FIXED MOBILE CONVERGENCE IN THE TRANSITION TO 5G

A Technical Paper prepared for SCTE/ISBE by

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Abstract

2017 is witnessing big changes in mobile and fixed industries, from unlimited plans on LTE, to major MSO acquiring 600MHz in the latest auction, to 5G millimeter wave trials, to the heated discussion on adding the 3.7GHz – 4.2GHz adjacent to CBRS band to the trials. Introduction of 5G technologies like higher spectrum bands, wider carriers and massive MIMO creates an opportunity for the convergence of fixed and mobile services both for traditional telecom operators and MSOs.

Both site solutions for small cell grid and high capacity backhaul are of the biggest challenges for Gigabit wireless to the home. MSO have some of the answers to these problems via the extensive Fiber network in residential area to the strand mount right of the way with power and backhaul ready.

Join Anders Svensson, Principal Solution Manager, 5G, Strategic network evolution at Ericsson North America, to learn about technology and deployment strategy of the mix of technologies for Fixed Wireless Access in the convergence of fixed and mobile services.

This paper gives an overview of 5G requirements and capabilities, how 5G technologies may impact the industries and enable convergence of services. The paper covers selected finding around deployment of FWA for both CBRS and 5G at mmw, and the opportunities and challenges with different spectrums.

Overview of the 5G Network

The overall aim of 5G is to provide ubiquitous connectivity with optimal characteristics for any kind of device and any kind of application that may benefit from being connected. It will address high traffic growth and increasing demand for high-bandwidth connectivity. It will also support massive numbers of connected devices with long battery life and low power consumption and meet the real-time, low latency high-reliability communication needs of mission-critical applications. The 5G system is a use case driven network where one network can support multiple use cases via optimized network slicing.

The standardization of 5G is important to build the global eco-system that provide economic of scale and allows the technologies to address the broader use in a Networked Society. The standardization of 5G is aiming to provide capabilities defines by ITU as part of the IMT-2020. The standardization of the implementation and use of technologies are done in 3GPP. The schedule for this standardization has been divided in two phases, with Phase 1 targeting ready June 2018 and Phase 2 target to be ready in second half 2019. Phase 1 is mainly focusing on high capacity/throughput use cases and ultra-reliable / low latency communication(URLLC) use cases, while Phase 2 target the full compliance with the IMT-2020, including massive IoT use cases.

Parallel to the standardization 5G is gaining momentum. It started with trials in 2016 to show case and validate 5G technologies and use cases. Trials as expected to continue through 2018 with early deployments expected in 2018 and 2019. Most interest has been shown in US, China, Korea, Japan. The massive growth of mobile data traffic, primary driven by video consumption, drives the interest in 5G for enhanced Mobile broadband “eMBB” which is gaining tractions in almost all regions (NA, APAC, EMEA). The high capacity provided by 5G also make it attractive for the Fixed Wireless Access(FWA) use case. FWA as an alternative to fiber residential and enterprise is the leading use case in US, while in APC and Europe, a special focus has been seen on the industrial use cases. Examples of industrial use cases are connected factories, deep communication in mines, connected ports and logistics.

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.

LTE is expected to evolve in a way that recognizes its role in providing excellent coverage for mobile users. 5G networks will incorporate LTE access along with new air interface, NR, in a transparent manner toward both the service layer and users. 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. NR should also allow for user-plane aggregation, i.e. joint delivery of data via LTE and NR component carriers.

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 can 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.

By 2022, it is expected to have more than 500M 5G connections globally. In US the forecast it that 25% of subscription will be 5G enabled according the “Ericsson Mobility Report”.

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.

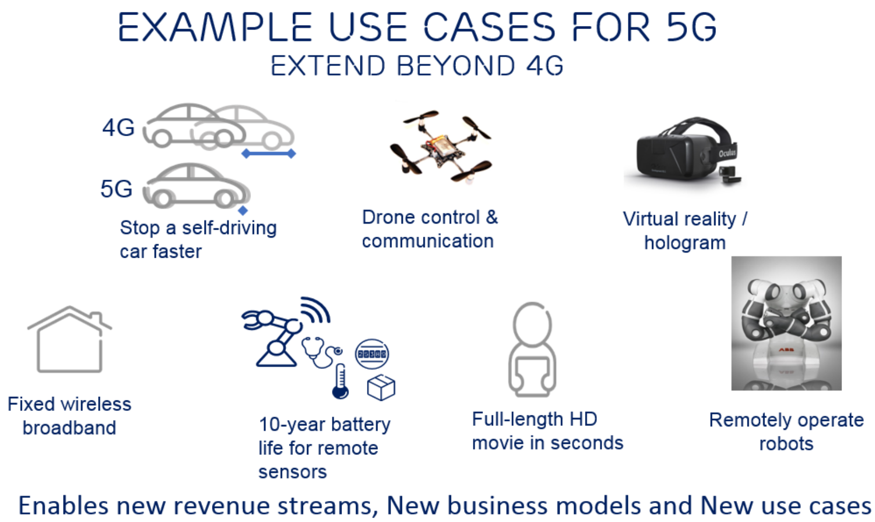

Figure 1 – 5G Use Case examples

Figure above shows some examples use cases that is targeted with 5G. These represents applications that leverage either one or several of the capabilities that 5G will enable in addition to 4G networks that is widely deployed today. The timing of the use cases will be dependent of availability of the technologies as well as the consumer and industry adaption. In North America, the first use cases expected to be widely adopted are fixed wireless broadband, as seen on picture blow, and enhanced mobile broadband eMBB with Gigabit Mobile data.

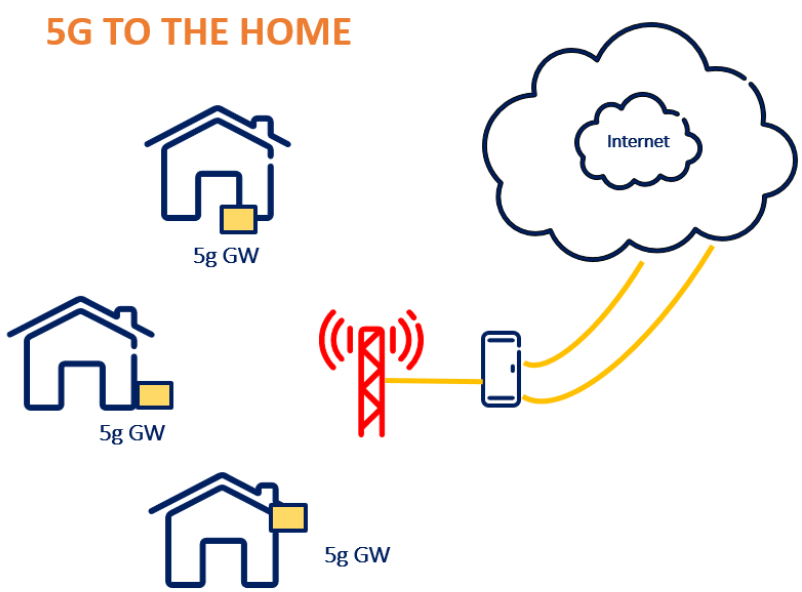

Figure 2 – Fixed Wireless Access using 5G

Both these Use Cases has well established business models which allows for a faster adaption as soon as technology becomes available. Other use cases, which require new business models for operators and surrounding industries, are expected to have a slower adaption to reach mass market However, for operators and MSO that are planning to deploy 5G, it is important to consider the future services when deploying networks.

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.

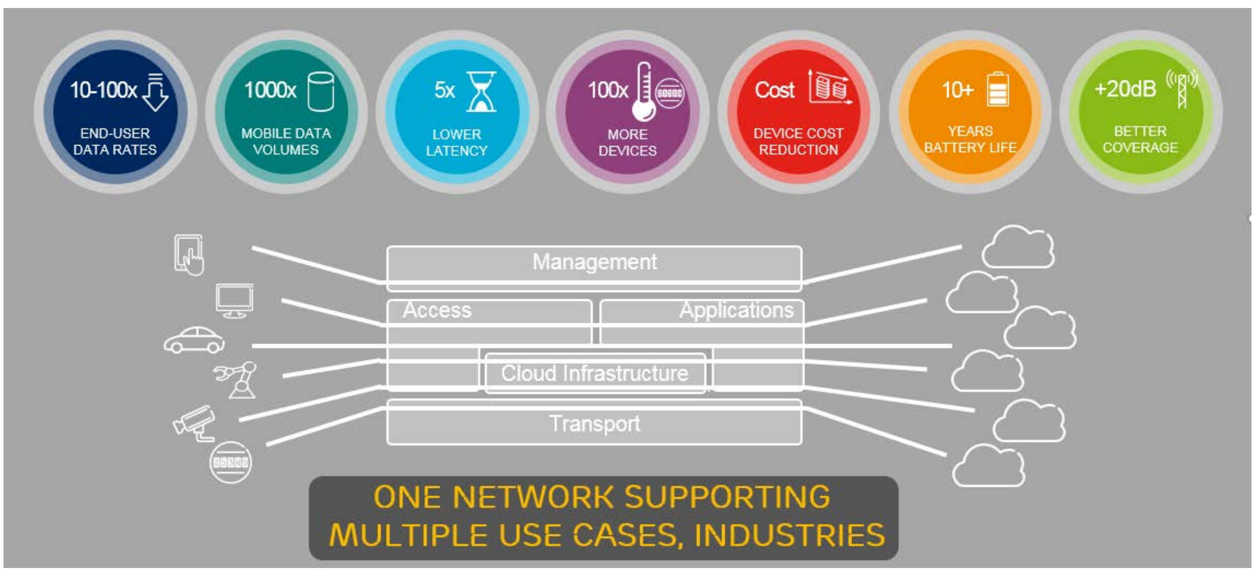

Figure 3 – 5G Capabilities

Figure above shows some of the targets for 5G relative the 4G system that is today widely used for mobile communication.

2.1. MASSIVE SYSTEM CAPACITY

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

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

The increase in data consumption will result in an increased energy footprint from networks. While device energy consumption has always been prioritized, energy efficiency on the network side has recently emerged as an additional KPI. 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.

There are three main drivers for more energy efficient networks:
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.

2.7. SUBSCRIBER SPECIFIC SERVICES

New use cases with largely different business cases and business models will require service providers to be able to differentiate the services based on the application and Use Case. 5G will enable this with a functionality called Network Slicing. Network Slicing enables creation of virtual network that run independently on the same infrastructure with different characteristics with regards to peak speed, delays, reliability, device functionality, etc. The operators will use slicing to create new offering addressing the Use Cases in an efficient way.

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. 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 will 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.

3.2. 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.

3.3. 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.

The use of high degree of beamforming also enable a more efficient use of Multi-user MIMO. The high directivity with beamforming decrease the level of interference in the part of the cell that is not used, which gives the opportunity to sending simultaneously to another user in that part of the cell creating low intra-cell interference. This is an important capacity enabler in 5G, increasing the sector capacity.

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 to extend coverage and to provide higher data rates over larger area.

3.4. 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.

3.5. 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 Spectrum

The evolution of 4G/LTE as developed to exploit a large number of spectrum to handle the massive growth of mobile data over the last 10 year. With the forecast that this traffic growth will continue, driven by a larger usage of video and other digital technologies, more capacity will be needed. To support the 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 including millimeter wave spectrum. The 5G standard is both specifying how to leverage these new spectrum band as well as how spectrum can be combined efficiently in a system to provide the diverse 5G services in when deployed.

1. Higher frequency band and mmWave

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) above 24 GHz.

In the US, the FCC has allocated 4 primary 5G bands; **28GHz** (27.5GHz-28.35GHz), **37GHz** (37GHz-38.6GHz), **39GHz** (38.6GHz-40GHz) licensed bands and **64-70GHz** as unlicensed band. The 28GHz spectrum is re-farmed to 2 licenses each at 425MHz on county area, the 39GHz will be re-farmed to 7x 200MHz channels on PSA area, and upper 1MHz of the 37GHz will be new band 5x 200MHz auctioned at PSA level. The lower 600MHz part of the 37GHz is under consideration for shared spectrum scheme. There is a proposal for adding more spectrum in 24GHz, 32GHz, 42GHz, 48GHz, 51GHz, 70GHz and 80GHz.

The race to secure these new band allocated by FCC has already started. Verizon has acquired sizable amount of the 28GHz via its actuations of XO followed by acquisition of StraightPath. The latter also provides Verizon with good holding in the 39GHz. AT&T acquired Fiber Tower and secured licenses in 39GHz. T-Mobile had already ownership of some 39GHz and 28GHz holding from MetroPCS acquisition. The spectrum that does not have an ownership today is planned to be sold by FCC.

2. Medium high frequency band

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 (CBRS) for 3.5GHz in the US. CBRS is 150MHz of spectrum shared between the incumbent FSS and costal radar as high priority incumbents, then 10MHz channels up to 7 channels is priority access licenses that would be licensed by FCC and will have second level of protection and priority after the incumbent, and finally the General access authorization (GAA) which spans the entire 150MHZ with the lowest priority. Environmental sensing system (ECS) that detects the activities of the incumbents, and feeds into the Shared Access system SAS database and control system allow the control and assignment of the shared spectrum among the different tiers. Initially the FCC rules is to have the PAL licensed renewed once for 3 years and on a census track level. Recent proposals are suggesting increase the licensing terms to 10 years and licensing areas to PSA from census tracks.

In the US, cellular and FWA industry is contemplating having 3.7-4.2GHz as NR band. This band has not yet been identified as a 5G band. It is currently used as uplink for the c-band satellite services, but FCC have issued a Notice of Inquiry(NOI) “Expanding Flexible Use in Mid-Band Spectrum Between 3.7 and 24 GHz” which cover the 3.7 – 4.2 GHz. The NOI also explore the used of 5.925-6.425 GHz and 6.425-7.125 GHz, and is due for comment in October 2017

Propagation Characteristics

The propagation channel characteristics is dependent on the frequency band. Figure below summarize the difference between the typical cellular band deployed today in 2.1 GHz and mid-bands like CBRS and mmWave bands.

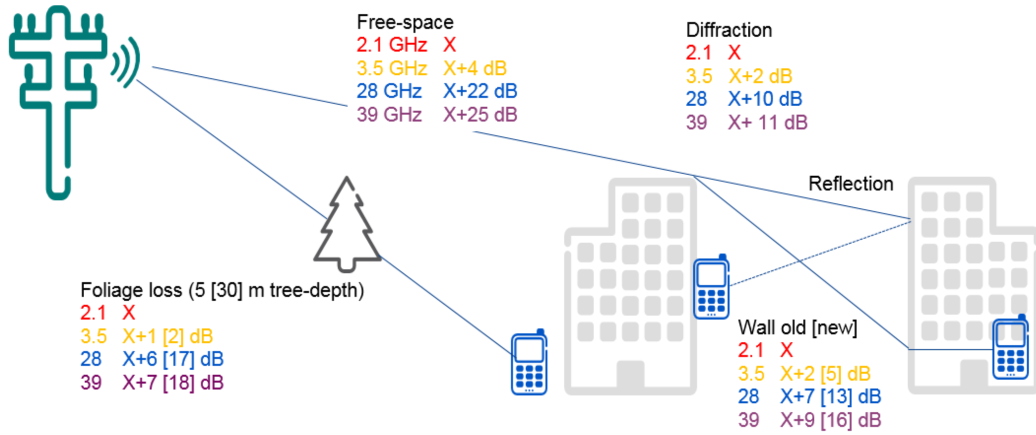

Figure 4 – Path loss comparison between spectrum bands

There is slight difference between the cellular and CBRS, for example it is less than 4dB on free space propagation loss, 2 dB foliage loss and building penetration loss old older buildings. For newer energy efficient building the penetration is even higher. On the other hand, free space propagation loss between mmw and cellular is ranging from 22-25dB, foliage between 6 and 18dB, depending on the tree depth (size) and frequency (28GHz vs 39GHz), diffraction loss is around 10dB more loss, and building penetration loss is more than B1 by 7-16dB depending on type of wall and frequency. It should be noted that reflection losses are rather independent on frequency.

Fixed Wireless Access Performance

The large improvement of capacity access capacity with 5G technologies leveraging much larger channels available in high bands and improving the sector capacity using massive MIMO makes it attractive the address the broadband market to residential and enterprise customers (i.e. Fixed Wireless Access service).

While the wider channels, and a carrier aggregation between them, can be used in any spectrum, the availability of such spectrum is more common in higher mmw bands. The last year there has been significant interest in using these bands, recently made available by FCC, for fixed wireless. Due to mmw limited reach and sensitivity to penetration losses the interest has focused on the possible coverage that can be achieved when offering a FWA service using these bands. Studies shows that the performance that can be expected is dependent on decisions, and viability, to where to deploy both base station antennas and the customer premises equipment (CPE) antennas. The performance of Fixed Wireless Access varies with the deployment scenarios and the spectrum used.

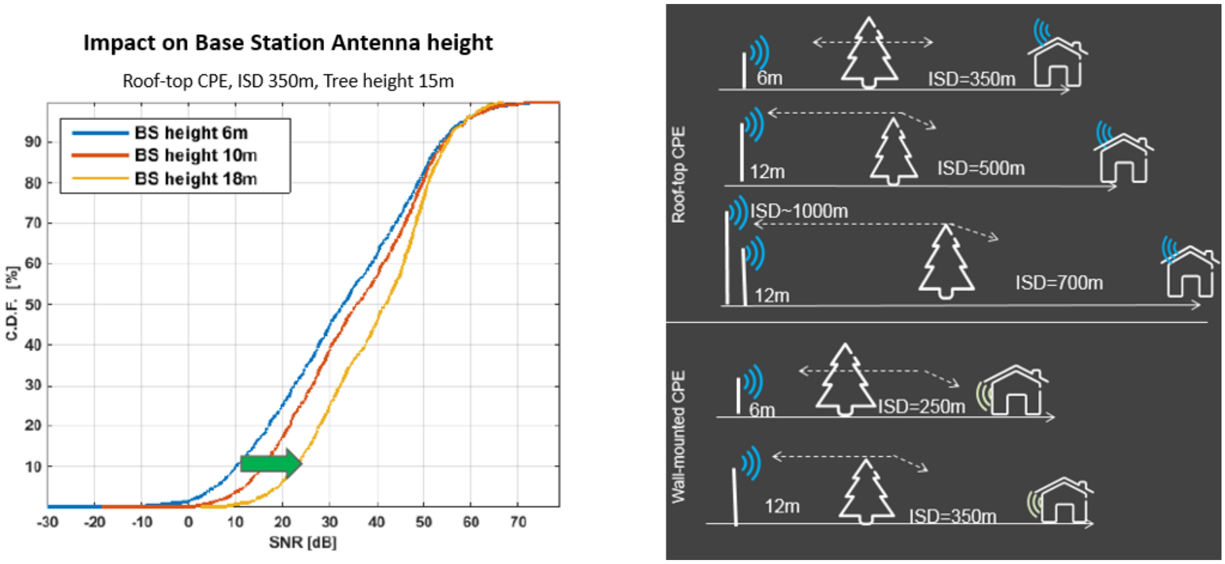

Figure 5 – Performance impacts in mmWave deployment scenarios

The left diagram above shows a result of 28 GHz simulation with different location of the base station antenna and the impact on the SNR received by the CPEs distributed at the houses in a typical single family resident area with mix of single and dual story houses. The graph shows a significant improvement of the cell edge SNR with higher mounted antennas, which translates to large improvement of throughput at the cell edge, which represents the throughput that can be offered to the households in the area.

In addition to the improvement with higher elevated base station antennas, the coverage area is also sensitive to the location of the CPE antenna. The right picture in figure shows the impact on Inter-Site Distance dependent on the different location. All scenarios provide the same cell edge throughput for the user with the most challenges locations, equal to 100 Mbps per 100 MHz of spectrum. While the simulation is done with homogenous deployed CPE, is should be noted that in real scenarios may be a mixed CPE deployment, with roof-top CPE deployed in locations(houses) at challenging RF condition and wall-mounted where RF is less challenging.

For operator and MSO considering deployment in FWA service with mmWave should as part of developing and evaluating the service consider deployment of both the Base Station antennas and CPE antenna. The overall high capacity in mmWave, but limited coverage makes this spectrum most attractive for deployment in urban and suburban single- and multi-family residential area. The high peak speed enabled with the wide channels also make mmWave attractive for enterprise offering.

The other spectrum that has been receiving attraction for FWA service using 5G technologies is the mid-band spectrum 3-4 GHz. While the have potential significant more spectrum than current cellular spectrum, it is expected to be smaller than mmWave. The focus in this spectrum has been more concentrated to the massive MIMO capability with high level of beamforming an MU_MIMO capabilities. These technologies are important to be able to provide the capacity need for the FWA service.

As with mmWave, the important aspect to consider is the cell edge throughput, but in the many cases the mid-band will be primarily capacity limited. Graph below shows the cell edge throughput for different base station antenna configuration under load (Mbps/km2).

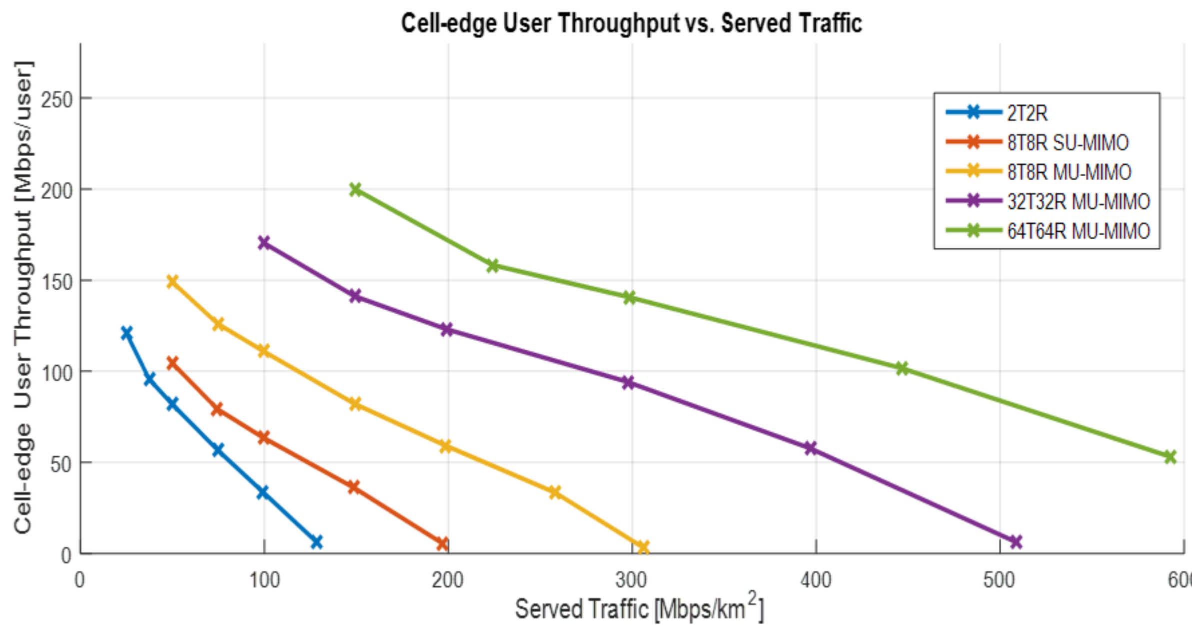

Figure 6 – Capacity enhancements using 5G technologies beamforming and MU-MIMO

The baseline is a non-BF system, with 2x2 MIMO. With adding a 8x8 antenna on the base station, the capacity increase both with beamforming and MU-MIMO. For example, with 50 Mbps cell edge at load, the introduction for beamforming with SU-MIMO increase cell capacity from ~80 Mbps to ~130 Mbps (62% increase) and introduction of MU-MIMO increase to further up to ~220 Mbps (total 175% increase). Use higher order of massive MIMO increase the capacity even further.

The better reach and penetration with the mid-band spectrum makes this band attractive for deployment in suburban areas with medium to low density or rural areas. The increased capacity gained with 5G technology enables higher density of subscriber, addressing the high to medium dense suburban areas better.The better penetration through walls also makes this spectrum attractive as a capacity booster for enhance MBB.

Conclusion

The new capabilities enabled by the emerging 5G technology creates an opportunity for a fixed wireless converges. We have started to see the communication industry players in wireless and wireline moving towards each other's domains offering combinations of residential, enterprise, mobile and entertainment/media services.

One area that is seen in US to be an early 5G service is fixed wireless access, offering residential and enterprise customer high speed broadband service in an efficient way. The networks build for FWA are prepared to support full mobility, and will when combined over wireless network currently deployed network, provide a high capacity network to address the increases data demands for mobile users.

Leverage 5G in the convergence of wireless and wireline business will give an operator or a MSO a flexible network that enables the opportunity to offer a wide range of communication services that can be tailored in capability and characteristics based on the end-user and application requirements.

Abbreviations

Table 1 – Abbreviations

3GPP	3rd Generation partnership project
4G	4th Generation mobile technology
5G	5th Generation Mobile technology
AP	access point
MBB	Mobile Broadband
bps	bits per second
BF	Beam forming
CBRS	Citizen Broadband radio services
CPE	Customer Premises Equipment
DL	Downlink
ECS	Environmental sensing system
FEC	forward error correction
GAA	General access authorization
HD	high definition
HFC	hybrid fiber-coax
Hz	hertz
ISBE	International Society of Broadband Experts
LTE	Long term evolution
MIMO	Multiple input, multiple output " Antenna systems"
mmW	Millimeter Wave frequencies
MNO	Mobile Network Operator
MSO	Multiple System Operator
OFDM	Orthogonal frequency division multiplexing
SCTE	Society of Cable Telecommunications Engineers
UL	Uplink

Bibliography & References

1. Bibliography

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