom Mobile.

5G Drivers

5G promises to dramatically transform the role that mobile technology plays in the world, creating new economic opportunities and promoting social development. By 2020, 5G is expected to add \$1 trillion to the economy of North America alone [1]. It will also impact all aspects of our society from facilitating smart-city energy grids and the Internet of things (IoT) to enabling autonomous vehicles and remote healthcare. The key drivers behind the shift to 5G include growing global demand for wireless services, ongoing advancement of wireless technologies, emergence of new use cases, development of global standards and the availability of new spectrum bands for 5G. These drivers are explained in more detail in the following subsections.

1. Demand

Global demand for mobile data continues to grow unabated as subscribers increasingly consume and share video content. In addition, as mobile devices become even more capable with added processing power, higher-resolution screens, and advanced features such as gesture-based interfaces, consumers are demanding faster, more reliable mobile connectivity.

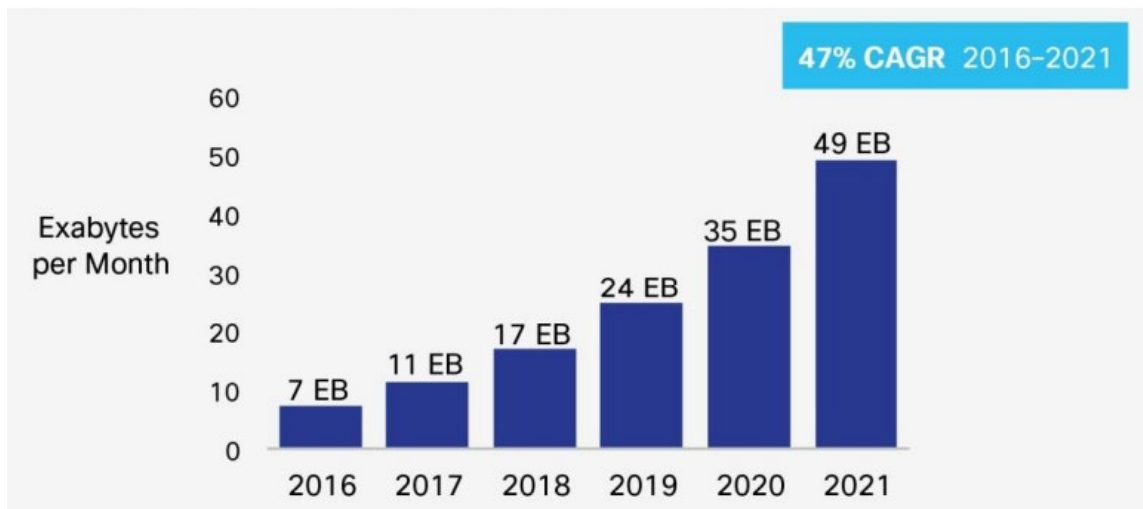


Figure 1 - Global Mobile Data Traffic (Source: Cisco Visual Networking Index 2017)

As shown in Figure 1, the Cisco Visual Networking Index (VNI) predicts that global mobile data traffic will increase 7-fold between 2016 and 2021, representing a cumulative average growth rate (CAGR) of

47% [2]. Cisco also forecasts that average mobile connection traffic per month will grow by over 5 times during the same period, from 1 GB in 2016 to 5.4 GB in 2021. The same study predicts that the number of mobile-connected devices per capita will reach 1.5 by 2021.

2. Technology

Another important driver for the adoption of 5G is the rapid evolution of wireless technology. Two key developments are massive multi-input multi-output (MIMO) systems and beamforming antennas, which together offer improved network coverage and traffic capacity. As shown in Figure 2, beamforming creates highly-focused beams from the base station to individual users. This counteracts propagation losses, particularly at mmWave frequencies and minimizes interference from other sources, both of which allow higher data rates to be supported than would otherwise be the case.

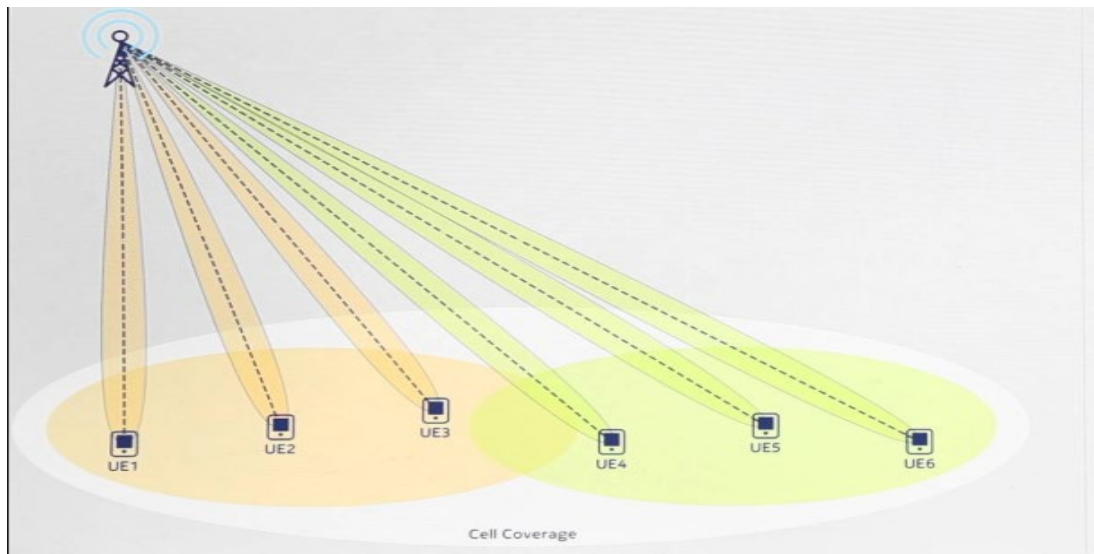


Figure 2 – Beamforming (Source: Nokia)

Massive MIMO in turn uses multiple antennas to simultaneously serve many users by exploiting multiple radio paths to increase system capacity.

Another key technology driving 5G is advanced channel coding techniques, which provide more efficient and robust data transmission compared with previous coding methods, supporting larger data blocks and more reliable control channels. A scalable OFDMA air interface has also been developed that efficiently addresses different spectrum, deployment and service scenarios by adopting a flexible subcarrier spacing and slot structure.

The 5G core network is also evolving to fully embrace network function virtualization (NFV) and software defined networking (SDN), which together will enable faster, more agile and scalable networks. As shown in Figure 3 below, network slicing will also allow core networks to be dynamically configured on a per vertical or per service basis.



Figure 3 - Network Slicing (Source: Nokia)

3. Standards

5G standards are also proceeding rapidly with the recent finalization of 3GPP Release 15 in June 2018. This release defines the 5G new radio (NR) standards for both non-standalone (NSA) and standalone (SA) operation. NSA operation allows inter-working with the existing 4G evolved packet core (EPC), while standalone (SA) operation is for the new 5G core network (CN). As shown in the figure below, the 5G CN standards are expected to be completed in Release 16 in the 1st half of 2019.

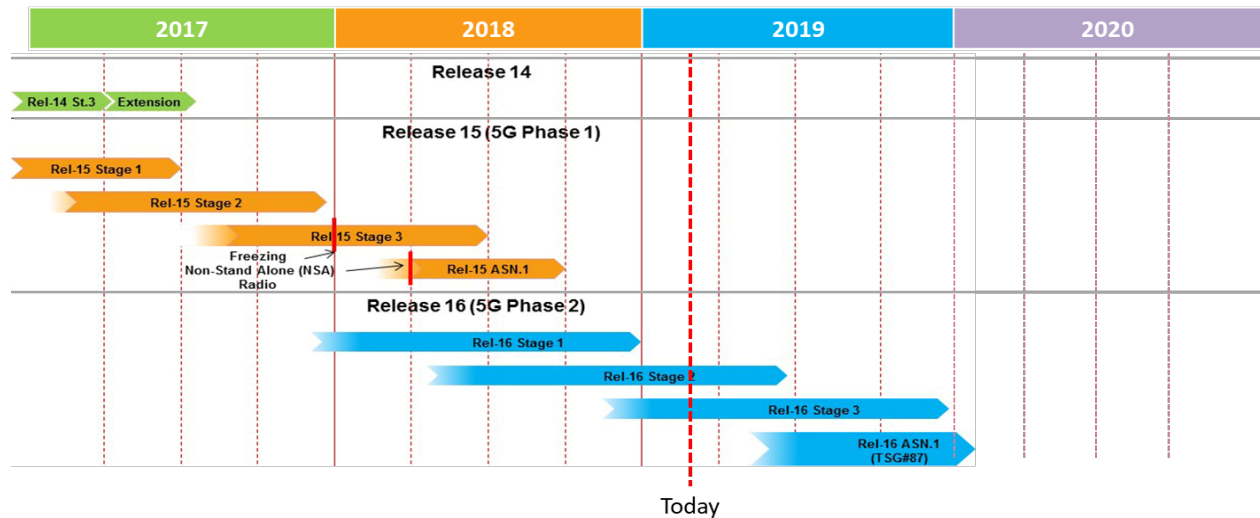


Figure 4 - 3GPP 5G Standards Roadmap (Source: 3GPP)

4. Spectrum

The allocation of low, mid and high band (mmWave) spectrum for 5G is also well underway or completed in several countries around the globe, including the U.S., Canada, Japan, China Korea, and European countries (see Figure 5).



Figure 5- Global 5G Spectrum Allocations (Source: Qualcomm)

In the U.S. and Canada, the initial bands designated for 5G include the 600 MHz, 3500 MHz and 24-28 GHz bands. Additional spectrum bands under consideration include the 3.7-4.2 GHz, 37-40 GHz and 64-71 GHz bands. The use of high-frequency mmWave spectrum bands above 24 GHz is emerging as a key 5G enabler. The use of these bands is very compelling because of the large bandwidths available at mmWave frequencies, enabling extremely high data rates and significant increases in capacity.

5. Use Cases

The key technologies noted above coupled with supporting standards and spectrum, create a range of fundamental new capabilities illustrated in Figure 6. As defined in IMT-2020 [3], these capabilities include 10x higher data rates, 10x lower latency, and 10x higher network efficiency than previous 4G networks.

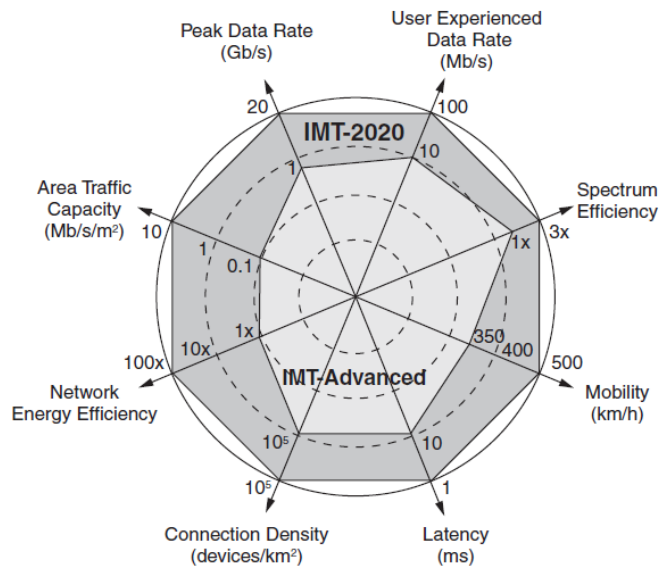


Figure 6 - 5G Capabilities

Given these new capabilities, 5G is expected to support myriad use cases, some of which haven't even been envisaged yet. Those that have can be grouped into 4 main categories: fixed wireless access (FWA), enhanced mobile broadband (eMBB), machine type communications (mTC), and ultra-reliable low latency communications (uRLLC), as shown in Figure 7.

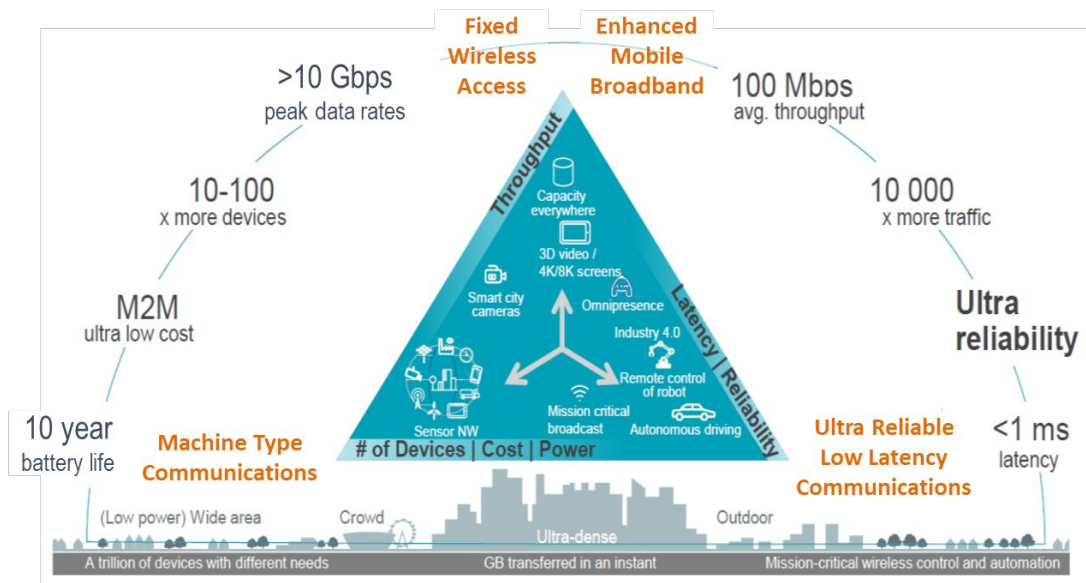


Figure 7 - 5G Use Cases (Source: adapted from Nokia)

FWA promises to deliver multi-gigabit speeds to fixed residential and business premises using mmWave spectrum. As such, FWA is an alternative to wired broadband services and represents a potential threat to traditional wireline providers including MSOs. At the same time, FWA also provides MSOs with the opportunity to deliver broadband services in “brown-field” areas that are not currently served by the

operator such as new residential markets and industrial/business parks. FWA can also be used to provide critical small cell backhaul in areas without existing wireline infrastructure.

eMBB, with its multi-gigabit per second speeds and inherent mobility, will support new immersive experiences such as virtual and augmented Reality (VR/AR), high resolution video, and “flash download/upload” uses cases such as software updates and video downloads. eMBB will also be used to support highly congested environments such as stadiums and airports.

At the other end of the scale, mTC will require much lower throughputs but will need to support billions of devices, often with very low energy consumption requirements. mTC has numerous applications in sensor networks, smart cities, agriculture, retail, logistics, and a plethora of other use cases in a world of increasing connected things.

uRLLC encompasses mission critical real-time applications such as industrial control, remote robotics, remote surgery/health and autonomous driving.

Network Densification and Small Cells

While 5G opens up a world of new use cases, it also comes with a number of important implications. One that represents both a challenge and an opportunity, particularly for MSOs, is network densification. That is, to realize the higher data rates and area traffic capacities promised by 5G, operators will need to deploy much denser network topologies using small cells. Figure 8 illustrates the transition that needs to be made from today’s networks, which are larger composed of macro cells, to 5G networks of the future with the targeted deployment of small cells.

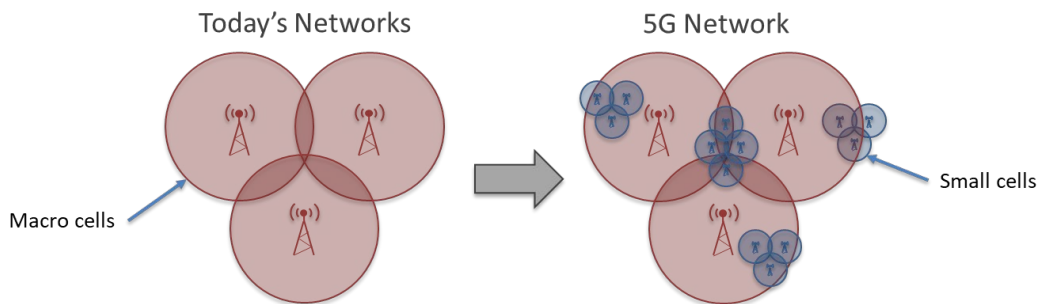


Figure 8 - Network Densification

For eMBB applications, for example, small cells will likely be deployed in both mid-band and mmWave bands depending on the type of environment. As shown in Figure 9, mid-band (e.g., 3.5 GHz) small cells are best suited for dense urban areas, whereas mmWave (e.g., 28 GHz) small cells will typically be deployed in extremely high traffic areas such as stadiums, airports and pedestrian zones. In addition, mmWave small cells may also be deployed for FWA or flexible use deployments, serving both fixed and mobile subscribers. In contrast, 600 MHz will most likely be deployed at macro sites to provide wide area and in-building coverage.



Figure 9 - 5G Network Deployments by Spectrum Band

6. Challenges & Opportunities

The main challenges associated with deploying 4G/5G small cells include site acquisition, backhaul, synchronization and powering.

6.1. Site Acquisition

Certainly, one opportunity for the cable industry is to leverage their existing Wi-Fi hotspot and/or 4G small cell locations to deploy 5G small cells. With access rights to millions of public Wi-Fi hotspots, often in prime “beach front” properties, the cable industry is uniquely positioned to capitalize on this opportunity, either as a wireless player or a wholesale provider to existing MNOs.

At Freedom Mobile this strategy is currently being used to deploy 4G/LTE-A small cells. Figure 10 shows an indoor small cell that was installed at an existing Wi-Fi hotspot (left) and a new outdoor small cell at a transit station (right). In the future, both locations will be used for the deployment of 5G small cells.

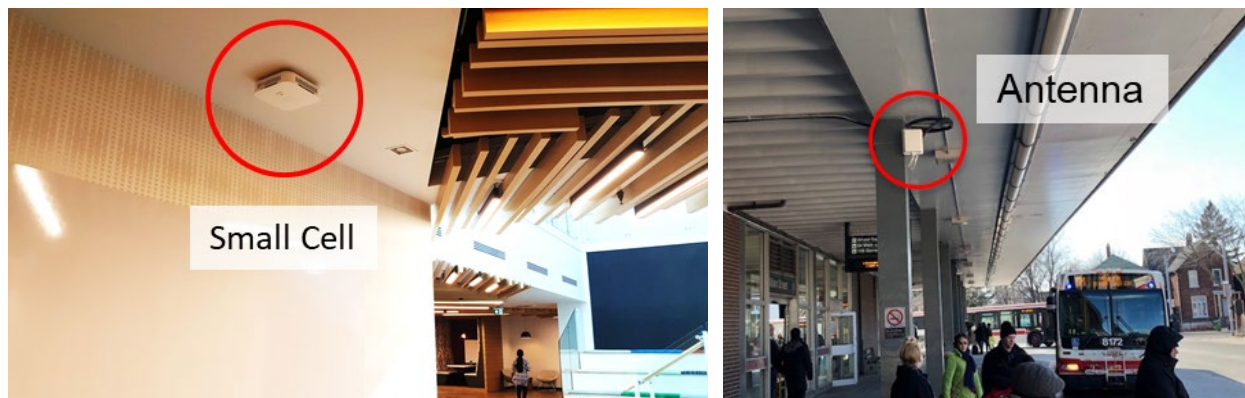


Figure 10 - 4G Small Cell Deployments

In addition, MSOs can leverage their existing cable infrastructure, and in particular aerial plant, to quickly deploy small cells in targeted areas. Deploying small cells on aerial plant addresses three key challenges with small cell deployments: site access, backhaul and power. That is, access is usually already covered by existing pole-line attachment agreements and both backhaul and power are available on the coaxial cable plant.

Figure 11 shows one such deployment in a major metro area by Freedom Mobile. In this case, strand-mount 4G/LTE-A small cells are being installed on aerial strand with inter-site distances ranging from 175 to 225 meters.

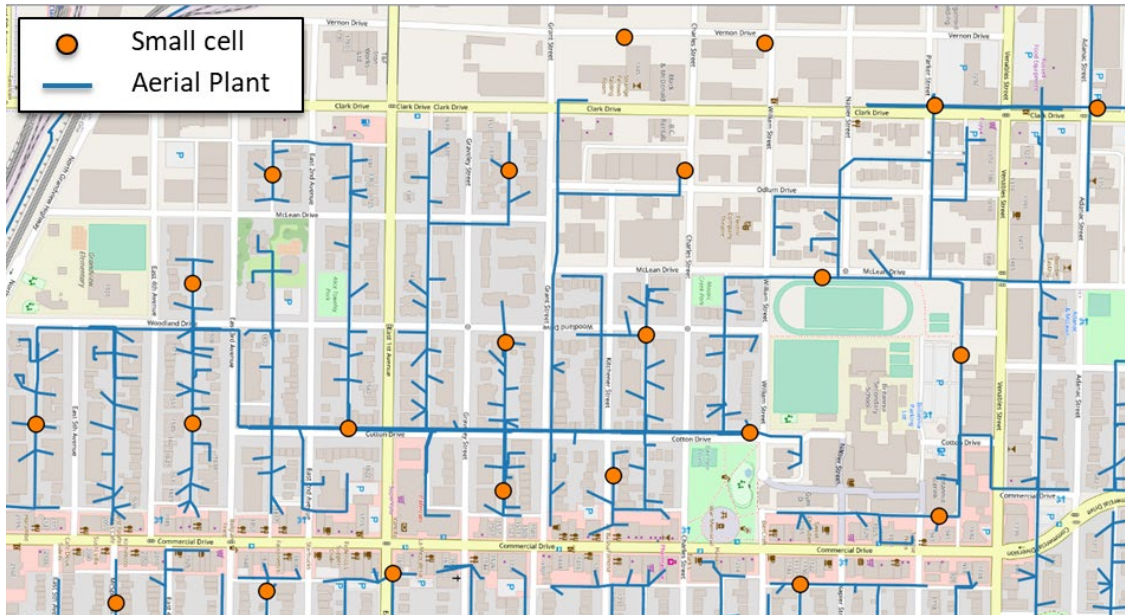


Figure 11 - Strand-Mount 4G Small Cell Deployments

Figure 12 shows a typical strand-mount small cell installation, which consists of a small cell gateway, an 4G/LTE-A small cell and directional coupler. The small cell gateway contains a DOCSIS 3.1 cable

modem and power supply, which converts 90 V_{AC} quasi-square wave input power (i.e., Power-over-Cable) to 115 V_{AC} output power for the small cell.

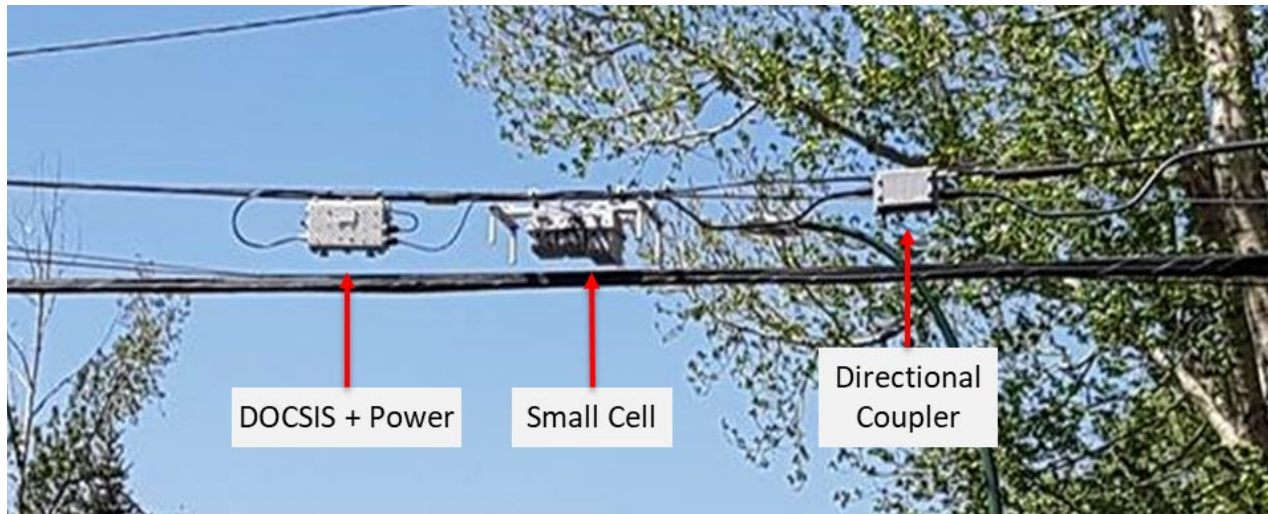


Figure 12 - Typical Strand-mount Small Cell Installation

The 4G/LTE-A small cell can be equipped with up to 3 radio frequency (RF) modules, each capable of supporting 2 x 2 MIMO with up to 2 x 5W transmit power. For dense pedestrian zones, the small cell is typically equipped with a license-assisted access (LAA) RF module, which operates in the 5 GHz unlicensed band. In this configuration, the small cell supports a peak data rate of up to 450 Mbps using two 20 MHz carriers in the unlicensed band and one 15 MHz carrier in the licensed AWS-3 band. The directional coupler connects the small cell gateway to the hybrid fiber-coaxial (HFC) cable plant, which provides both the power and connectivity for the DOCSIS backhaul circuit. At the cable modem termination system (CMTS), the small cell backhaul circuit is routed to the LTE evolved packet core (EPC) network.

As mentioned, a key advantage of using the HFC cable plant for small cell deployments is the availability of power in addition to backhaul connectivity. As a result, small cells can be deployed quickly and easily wherever the MSO has existing coaxial plant. In contrast, passive optical networks (PONs), for example, require a separate power service to be installed, which adds to the cost, time and complexity of the installation.

6.2. RF Coverage

A key consideration in 5G small cell deployments is meeting radio frequency (RF) coverage requirements. Although inter-site distances for the outdoor small cell deployments in Figure 11 were designed for LTE at 2500 MHz band, comparable coverage can be achieved with 5G NR at 3500 MHz. Figure 13 shows RF coverage predictions for LTE at 2500 MHz and 5G NR at 3500 MHz using Infovista's Planet 7 RF network planning tool. This figure shows that the coverage is virtually identical for both bands.

Simulation studies of 5G NR mmWave network coverage by Qualcomm also show that significant coverage is possible when co-locating mmWave equipment with existing 4G macro and small cell sites [4]. Of the 15 cities studied, the outdoor downlink coverage at 28 GHz varied from 50% to 80% of the existing 4G network coverage in 9 of the 15 cities studied. These results suggest that deploying mmWave small cells in urban areas using existing 4G cell sites is entirely feasible, especially in areas with high-

density deployments. While outdoor-to-indoor coverage is not feasible in the mmWave band due to much higher material attenuation (e.g., low-e glass), providing outdoor mmWave coverage would free-up significant capacity in the sub-6 GHz band for outdoor-to-indoor capacity.

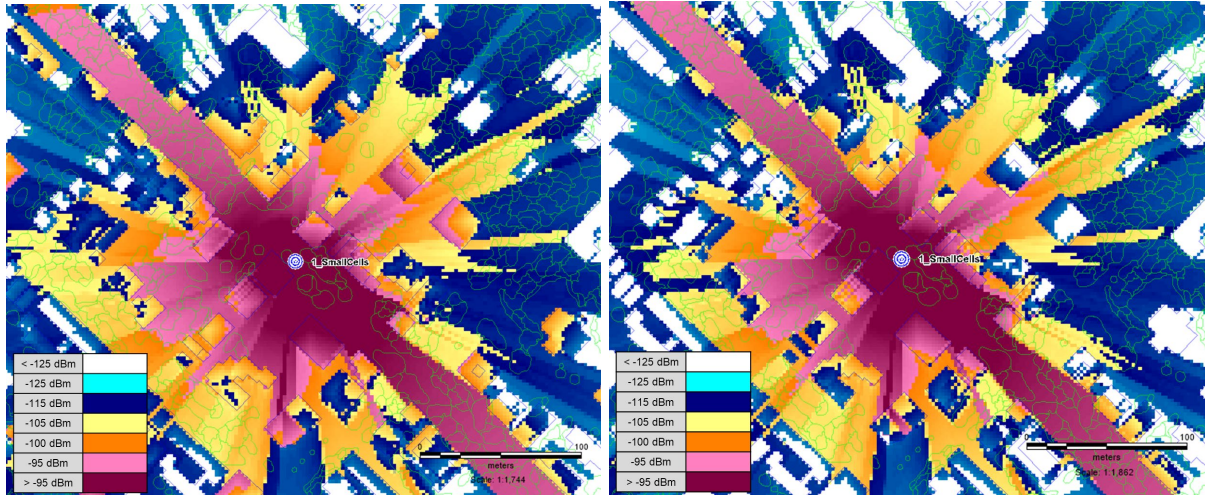


Figure 13 – Outdoor small cell coverage predictions for LTE @ 2500 MHz (left) and 5G NR @ 3500 MHz (right)

For indoors locations, we expect that 5G NR coverage at 3500 MHz to be virtually identical to LTE at 2500 MHz as well. Qualcomm also conducted indoor network coverage simulations at mmWave frequencies with similar results. A simulation study was done for the Las Vegas Convention Center using existing 4G antenna locations in the venue. A one-to-one overlay of 5G mmWave radios on the existing 4G/LTE antenna locations resulted in significant coverage (up to 85%) throughout the facility.

In buildings with existing Wi-Fi access points, the above results suggest that coverage parity might be achieved with a one-to-one mmWave small cell overlay since inter-access point distances for Wi-Fi access points are typically much shorter than 4G small cells. Replacing existing Wi-Fi access points and/or 4G small cells with 5G equipment could result in substantial cost and time savings for 5G deployments.

6.3. Backhaul

As noted earlier, another substantial challenge in deploying small cells is securing the necessary backhaul connectivity (or transport) from the small cell to the core network. There are multiple transport solutions available today, including dedicated fiber, wavelength division multiplexing (WDM), passive optical networks (PON), DOCSIS and microwave radio. The preferred solution is dependent on a variety of factors and considerations, including technical performance, immediacy of deployment, capacity, cost, and accessibility.

Historically, Freedom Mobile has relied primarily on dedicated fiber and microwave for macro cell backhaul. With the introduction of 4G small cells, however, DOCSIS 3.1 is now being successfully used to backhaul traffic from both indoor and outdoor small cells in locations that fall within Shaw’s cable footprint.

When deployed in areas with a mid-split 1 GHz HFC plant, these cable modems are provisioned for maximum downlink (DL) and uplink (UL) data rates of 500 Mbps and 100 Mbps, respectively. These

maximum data rates coincide with the peak data rates of the 4G small cells currently being deployed. However, since the peak data rates can only be achieved under ideal conditions, the average the DL/UL data rates during the busy hour are much lower, typically 20-25% of the peak rates. Therefore, up to 5 small cells can usually be served by a single cable modem.

The main advantages of DOCSIS compared with the other alternatives are its low cost, scalability, access to power, and ease of deployment. Another key advantage of DOCSIS is availability. Within Shaw’s HFC network, for example, there is typically 3 to 5 times more coaxial cable than fiber in major metros markets. Over time this ratio will certainly decrease but in the short-to-medium term there is a huge incentive leverage DOCSIS for 5G small cell densification.

With its higher peak data rates and lower latencies, however, 5G introduces a new set of demands on the backhaul/ transport facilities, which are discussed in further detail in the sections below.

6.4. RAN Architectures

For 5G NR small cells, the transport requirements depend on several factors including: the total channel bandwidth; the number of MIMO Layers; the maximum supported modulation scheme; and the number of transmit and receive antennas. The division of radio functions between the remote radio sites and centralized locations also plays an important role in the transport requirements. These radio functions include RF signal processing, baseband (or Layer 1) signal processing, and other networking layers (i.e., Layer 2 & 3) in the end-to-end protocol stack.

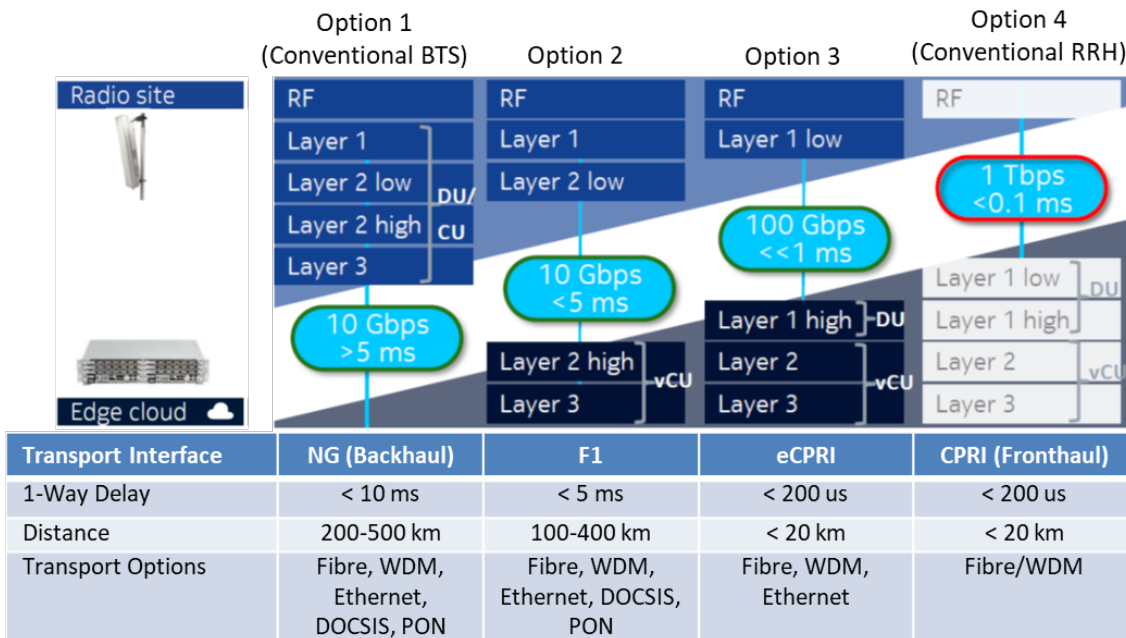


Figure 14 - Possible 5G NR Functional Splits (Source: adapted from Nokia)

As illustrated in Figure 14, there are several possible options for splitting these functions between the radio site and a central location such as a hub site. The upper portion of this figure shows the functions residing at the radio site whereas the lower portion shows the functions at a central site. The throughput and latency requirements are shown over the links between the two.

The first option on the left-hand side (Option 1) represents a conventional base station (BTS) where all functions are implemented at the radio site. The transport facility in the case is referred to as “backhaul”. The advantage of this option is the throughput and latency are minimized because all processing is done at the radio site. In the 5G NR standard, the interface between the BTS and core network is known as the ‘NG’ interface [5]. The backhaul options for the NG interface include dedicated fiber, WDM, DOCSIS and PON.

Option 4 at the other end of the scale represents the conventional remote radio head (RRH) architecture, sometimes referred to a centralized radio access network (C-RAN) or virtualized radio access network (vRAN), if the functions run on virtualized platforms. The RRH performs the RF signal processing only and leaves all other functions to be performed in a baseband unit (BBU) at a central site. With C-RAN, the transport is referred to as “fronthaul” and typically uses the common public radio interface (CPRI) to transport digitized IQ samples of the baseband signal over fiber or WDM from the radio site to the BBU.

The advantages of this approach include simpler radio equipment at the network edge, easier operation, and cheaper maintenance. C-RAN also allows BBU processing capacity to be efficiently reused or shared as demand patterns shift over time. This is particularly relevant for high-density 5G deployments such as stadiums where peak and off-peak demand vary dramatically. The challenge with C-RAN deployments is it requires the RRH and BBU to be connected through a high-speed, low-latency, and accurately synchronized network. Figure 15 shows the required CPRI line rate (without coding) for various channel bandwidths and numbers of transmit/receive antennas. This figure clearly shows that with the higher channel bandwidths and transmit/receive antenna counts associated with 5G, it quickly becomes impractical to use CPRI for 5G fronthaul [6].

With the above in mind, the industry partners responsible for the CPRI specification have developed a new fronthaul specification known as evolved CPRI (eCPRI) [7]. eCPRI offers a ten-fold reduction in the required data rate and allows packet-based transport technologies such as Ethernet to be used. This is Option 3 above.

The final option (Option 2) is based on the F1 interface defined in the 5G NR standard, which assigns the RF, Layer 1 and low-level Layer 2 functions to the radio sites and the other functions in the central site. The advantage of this split is it retains some of the benefits of lower layer splits, while minimizing the throughput and latency requirements.

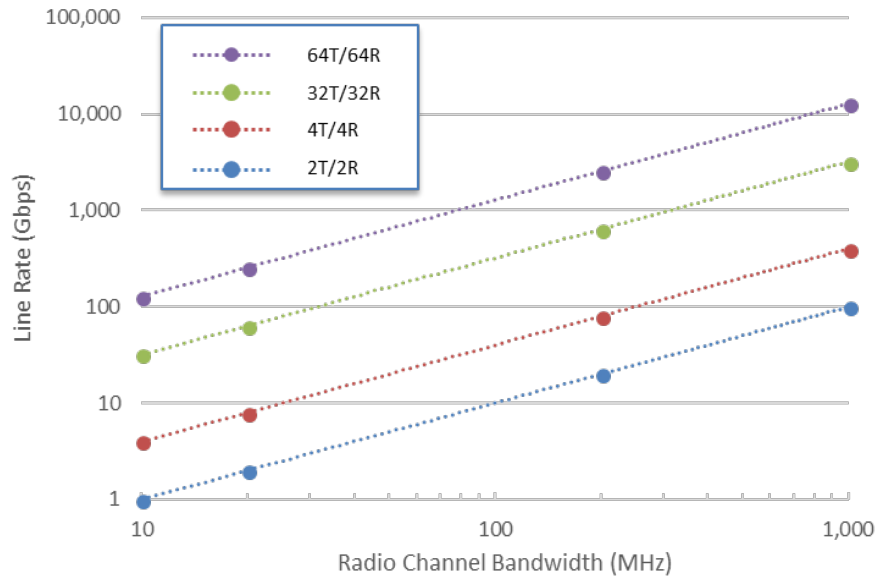


Figure 15 - CPRI Line Rates

With the continued evolution of DOCSIS standards, we believe that DOCSIS is a viable transport technology for 5G small cells. While the required line rates for eCPRI of up to 100 Gbps are too high for DOCSIS technology, small cells that implement the F1 or NG interfaces could conceivably be carried over DOCSIS. As shown in Figure 16 below, the projected DOCSIS line rates for full duplex DOCSIS (FDX) and extended spectrum DOCSIS, are well within range of those required for the F1 and NG interfaces.

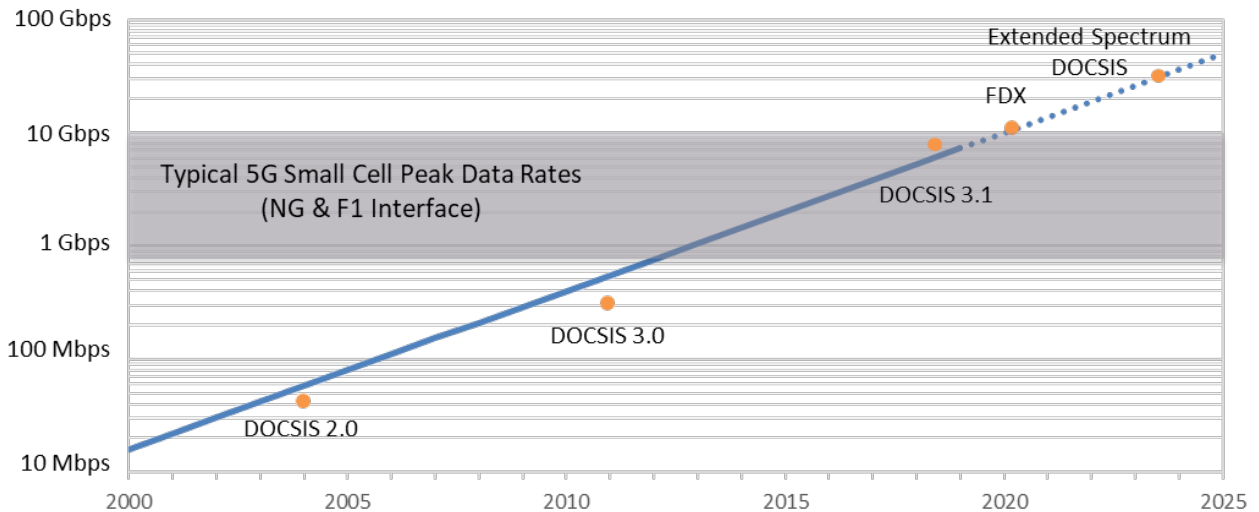


Figure 16 - Evolution of DOCSIS Aggregate Line Rates

Although latency on typical DOCSIS networks currently exceeds the requirements for the F1 interface (i.e., < 5 ms), work by Andreoli-Fang and Chapman [8] demonstrates that latencies of 1-2 ms can be achieved using upstream grant pipelining techniques between LTE/5G and DOCSIS.

6.5. Synchronization

Another important consideration for small cell deployments is synchronization. Unlike Wi-Fi access points, 4G and 5G small cells require precise synchronization to minimize inter-site interference. The minimum frequency and phase requirements for 4G and 5G small cells are listed in Table 1 below.

Table 1 - 4G & 5G Small Cell Synchronization Requirements

Parameter	4G ¹	5G
Frequency	+/- 50 ppb	+/- 50 ppb
Phase	N/R	< 1.5 μ s

1. Assumes FDD mode with no advanced features enabled such as CoMP, eICIC, etc.

In Freedom Mobile’s current mobile network, 4G small cells are synchronized via either GPS or precision time protocol (PTP), also known as IEEE 1588v2. GPS/GNSS is currently used for outdoor small cells and PTP is used for indoor small cells. In cases where the outdoor small cell does not have line of sight to a sufficient number of GPS/GNSS satellites, PTP can be used for synchronization as well. Since none of Freedom’s 4G small cell operate in TDD mode or use advance features (e.g., coordinated multipoint (CoMP), enhanced inter-cell interference coordination (eICIC)), phase synchronization is not required.

For indoor small cells, PTP is distributed from centrally located grandmaster clocks in each metro area to the small cells over the transport network. This eliminates the need to deploy a local grand master clock on site or install external GPS/GNSS antennas and coaxial cabling for each small cell, both of which would introduce significant deployment costs and time delays.

For indoor sites with fiber backhaul, PTP can be used to reliably distribute both frequency and phase synchronization. For sites with DOCSIS backhaul, however, PTP can only be used to distribute frequency synchronization due to the asymmetric latency between the DOCSIS downlink and uplink and the lack of support for PTP in existing DOCSIS implementations .

During initial small cell deployments there were doubts whether frequency synchronization could be distributed transparently over DOCSIS using PTP. Through extensive testing, however, Shaw has validated that the frequency error meets the 3GPP specification of +/- 50 ppb limit. Figure 17 shows actual frequency error test results from a 4G small cell on a production DOCSIS network. These results show that the frequency is well within specification. To the best of our knowledge, this is the first time that frequency synchronization has been distributed to 4G small cells over a DOCSIS network using PTP.

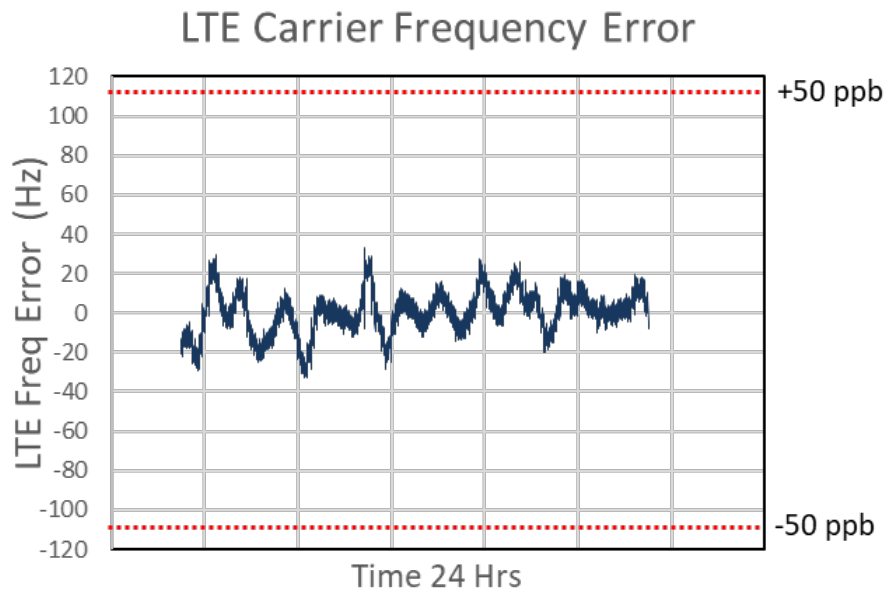


Figure 17 - LTE Carrier Frequency Error on a production DOCSIS network

For 5G small cells, however, the lack of support for phase synchronization over DOCSIS is a serious shortcoming. Fortunately, the DOCSIS timing protocol (DTP), which is part of the DOCSIS 3.1 specification, and allows phase and time synchronization to be accurately distributed over DOCSIS [9]. Further work is required, however, by DOCSIS chipset, CMTS and cable modem vendors to fully implement DTP before 5G small cell deployments begin, likely in late 2019 or early 2020.

6.6. Converged Access Network

In addition to leveraging DOCSIS for small cell backhaul, MSOs could also take advantage of obvious synergies between 5G small cells and distributed access architectures (DAA) and fiber deeper initiatives. For example, as shown in Figure 18 below, wavelength division multiplexing could be used to aggregate traffic from both DAA nodes and 5G NR macro and small cell sites.

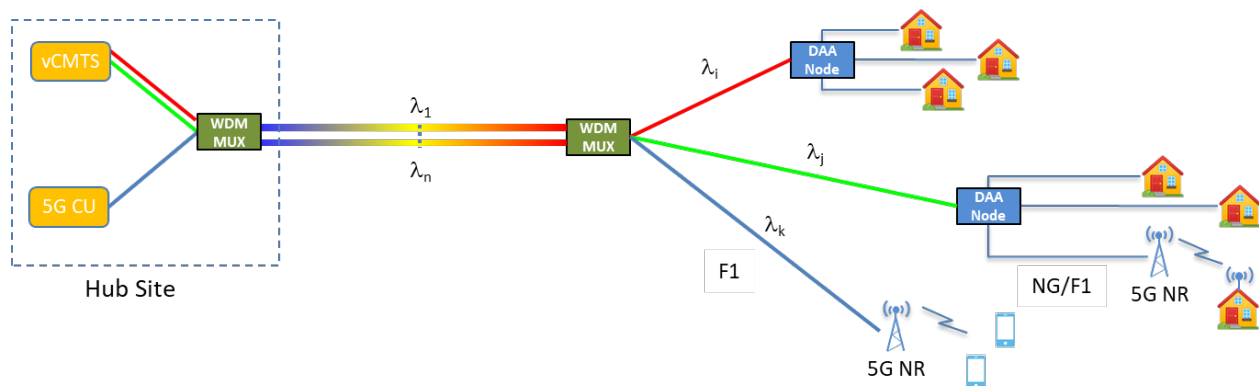


Figure 18 - Converged DAA/5G Access Network

This would allow eCPRI, for example, to be used for high-density 5G NR sites (i.e., both macro and small cells) where peak data rates exceed DOCSIS capacities. Of course, this would not preclude using DOCSIS for backhaul at lower density sites, as required.

Conclusion

5G promises to dramatically transform the role that mobile technology plays in the world. By leveraging their existing and planned network assets, MSOs are well-positioned to capitalize on emerging 5G opportunities, either as mobile network operators or wholesale providers. As wireless networks evolve from 4G/LTE to 5G, small cells will be a key component for delivering the high bandwidth, low-latency connections required by the broad range of use cases 5G makes possible. With hundreds of thousands of Wi-Fi hotspots around the globe and existing support structure agreements, MSOs should have ready access to prime real estate for small cell deployments. This paper also shows that current DOCSIS networks are quite capable of supporting 4G small cells today and evolving to meet the needs 5G small cells in the future. Two key 5G requirements that need to be addressed by DOCSIS chipset and equipment vendors, however, are phase/time synchronization and lower latency. Finally, distributed access architectures (DAA) and fiber deeper initiatives offer the prospect of further 5G/cable network convergence in the future.

Abbreviations

5G	fifth generation
AP	access point
AR	augmented reality
BBU	base band unit
bps	bits per second
CAGR	Cumulative Average Growth Rate
CMTS	cable modem termination system
CN	core network
CoMP	coordinated multi-point
CPRI	common public radio interface
C-RAN	centralized RAN
CU	central unit
DAA	distributed access architecture
DL	downlink
DOCSIS	data over cable service interface specification
DTP	DOCSIS timing protocol
DU	distributed unit
eICIC	enhanced inter-cell interference coordination
eMBB	enhanced mobile broadband
FDX	full duplex DOCSIS
FEC	forward error correction
FWA	fixed wireless access
GB	Giga byte
Gbps	Giga bits per second
HFC	hybrid fiber-coax
HD	high definition

Hz	hertz
ISBE	International Society of Broadband Experts
LAA	license assisted access
MIMO	multi-input, multi-output
mmWave	millimeter wavelength
mTC	mobile type communications
NFV	network function virtualization
NR	new radio
NSA	non-standalone
PON	passive optical network
RAN	radio access network
RF	radio frequency
RRH	remote radio head
SA	standalone
SCTE	Society of Cable Telecommunications Engineers
SDN	software-defined networks
UL	uplink
uRLLC	ultra-reliable low latency communications
VNI	Virtual Networking Index
VR	virtual reality
vRAN	virtual RAN
WDM	wavelength division multiplexing
ZB	Zeta byte

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