Enabling Multi-Gigabit Residential and Enterprise Services in the Last Mile Using 5G Wireless

A Technical Paper Prepared for SCTE/ISBE by

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Abstract: In today's environment, consumers are looking for increased high-speed data to the home. The preferred solutions include upgrade to DOCSIS 3.1 or Fiber, both of which are capital intensive. Fixed Wireless systems have been providing alternative with limited Data rates. Emerging 5G wireless technologies at millimeter waves "mmw" have shown technology potential to provide fixed wireless high data rates to Homes and buildings ranging from 100Mbps to 1000Mbps.

Introduction

Internet and broadband usage is growing rapidly. In North America there is a race for broadband to the home. Among the technologies used are DOCSIS 3.1 and fiber deep architectures which are accelerating in deployment and promising gigabit data rates to home. Also Fiber to the home has been deployed with 100Mbps to gigabit speeds. With the advances in wireless communications, the next generation mobile communications, 5G, has the technology capabilities to reach gigabit to the homes with the promise of fewer wires and faster deployment time in the last mile. Globally, there are more and more operators who now have fixed and mobile networks. Their challenge and opportunity will be to work with their technology partners on strategies and architectures that fuse these networks and services together to create synergistic value and performance for their customers.

The industry debate on fixed versus wireless access rages on. However, the service provider (telco), mobile network operator (MNO) and cable operator (MSO) communities globally have begun the march to become "blended operators." A blended operator will fuse its numerous networks and other assets (eg. Content, broadcast, data centers, etc.) to create additional operational effectiveness, but more importantly new services and more robust experiences for their customer base. What is clear is that a robust mobile network relies on extensive, low latency and high speed backbone/backhaul networks. These fixed networks will be a key ingredient and critical component to existing mobile and future 5G networks. There are certainly are opportunities for MSOs to explore and expand their networks to participate in the growth and fusion of networks to enable 5G.

The next generation of mobile communication, 5G, needs to extend far beyond previous generations in order to cope with increased demands for traffic, latency, and speeds. This will be realized by continued development of the 3GPP long-term evolution (LTE) in combination with New Radio access technologies NR. Today, we foresee that overall 5G wireless access consists of two key elements; backwards-compatible LTE evolution, and new radio access technology, here denoted 5G-NR as shown in Figure 1. The NR will likely be deployed at new spectrum, primarily above 6 GHz, mainly due to the availability of larger bandwidth. Since 5G-NR primarily aims at new spectrum bands, it may be non-backwards compatible to LTE, enabling higher flexibility to achieve the 5G requirements [1]. In the US, both Verizon and AT&T have announced plans to deploy 5G at 28 and 39GHz as fixed wireless broadband with Verizon talking about potential deployment as soon as 2018 [4-5]. Other MNOs are showing interest in testing and trialing 5G-NR.

As cable operators or operators that have invested in HFC as their fixed access technology of choice look to find their way in 5G, these fixed networks can indeed be used optimally in the densification of 5G and mobile services while offering new opportunities for network simplification and network convergence. DOCSIS 3.1 technology now being deployed globally and new fiber being deployed in N+M (e.g. N+0) architecture will offer the opportunity for greater mobile backhaul capacities and low latency networks, both key ingredients in a high performance 5G network. In this paper, an overview of 5G requirements, capabilities, and features are discussed. Then the capabilities of LTE and 5G fixed wireless systems in terms of coverage, data rates, and capacity are discussed and evaluated. Simulations for fixed wireless broadband use case are presented.

Overview of the 5G network

5G radio access technology will be a key component of the Networked Society. It will address high traffic growth and increasing demand for high-bandwidth connectivity. It will also support massive numbers of connected devices and meet the real-time, high-reliability communication needs of mission-critical applications. High capacity backhaul networks will continue to be a key ingredient in 5G.

The overall aim of 5G is to provide ubiquitous connectivity for any kind of device and any kind of application that may benefit from being connected.

5G networks will not be based on one specific radio-access technology. Rather, 5G is a portfolio of access and connectivity solutions addressing the demands and requirements of mobile communication beyond 2020.

The specification of 5G will include the development of a new flexible air interface, NR, which will be directed to extreme mobile broadband deployments. NR will also target high-bandwidth and high-traffic-usage scenarios, as well as new scenarios that involve mission-critical and real-time communications with extreme requirements in terms of latency and reliability. Further capacities deployed in 5G NR will put a broader emphasis on rich fiber networks capable of backhauling this ever growing volume of traffic but will also allow new players to enter the market to provide mobile and fixed wireless services that leverage their regional or nationwide fixed access network. This would include HFC and fiber networks currently deployed in the MSO community.

In parallel, the development of Narrow-Band IoT (NB-IoT) in 3GPP is expected to support massive machine connectivity in wide area applications. NB-IoT will most likely be deployed in bands below 2GHz and will provide high capacity and deep coverage for enormous numbers of connected devices.

Ensuring interoperability with past generations of mobile communications has been a key principle of the ICT industry since the development of GSM and later wireless technologies within the 3GPP family of standards. HFC and DOCSIS networks are already backhauling varying amounts of mobile and WIFI traffic. There would certainly be an opportunity for further convergence by harmonizing these technologies in the cable access and radio access networks. One of these possible areas of fusion could indeed be guaranteeing services that are portioned network slices that traverse the 5G RAN.

In a similar manner, LTE will evolve in a way that recognizes its role in providing excellent coverage for mobile users.   5G networks will incorporate LTE access (based on Orthogonal Frequency Division Multiplexing, OFDM) along with new air interface, NR, in a transparent manner toward both the service layer and users.

Around 2020, much of the available wireless coverage will continue to be provided by LTE, and it is important that operators with deployed 4G networks have the opportunity to transition some – or all – of their spectrum to newer wireless access technologies. For operators with limited spectrum resources, the possibility of introducing 5G capabilities in an interoperable way – thereby allowing legacy devices to continue to be served on a compatible carrier – is highly beneficial and, in some cases, even vital.

At the same time, the evolution of LTE to a point where it is a full member of the 5G family of air interfaces is essential, especially since initial deployment of new air interfaces may not operate in the same bands. The 5G network will enable dual-connectivity between LTE operating within bands below 6GHz and the NR air interface in bands within the range 6GHz to100GHz as shown in Figure 2. NR should also allow for user-plane aggregation, i.e. joint delivery of data via LTE and NR component carriers.

5G Requirements and Use Cases

5G is considered to support many use cases beyond the traditional 4G mobile broadband, and thus the requirements on 5G networks are reflecting a wide range of capabilities to enable the many varieties of use cases.

1. 5G use cases

5G will provide wireless connectivity for a wide range of new applications and use cases, including wearables, smart homes, traffic safety/control, critical infrastructure, industry processes and very-high-speed media delivery. As a result, it will also accelerate the development of the Internet of Things. In North America, the first use cases adopted by top mobile operators are fixed wireless broadband (as shown in Figure 3) and enhanced mobile broadband eMBB with Gigabit Mobile data.

2. 5G requirements

In order to enable connectivity for a very wide range of applications with new characteristics and requirements, the capabilities of 5G wireless access must extend far beyond those of previous generations of mobile communication. These capabilities will include massive system capacity, very high data rates everywhere, very low latency, ultra-high reliability and availability, very low device cost and energy consumption, and energy-efficient networks.

2.1. Massive System Capacity

By 2021, it is estimated that there will be 28 billion connected devices globally – close to 16 billion of which will be part of the Internet of Things [1,2]. To support this traffic in an affordable way, 5G networks must deliver data with much lower cost per bit compared with the networks of today. Furthermore, the increase in data consumption will result in an increased energy footprint from networks. 5G must therefore consume significantly lower energy per delivered bit than current cellular networks. Much like the Energy 2020 initiative being pursued by the STCE, 5G will focus some significant efforts on how to improve mobile services without creating unsustainable energy footprints.

The exponential increase in connected devices, such as the deployment of billions of wirelessly connected sensors, actuators and similar devices for massive machine connectivity, will place demands on the network to support new paradigms in device and connectivity management that do not compromise security. Each device will generate or consume very small amounts of data, to the extent that they will individually, or even jointly, have limited impact on the overall traffic volume. However, the sheer number of connected devices seriously challenges the ability of the network to provision signaling and manage connections. We expect that a significant amount of traffic and connections will also come from within the household where fixed access networks will see an increase in devices accessing the network. Some of these devices may also collect data while outside the home while using a household internet connection as a connection to report non real-time sensor data to centralized data collection cloud infrastructure.

2.2. Very High Data Rates Everywhere

Much like DOCSIS, every generation of mobile communication has been associated with higher data rates compared with the previous generation. In the past, much of the focus has been on the peak data rate that can be supported by a fixed or wireless-access technology under ideal conditions. However, a more important capability is the data rate that can actually be provided under real-life conditions in different scenarios.

5G should support data rates exceeding 10Gbps in specific scenarios such as indoor and dense outdoor environments.

Data rates of several 100Mbps should generally be achievable in urban and suburban environments.

Data rates of at least 10Mbps should be accessible almost everywhere, including sparsely-populated rural areas in both developed and developing countries.

There are certainly further opportunities for “blended operators” to “fuse” services together to offer data buckets that are commonly shared between mobile and fixed access services.

2.3. Very Low Latency

Very low latency will be driven by the need to support new applications. Some envisioned 5G use cases, such as traffic safety, control of critical infrastructure, and industry processes, may require much lower latency compared with what is possible with the mobile-communication systems of today.

To support such latency-critical applications, 5G should allow for an application end-to-end latency of 1ms or less, although application-level framing requirements and codec limitations for media may lead to higher latencies in practice. Many services will distribute computational capacity and storage close to the air interface. This will create new capabilities for real-time communication and will allow ultra-high service reliability in a variety of scenarios, ranging from entertainment to industrial process control.

2.4. Ultra-High Reliability And Availability

In addition to very low latency, 5G should also enable connectivity with ultra-high reliability and ultra-high availability. For critical services, such as control of critical infrastructure and traffic safety, connectivity with certain characteristics, such as a specific maximum latency, should not merely be ‘typically available.’ Rather, loss of connectivity and deviation from quality of service requirements must be extremely rare. For example, some industrial applications might need to guarantee successful packet delivery within 1 ms with a probability higher than 99.9999%.

2.5. Very Low Device Cost And Energy Consumption

Low-cost, low-energy mobile devices have been a key market requirement since the early days of mobile communication. The reduction of energy consumption in set top boxes has also generated some voluntary but effective power consumption best practices within the home. To enable the vision of billions of wirelessly connected sensors, actuators and similar devices, a further step has to be taken in terms of device cost and energy consumption. It should be possible for 5G devices to be available at very low cost and with a battery life of several years without recharging.

2.6. Energy-Efficient Networks

While device energy consumption has always been prioritized, energy efficiency on the network side has recently emerged as an additional KPI, for three main reasons:

First it is an important component in reducing operational cost, leading to lower total cost of ownership. Second, it enables off-grid network deployments that rely on medium-sized solar panels as power supplies, thereby enabling wireless connectivity to reach even the most remote areas with renewable energy sources. And third, it is essential to realizing operators' ambition of providing wireless access in a sustainable and more resource-efficient way.

The importance of these factors will increase further in the 5G era, and energy efficiency will therefore be an important requirement in the design of 5G wireless access. The SCTE energy 2020 initiative is also focused on many of these general goals as well.

5G Spectrum

Much like DOCSIS 3.1, in order to support increased traffic capacity and to enable the transmission bandwidths needed to support very high data rates, 5G will extend the range of frequencies used for mobile communication. This includes new spectrum below 6GHz, as well as spectrum in higher frequency bands. Although cable has not included spectrum in this range in DOCSIS 3.1, it is not inconceivable that future specifications used in DOCSIS could indeed make us of these radio frequencies in the future.

Specific candidate spectrum for mobile communication in higher frequency bands is yet to be identified by the ITU-R or by individual regulatory bodies. The World Radio Conference (WRC)-15 discussions have resulted in an agreement to include an agenda item for IMT-2020, the designated ITU-R qualifier for 5G, in WRC-19. The conference also reached agreement on a set of bands that will be studied for 5G, with direct applicability to NR. Many of the proposed bands are in the millimeter wave (mmw) region and include:

> 24.25GHz to 27.5GHz, 37GHz to 40.5GHz, 42.5GHz to 43.5GHz, 45.5GHz to 47GHz, 47.2GHz to 50.2GHz, 50.4GHz to 52.6GHz, 66 GHz to 76GHz and 81GHz to 86GHz, which have allocations to the mobile service on a primary basis; and 31.8GHz to 33.4GHz, 40.5GHz to 42.5GHz and 47GHz to 47.2GHz, which may require additional allocations to the mobile service on a primary basis.

In the US, the FCC has allocated 4 primary 5G bands; 28GHz, 37GHz, 39GHz and 64-70GHz. There is a proposal for adding more spectrum in 24GHz, 32GHz, 42GHz, 48GHz, 51GHz, 70GHz and 80GHz.

The mobile industry will strive to gain access to spectrum in the 6GHz to 20GHz range, but the policy directions being followed by regulators seem to be focused on frequency bands above 30GHz. In the US, the FCC has issued two Notices of Public Rule Making (NPRM) on bands above 24GHz. Ofcom has likewise indicated a preference for bands above 30GHz within the mobile industry.

The capacity needs of the mobile industry will continue to be served by licensed spectrum, although novel sharing arrangements for spectrum will become progressively more important as restricted opportunities for new spectrum start to impact incumbent services such as satellite communication and radio location. Two examples of sharing arrangements include LSA planned in Europe for the 2.3GHz band and the Citizens Band Radio Service for 3.5GHz in the US

5G Features

Beyond extending operation to higher frequencies, there are several other key technology components relevant for the evolution to 5G wireless access. These components include access/backhaul integration, device-to-device communication, flexible duplex, flexible spectrum usage, multi-antenna transmission, ultra-lean design, and user/control separation. In the following sections, brief descriptions of these features are introduced.

3. Radio Access Network features

3.1. Access/Backhaul Integration

Wireless technology is already frequently used as part of the backhaul solution. Such wireless-backhaul solutions typically operate under line-of-sight conditions using proprietary radio technology in higher frequency bands, including the millimeter wave (mmW) band. Cable operators are in a strong position with very extensive HFC and fiber networks that can be used for backhaul of mobile and broadband traffic in their respective operating territories.

In the future, the access (base-station-to-device) link will also extend to higher frequencies. Furthermore, to support dense low-power deployments, wireless backhaul will have to extend to cover non-line-of-sight conditions, similar to access links.

In the 5G era, the wireless-access link and wireless backhaul should not therefore be seen as two separate entities with separate technical solutions. Rather, backhaul and access should be seen as an integrated wireless-access solution able to use the same basic technology and operate using a common spectrum pool. This will lead to more efficient overall spectrum utilization as well as reduced operation and management effort.

3.2. Direct Device-To-Device Communication

The possibility of limited direct device-to-device (D2D) communication has recently been introduced as an extension to the LTE specifications. In the 5G era, support for D2D as part of the overall wireless-access solution should be considered from the start. This includes peer-to-peer user-data communication directly between devices, but also, for example, the use of mobile devices as relays to extend network coverage.

D2D communication in the context of 5G should be an integral part of the overall wireless-access solution, rather than a stand-alone solution. Direct D2D communication can be used to offload traffic, extend capabilities and enhance the overall efficiency of the wireless-access network. Furthermore, in order to avoid uncontrolled interference to other links, direct D2D communication should be under network control. This is especially important for the case of D2D communication in licensed spectrum.

3.3. Flexible Duplex

Frequency Division Duplex (FDD) has been the dominating duplex arrangement since the beginning of the mobile communication era. In the 5G era, FDD will remain the main duplex scheme for lower frequency bands. However, for higher frequency bands – especially above 10GHz – targeting very dense deployments, Time Division Duplex (TDD) will play a more important role.

In very dense deployments with low-power nodes, the TDD-specific interference scenarios (direct base-station-to-base-station and device-to-device interference) will be similar to the ‘normal’ base-station-to-device and device-to-base-station interference that also occurs for FDD.

Furthermore, for the dynamic traffic variations expected in very dense deployments, the ability to dynamically assign transmission resources (time slots) to different transmission directions may allow more efficient utilization of the available spectrum.

To reach its full potential, 5G should therefore allow for very flexible and dynamic assignment of TDD transmission resources. This is in contrast to current TDD-based mobile technologies, including TD-LTE, for which there are restrictions on the downlink/uplink configurations, and for which there typically exist assumptions about the same configuration for neighbor cells and also between neighbor operators.

3.4. Flexible Spectrum Usage

Since its inception, mobile communication has relied on spectrum licensed on a per-operator basis within a geographical area. This will remain the foundation for mobile communication in the 5G era, allowing operators to provide high-quality connectivity in a controlled-interference environment.

However, per-operator licensing of spectrum will be complemented by the possibility of sharing spectrum. Such sharing may be between a limited set of operators, or may occur in license-exempt scenarios. The Citizens Band Radio Service in the US in the 3.5GHz band and the 5GHz unlicensed spectrum are examples of managed and unlicensed sharing regimes respectively.

New air interfaces like NR will likely be well served by more conventional licensed allocations of spectrum, mainly due to the need to establish a basic foundation for the technology to operate in an independent manner while interoperability is established with technologies like LTE. At some point, further allocations of spectrum for 5G may leverage the mobile industry’s experience of sharing approaches in lower cellular bands.

3.5. Multi-Antenna Transmission

Multi-antenna transmission already plays an important role in current generations of mobile communication and will be even more central in the 5G era, due to the physical limitations of small antennas. Path loss between a transmitter and receiver does not change as a function of frequency, as long as the effective aperture of the transmitting and receiving antennas does not change. The antenna aperture does reduce in proportion to the square of the frequency, and that reduction can be compensated by the use of higher antenna directivity. The 5G radio will employ hundreds of antenna elements to increase antenna aperture beyond what may be possible with current cellular technology.

In addition, the transmitter and receiver will use beamforming (BF) to track one another and improve energy transfer over an instantaneously configured link. Beamforming will also improve the radio environment by limiting interference to small fractions of the entire space around a transmitter and likewise limiting the impact of interference on a receiver to infrequent stochastic events. The use of Beamforming will also be an important technology for lower frequencies; for example, to extend coverage and to provide higher data rates in sparse deployments.

3.6. Ultra-Lean Design

Ultra-lean radio-access design is important to achieve high efficiency in 5G networks. The basic principle of ultra-lean design can be expressed as: minimize any transmissions not directly related to the delivery of user data. Such transmissions include signals for synchronization, network acquisition and channel estimation, as well as the broadcast of different types of system and control information.

Ultra-lean design is especially important for dense deployments with a large number of network nodes and highly variable traffic conditions. However, lean transmission is beneficial for all kinds of deployments, including macro deployments.

By enabling network nodes to enter low-energy states rapidly when there is no user-data transmission, ultra-lean design is an important component in delivering high network energy performance. Ultra-lean design will also enable higher achievable data rates by reducing interference from non-user-data-related transmissions.

3.7. User/Control Separation

Another important design principle for 5G is to decouple user data and system control functionality. The latter includes the provisioning of system information; that is, the information and procedures needed for a device to access the system.

Such a decoupling will allow separate scaling of user-plane capacity and basic system control functionality. For example, user data may be delivered by a dense layer of access nodes, while system information is only provided via an overlaid macro layer on which a device also initially accesses the system.

User/control separation is also an important component for future radio-access deployments relying heavily on Beamforming for user data delivery. Combining ultra-lean design with a logical separation of user-plane data delivery and basic system connectivity functionality will enable a much higher degree of device-centric network optimization of the active radio links in the network.

5G Network Performance

In [3] Ericsson conducted a simulation-based study of extreme MBB using higher frequency bands at 15GHz carrier aggregated with low band, 2.5GHz in a dense area.

The 5G – NR at 15GHz BS employed Beamforming using a rectangular antenna array with 5 columns and 20 rows of dual-polarized antenna elements separated by 0.7 and 0.6 wavelengths in the horizontal and vertical dimensions, respectively.

With the physical antenna size of 7.24 cm^2, the radiation pattern of a single antenna element is modeled with the same model as described for LTE above, but with 65_azimuth HPBW, 90_ elevation HPBW, and 8 dBi gain. Thus, the maximum antenna gain is 28 dBi.

For the System Area traffic calculation, the area under study is 1kmx1km, the user monthly data volume is 20GB, assuming 12% of daily traffic at a busy hour, with 10,000 simultaneously active users. The total area traffic is 1778Mbps.

Another set of simulations at 28GHz for suburban under fixed wireless configuration with Beamforming with 96 antenna ports, cross polarized, and 200MHz channels, shows probability of users > 400Mbps under low load is 85%, while under heavy load it is 60%. The minimum sustained throughput is 40Mbps in DL at cell edge. Increasing the channel BW to 400MHz or 800MHz, will either increase the capacity of the system or increase the speed per user for same capacity.

Conclusion

5G is the next step in the evolution of mobile communication and will be a key component of the Networked Society. In particular, 5G will accelerate the development of the Internet of Things. To enable connectivity for a wide range of applications and use cases, the capabilities of 5G wireless access must extend far beyond those of previous generations of mobile communications.

These capabilities include very high achievable data rates, very low latency and ultra-high reliability. Furthermore, 5G wireless access needs to support a massive increase in traffic in an affordable and sustainable way, implying a need for a dramatic reduction in the cost and energy consumption per delivered bit.

5G wireless access will be realized by the evolution of LTE for existing spectrum in combination with new radio access technologies that primarily target new spectrum. Key technology components of 5G wireless access include access/backhaul integration, device-to-device communication, flexible duplex, flexible spectrum usage, multi-antenna transmission, ultra-lean design, and user/control separation.

There are several common guiding principles and points of interest creating requirements for mobile technology that map directly to cable access networks. As more and more cable operators globally deploy mobile networks or merge with traditional MNOs, scenarios of network and technology convergence will continue to evolve to provide ubiquitous access to the network for consumer and enterprise services. Blended operators will have the opportunity to offer the best network performance, speed and agility by fusing their mobile and fixed assets to together and providing the most frictionless experience for their customers.

Abbreviations

MBB	Mobile Broadband
bps	bits per second
BF	Beam forming
4G	4^{th} Generation mobile technology
5G	5^{th} Generation Mobile technology

3GPP	3rd Generation partnership project
D2D	Device to device
mmW	Millimeter Wave frequencies
LTE	Long term evolution
BW	Bandwidth
DL	Downlink
UL	Uplink
MNO	Mobile Network operators
MIMO	Multiple input, multiple output " Antenna systems"
OFDM	Orthogonal frequency division multiplexing

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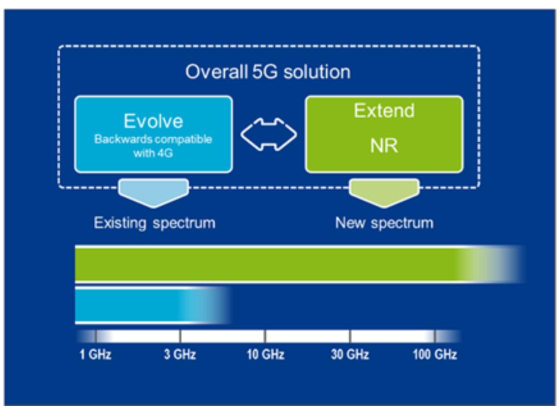

Figure 1 - Overall 5G RAN Solution

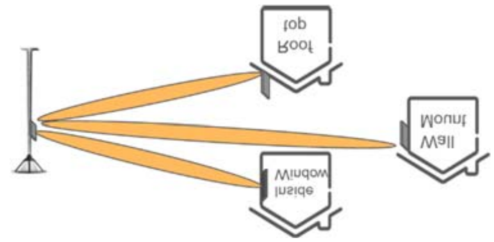

Figure 2 - Fixed wireless broadband use case

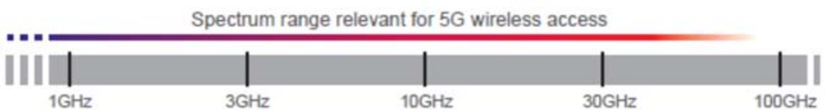

Figure 3 - 5G- Mmw Spectrum

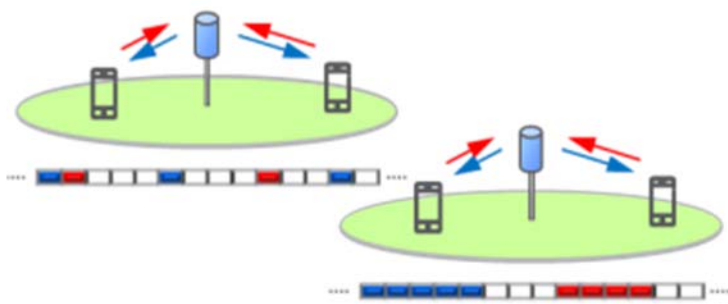

Figure 4 - TDD and FDD

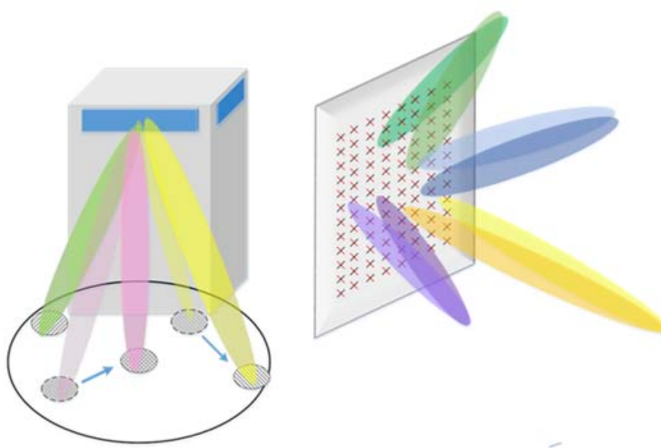

Figure 5 - Beam Forming And Beam Steering

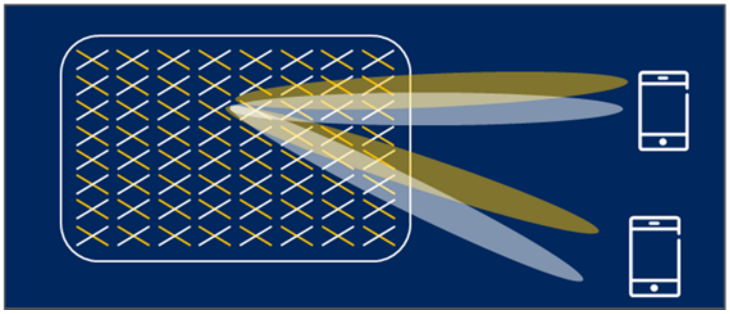

Figure 6 - Multi-user MiMO Provides Higher Capacity Gain

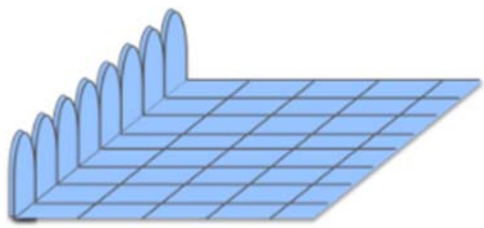

Figure 7 - OFDMA Based With Flexible Numerology

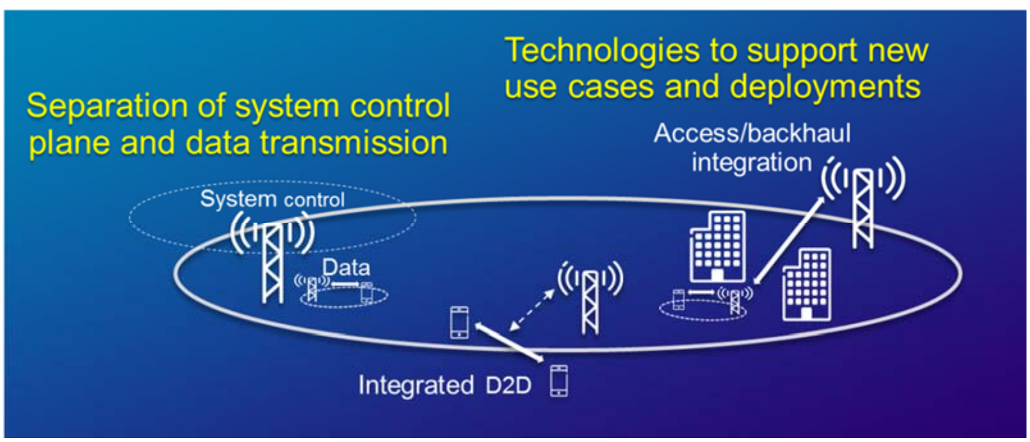

Figure 8 - 5G NR Features, Access/ Backhaul Integration, System Control and D2D

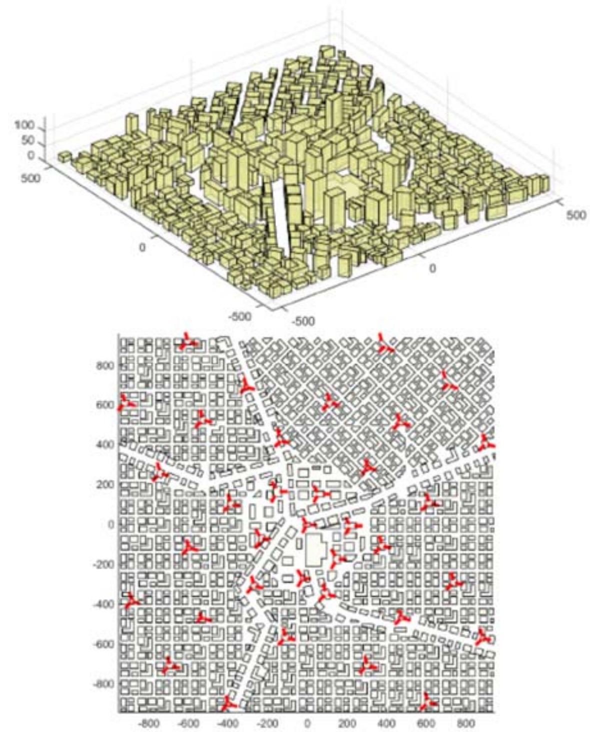

Figure 9 - Simulation Setup For Dense Area

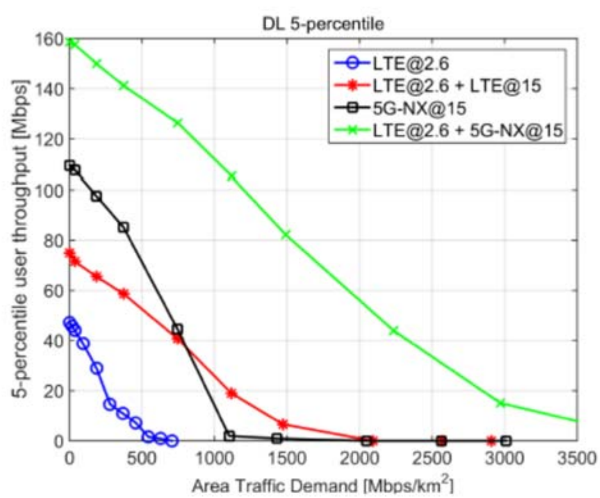

Figure 10 - Cell Edge Performance DL

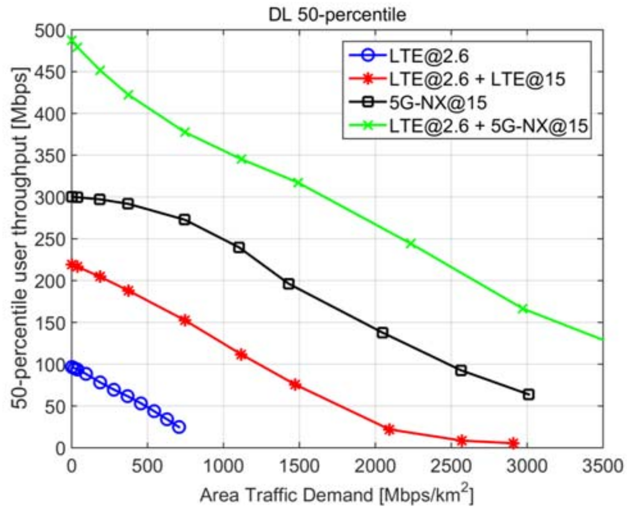

Figure 11 - Cell Capacity, Average Performance DL

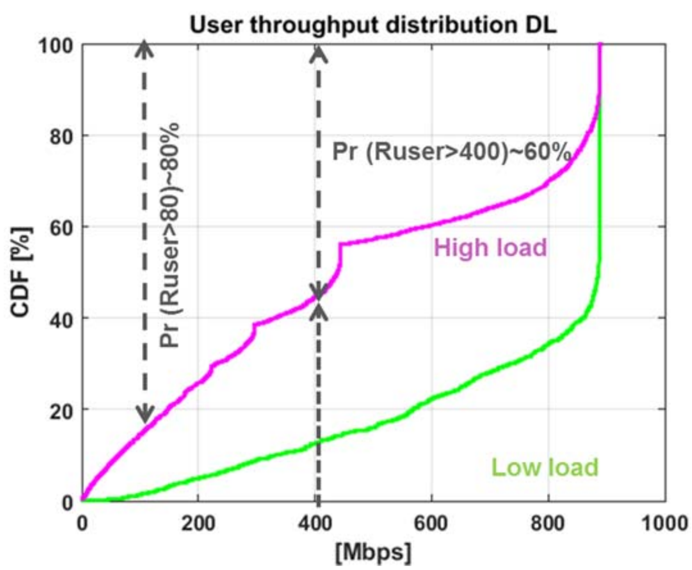

Figure 12 - FWBB Simulation of DL Cell Edge Throughput at 28GHz

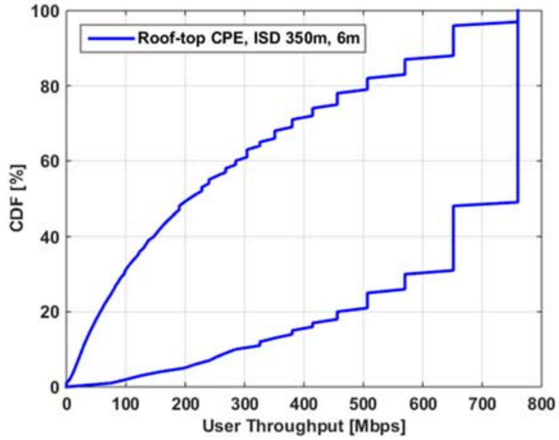

Figure 13 - FWBB Simulation of DL Rooftop High and Low Load at 28GHz

