QUALCOMM + NOKIA

Making 5G a reality:

Addressing the strong mobile broadband demand in 2019 & beyond

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Executive summary

To support the rapidly expanding connectivity needs for the next decade and beyond, 5G is envisioned to be a unifying connectivity fabric that will connect virtually everything around us — from enabling enhanced mobile broadband services and mission-critical communications to connecting the massive Internet of Things — as well as support use cases not completely known today. That is why 5G as the platform for future innovations is being designed with new levels of flexibility and scalability that will fuel mobile inventions beyond the next decade. But enabling all envisioned services will take time — LTE is already bringing the foundation to connect the massive number of IoT devices — so the initial focus is addressing today's most urgent needs. Unlike most 5G visionary essays, this paper will focus on the immediate 2019 timeframe, when 5G New Radio (NR) deployments will begin based on the 3GPP Release 15 standard.

The initial 5G commercial deployments will be driven by enhanced mobile broadband (eMBB) services primarily connecting consumer smartphones. The near-term demand among consumers is real — in a global survey commissioned for this paper, involving nearly 6,000 consumers, we found that close to 50% of respondents are likely to be early 5G adopters. Furthermore, 5G is the top feature that consumers are willing to pay more for with their next mobile device.

5G NR is being designed to deliver significantly more network capacity, higher user throughput, more uniform experience, lower latency, better reliability, and increased network flexibility — thanks to key 5G inventions such as the flexible framework, self-contained TDD subframe, massive MIMO, mobilizing millimeter wave (mmWave), network slicing, and more.

A key 5G opportunity is to unleash much more capacity by leveraging higher spectrum bands, including mobilizing the spectrum in the mmWave range (e.g., 28 GHz and 39 GHz) for the smartphone form factor. The mmWave propagation challenges are well known, but thanks to a new mmWave coverage study first presented here, we now know that we can realize a significant outdoor mmWave coverage by leveraging existing LTE outdoor small cells (e.g., used for LAA), in some dense urban cases even exceeding 80% outdoor coverage using existing sites. This study sufficiently confirmed that existing LTE cell sites in major cities can be easily leveraged as a viable and reasonable place to start 5G NR mmWave deployments, in addition to indoor mmWave deployments. Another example of the cost-effective upgrade to 5G NR is the design philosophy to leverage the significant investments already made in LTE, its vast coverage, and proliferation of Gigabit speeds that provide the foundation to 5G NR eMBB services.

To address the growing market demand, Qualcomm Technologies, Inc. (QTI) and Nokia are committed to make mobile 5G a commercial reality starting in 2019 based on standard-compliant 5G NR infrastructure and devices supporting both spectrum bands below 6 GHz and mobilizing mmWave. All in all, we are only at the dawn of the 5G era, and we expect the continued 5G evolution to unlock even more value in the next decade and beyond.

Entering the 5G era

The world is at the dawn of a new generation of mobile networks — 5G — a future innovation platform for the next decade and beyond. It is being designed to enhance existing services, but more importantly, it will open new capabilities and efficiencies not possible with today's networks.

5G is envisioned to deliver new and enhanced mobile broadband experiences, as well as to efficiently connect virtually everything — from next-generation virtual and augmented reality (VR/AR) glasses and mission-critical drones to low-complexity massive IoT devices such as sensors and meters. While 5G will be truly transformational for our societies by the time it fully proliferates — it is expected to generate more than $12T worth of goods and services by 2035[1].

Unlike most 5G visionary papers, our writing will focus on the immediate time horizon when 5G starts to roll out in 2019 based on 3GPP Release 15 — the first phase of the 5G NR (New Radio) global standard that focuses on enhanced mobile broadband (eMBB), and explore the benefits of 5G NR that will expand upon the foundation of the Gigabit LTE experience today.

The first 5G "killer app" – more capacity for enhanced mobile broadband experiences

While 3G ushered in the era of mobile data and 4G LTE delivered on the promise of Gigabit-class mobile networks, 5G is being designed to elevate mobile broadband experiences to the next level. 5G will initially address pain points of smartphone users today — as outlined later in a consumer survey — as well as enable a flexible platform for future innovations. From a service point of view, these use cases represent an evolutionary approach for mobile operators fueled by our insatiable demand for faster and better mobile experiences.

A recent study[2] showed that mobile data traffic has been growing at an astonishing rate, almost doubling each year since 2014, and the growth momentum continues to be strong in the foreseeable future, also fueled

1 The 5G Economy Study at https://www.qualcomm.com/invention/5g/economy
[2] Who will satisfy the desire to consume? - Nokia Bell Labs Consulting Report, 2016

by the introduction and proliferation of unlimited data plans. It is expected that by 2020, global mobile data traffic will be in the range of 8 exabytes, or 8 billion Gigabytes, per day, representing an impressive growth rate of over 75% per year from the period of 2014 to 2020. Further analysis shows the predominant mobile traffic will be media streaming (video, audio) with over 75% of all traffic, driven by improving content quality (e.g., 4k/8k UHD), more over-the-top (OTT) content being made available for mobile consumption (e.g., Netflix, Amazon Prime Video), and richer user-created content (e.g., WhatsApp, Instagram, Facebook).

Furthermore, smartphones will continue to lead the way as the dominant mobile broadband device for content creation and consumption. Today, the ~1.5B smartphones[3] are driving over 80% of all mobile data traffic, and this share is expected to grow in the years to come. In other words, the expected market penetration of many emerging mobile broadband form factors, such as dedicated VR/AR glasses, will be less significant than smartphones in the next couple of years, while smartphones will drive the initial 5G NR deployments in 2019 to offer newer and better mobile broadband experiences.

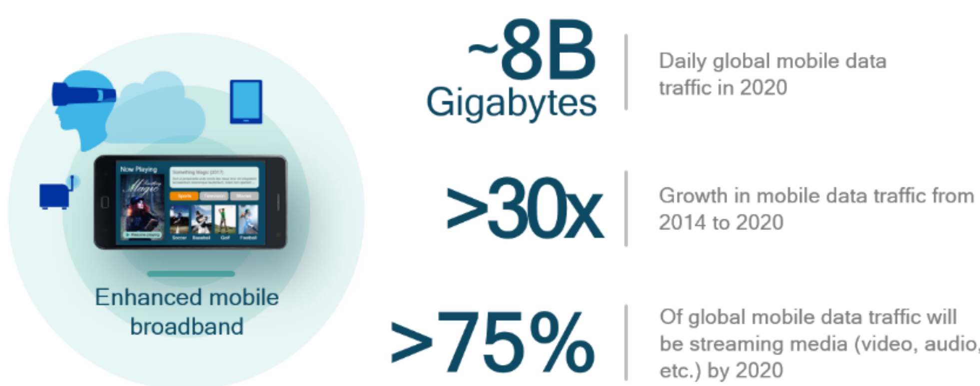

Figure 1: The insatiable demand for faster, better mobile broadband

The need for faster and better connectivity everywhere and key early 5G NR use cases

To better understand consumer interests in 5G, we recently conducted a comprehensive survey with the objective of discovering consumer pain points with today's mobile experiences and learning what consumers think about 5G. The survey involved more than 5800 consumers from six

[3] Gartner, June 2017

countries – USA, China, UK, France, Germany, and Finland – and it targeted a balanced range of demographics, with ages ranging from 18 to 64 across males and females to represent the overall global smartphone market. The outcome of the study was very encouraging – nearly 50% of respondents reported that for their next smartphone purchase they were likely to buy a device that supports 5G, while citing faster data speeds, faster response time, and more cost-effective data plans as the top reasons for this. In fact, over 86% of responded that they need or would like to have faster connectivity on their next smartphone.

Almost half of the respondents knew about 5G before the survey, and after 5G benefits were explained to all, 5G was the top feature that consumers were willing to pay more for in their next mobile device. The survey also showed great insight into what people really want – the ability to use cellular connectivity seamlessly and virtually everywhere (home, work, coffee shop, or on-the-go), and to also avoid the pain point of having to log onto Wi-Fi access points. Another highlight is the growing trend for unlimited data plans, close to 50% of respondents expect to have it once they migrate to 5G, which will satisfy their insatiable demand for better, faster mobile broadband.

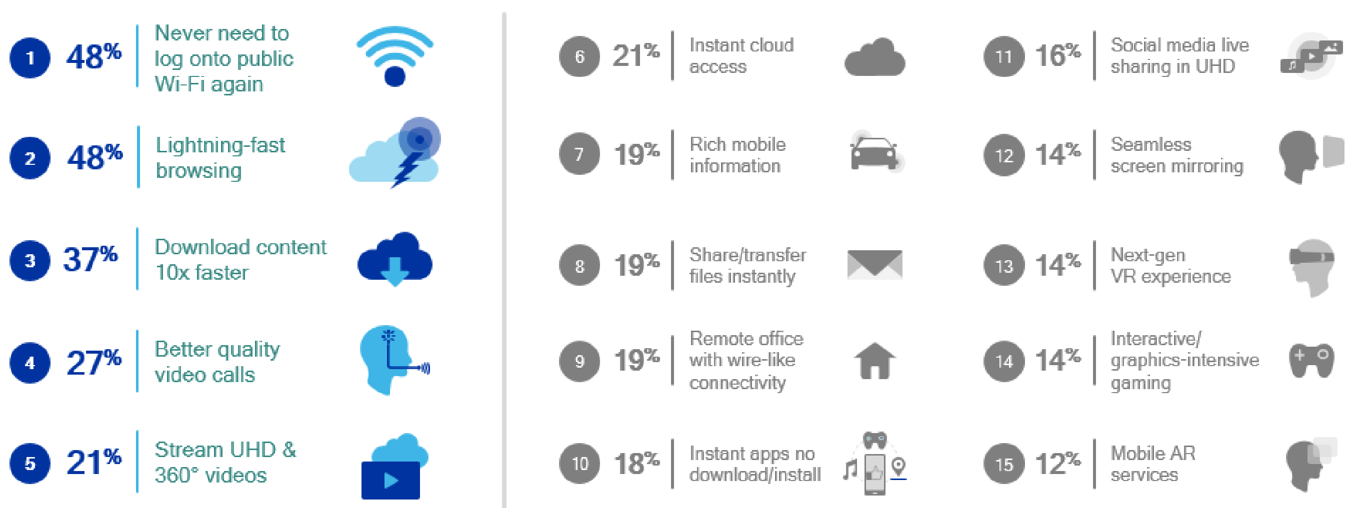

Figure 2: Top 5G eMBB use cases identified in recent consumer survey

In the next section, we will see how the new mmWave spectrum being made available will open new opportunities for enhanced mobile broadband and drive early 5G deployments in 2019 and beyond.

Opening new spectrum opportunities to meet data demand

From the radio access perspective, there are three main pillars to meet the increasing data demand: 1) to densify networks, 2) to deliver higher spectral efficiency, and 3) to gain access to more spectrum. To address these, 5G NR will natively support small cells, more antennas with massive MIMO, as well as many other technology enhancements; but a key aspect is the ability to mobilize higher spectrum bands that were previously not available for mobile applications. 4G LTE primarily utilizes lower bands – mostly in the sub-3 GHz range, which can deliver wider-area coverage but are intrinsically limited in bandwidth.

5G Spectrum landscape and opportunities – especially in higher bands

5G NR is being designed to natively support all spectrum types (licensed, unlicensed, shared) and spectrum bands (low, mid, high). In 3GPP Release 15, the Work Item focuses on licensed spectrum with a Study Item for operations in unlicensed spectrum; thus, early deployments in the 2019 timeframe will target licensed spectrum only, while future deployments based on 3GPP Release 16 and beyond are expected to also support unlicensed/shared spectrum and new services beyond eMBB.

Low bands below 1 GHz: longer range for e.g., mobile broadband and massive IoT

Mid bands 1 GHz to 6 GHz: wider bandwidths for e.g., eMBB and mission-critical

High bands above 24 GHz (mmWave): extreme bandwidths

Licensed Spectrum	Shared Spectrum	Unlicensed Spectrum
Exclusive use	New shared spectrum paradigms	Shared use

Figure 3: 5G NR will natively support all spectrum types and bands

In the bands below 3 GHz, mobile operators will continue to expand coverage with LTE buildouts as well as new 5G NR deployments in select markets, such as 600 MHz in the U.S. and 700 MHz in Europe. Via dual-connectivity, devices will leverage the lower bands for wider-area ubiquitous LTE coverage with Gigabit data rates, while simultaneously connecting to the higher 5G NR bands for more bandwidth and capacity. Deploying 5G NR in the lower bands will allow operators to rapidly establish ubiquitous 5G coverage and open opportunities to market 5G services broadly geographically. However, these lower bands are also intrinsically limited in bandwidth. Thus, Gigabit LTE will be essential for meeting user experience expectations in the early 5G era, and the bigger capacity opportunity will be unlocked by the expansion into higher spectrum – bringing wider contiguous bandwidths, enabled by 5G NR in two main ways:

1. 5G NR will extend the usable mid-band spectrum to above 3 GHz through advanced techniques such as massive MIMO. Mid-band spectrum in the 3 to 5 GHz range is picking up momentum in many key markets around the globe; for example, Europe and China, among many other regions, are focusing their early 5G NR deployments in the 3.5 GHz band, while Japan has also identified the 3.7 GHz and 4.5 GHz band as early targets.

2. The expansion into millimeter wave (mmWave) bands[4], roughly from 24GHz and beyond. The mmWave spectrum will deliver a vast amount of capacity with even wider contiguous bandwidths, typically up to 800 MHz wide per operator. With more advanced antenna design and RF processing techniques, mmWave is being mobilized to deliver multi-Gigabit performance for extreme mobile broadband use cases.

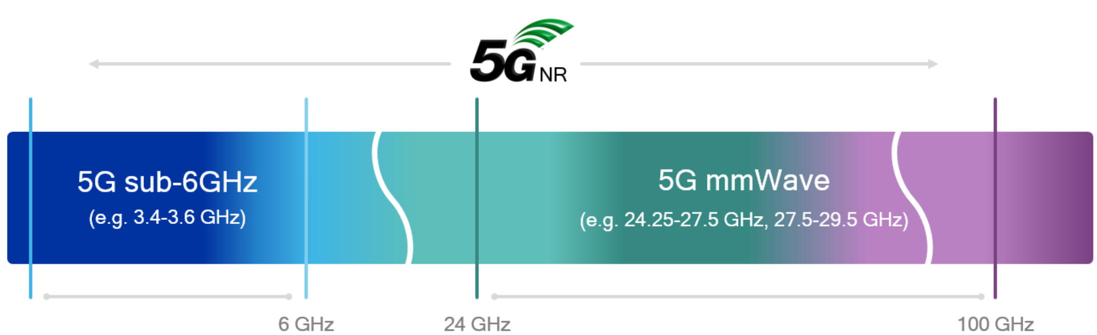

Figure 4: mmWave is the next frontier for extreme throughput and capacity

[4] Millimeter wave is technically considered from 30 GHz to 300 GHz

To make 5G NR in sub 6 GHz and mmWave deployments a reality starting in 2019, many regulatory bodies around the world are already defining 5G spectrum bands. Below is a snapshot of spectrum status in the potential early 5G markets. Thanks to focused efforts, we will see global scale deployments both in the 3 to 5 GHz range and in the key 28GHz mmWave band.

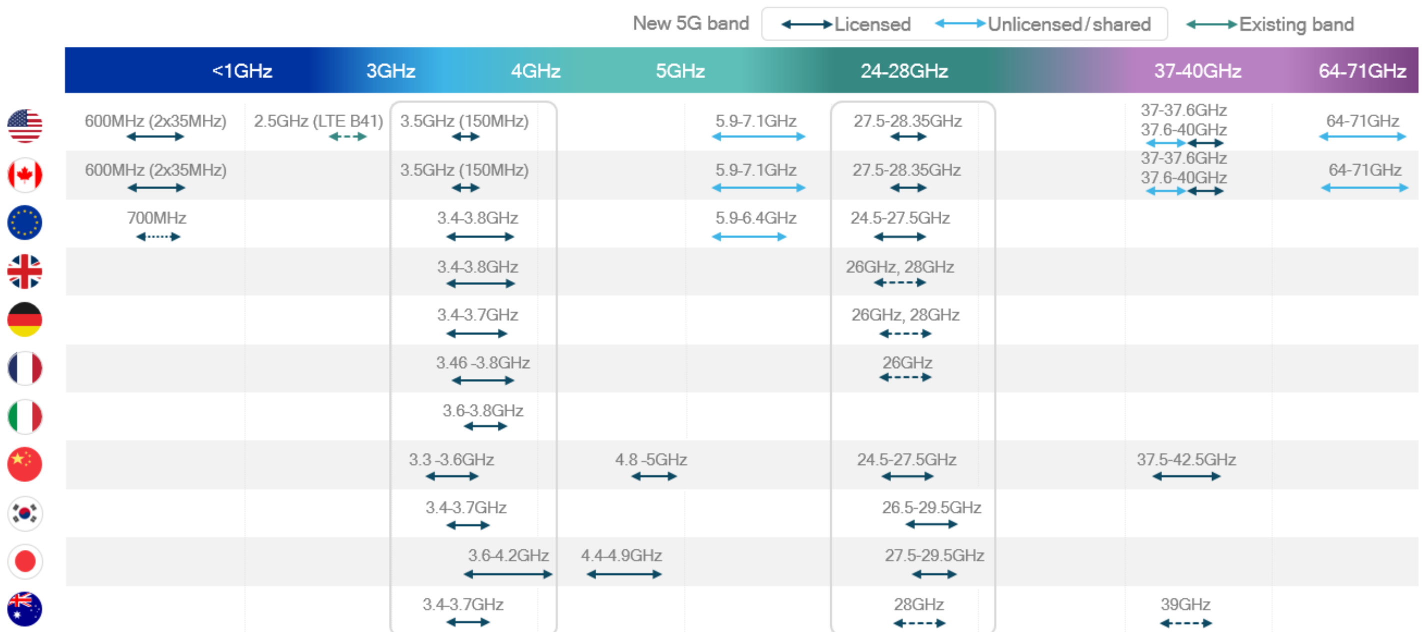

Figure 5: Global 5G spectrum at a glance – allocated and targeted bands for 5G NR

Elevating the enhanced mobile broadband experience

Starting in 3GPP Release 15, which is expected to be completed by the end of 2017, 5G NR is being designed to deliver more capacity, higher throughput, more uniform experience, lower latency, better reliability, and increased network flexibility – meeting the key pain points expressed by consumers in the recent survey, and adding flexibility and efficiency to support existing and new services cost-efficiently for mobile operators.

To efficiently support diverse spectrum bands – from sub-1 GHz to mmWave, 5G NR will have a unified design that leverages a flexible framework with scalability in both frequency (scalable numerology with 2^N subcarrier spacing – from 15 kHz to 120 kHz compared to LTE's 15 kHz) and time (scalable TTI[5] with slot/mini-slot – down to 0.125 ms) domains.

Spectrum	<1 GHz		>1 & <6 GHz			>20 GHz	
Maximum bandwidth (MHz)	50		100			400	
Subcarrier spacing (kHz)	15	30	15	30	60	60	120
Scheduling interval (ms)	0.5	0.25	0.5	0.25	0.125	0.125	

Table 1: 5G NR scalable numerology for more efficient support of diverse spectrum bands

Providing more flexible capacity

A key enabler for making higher spectrum bands usable for mobile is the support for massive MIMO[6] beamforming on 5G NR base stations (a.k.a. gNodeB). Massive MIMO will deliver higher spectral efficiency, and wider coverage area – particularly important at higher frequency bands. This is accomplished by massive MIMO beamforming that focuses energy in narrow beams to downlink users; thereby reducing interference and allowing for spatial multiplexing of multiple users within a sector, also called MU-MIMO[7].

[5] Transmission Time Interval
[6] Multiple Input, Multiple Output
[7] Multi-User MIMO

In comparison to a base station with just two transmit antennas, massive MIMO beamforming utilizing 64 transmit antennas can deliver up to 5x cell capacity gain, on average 4x gain in TDD and 3x gain in FDD — generally across all users in the cell. Massive MIMO is also a proven technology already being deployed on 4G LTE today; for example, it is a key enabler to support the higher 2.6 GHz band using existing base stations. The figure below illustrates the different massive MIMO configurations in different deployment scenarios.

TD-LTE at 2.6 GHz	5G at 3.5 GHz	5G at 28 GHz
• Improves uplink coverage up to 8 dB • Increases cell capacity up to 5x	• Increases spectral efficiency with massive MIMO • Enhances 5G coverage to match LTE at 2 GHz	• Supports NLOS with advanced antenna design and RF processing techniques • Achieves significant outdoor coverage with existing macro/small cells

Table 2: Massive MIMO configurations and use cases

5G NR will also support dynamic uplink and downlink that allows data scheduling to adapt to real-time traffic profile. This allows for much better spectrum utilization, as the full bandwidth can be allocated to either link direction based on immediate traffic needs. This is enabled by the flexible framework and self-contained subframe[8] design, and simulations have shown a potential capacity gain of 50%~100% compared to fixed allocation.

Achieving multi-Gigabit-per-second peak data rates

Another key benefit of the higher bands is the availability of wider contiguous spectrum; for example, we expect blocks of up to 100 MHz in the 3 to 6 GHz range to be available for operators to more efficiently support more capacity, better uniformity, and multi-Gigabit data rates.

With mmWave, operators will have access to up to 800 MHz of contiguous spectrum. With more advanced antenna design and RF processing techniques, the mmWave spectrum can be mobilized to initially deliver around 5 Gbps peak data rates for extreme mobile broadband services, with standard and future support up to 20 Gbps, offering a clear differentiation to today's Gigabit LTE and the higher rates achievable with 5G NR sub-6 GHz.

[8] Allowing the scheduling information, data, and acknowledgement to be all contained in the same subframe

Figure 6: Examples of 5G NR mmWave in action at QTI site

These higher data rates are also reflected in enhanced uplink throughputs compared with what is achievable in LTE. Combined with the downlink enhancements already discussed, 5G NR mmWave brings new opportunities for increased capacity and enhanced experience for use cases such as consumer HD video (4k, 8k), immersive VR, interactive AR, hotspots and fixed broadband access, industrial/enterprise video surveillance, and more.

Bringing ultra-low latency

5G NR will significantly lower the air interface latency down to the 1ms range, which represents a 10x improvement over LTE today. Ultra-low latency (ULL) communication, applicable at both the user and control planes, is enabled by several 5G NR technologies, such as the self-contained TDD subframe and scalable TTI. The lower network latencies enabled by 5G NR Release 15, previously not achievable with LTE, can enhance existing mobile experiences as well as enable new ones, such as industrial automation, remote sensing and monitoring of real-time, mission-critical applications.

Since the network to the cloud path can add 50 ms to over 100ms to the end-to-end latency today, we expect more edge content storage and processing will be deployed with 5G NR to significantly reduce the overall end-to-end latency. This is already starting to take shape through Mobile Edge Computing (MEC) deployments in LTE, and will only continue with future use cases enabled by 5G. This will help deliver enhanced experiences for many consumer-centric use cases as well as for specialized industrial and enterprise applications. As the importance of end-to-end latency increases, we also expect latency optimizations in the transport network. So, lowering user- and control-plane latency can significantly improve the user experience of existing applications as well as enable new ones.

In general, 5G NR ULL will benefit mobile broadband in multiple ways:

- *Delivering faster throughput and reaction to user response:* Reduced control-plane latency allows for faster connection setups for real-time critical applications and activation of carrier aggregation, while lower user-plane latency can improve user throughput by shortening the TCP Slow Start process

- *Providing more robust mobility:* Lower control-plane latency can also significantly reduce overall handover time to improve user experiences in a high mobility scenario

- *Benefitting new services beyond 2019:* URLLC future capabilities will help deliver broader latency and reliability sensitive services beyond eMBB to help untether many enterprise and industrial use cases previously not considered for wireless.

Increasing network reliability and uniformity

5G aims also to improve the network reliability and uniformity, a key enabler is through multi-connectivity — initially dual-connectivity with LTE — where the mobile device is simultaneously connected to more than one radio link. This can be across different spectrum bands within the same radio access technology, for example, a device connected to both 5G NR sub-6 GHz and mmWave, or across different radio access technologies, such as 5G NR and 4G LTE, or all the above. In addition to massive MIMO, multi-connectivity improves the cell-edge performance to provide a more uniform 5G experience. One of the 5G objectives is to achieve 100Mbps of data rates even at the cell edge.

In early deployments of 5G NR, both service coverage and reliability will be the utmost concern for early adopters. This is especially apparent for the new 5G NR mmWave network that will have limited coverage due to high diffraction and penetration losses and blockages at mmWave frequencies. Providing simultaneous connectivity to sub-6 GHz, either with 5G NR or LTE, will drastically improve the link reliability, as well as provide many essential services from day one such as voice with VoLTE.

Delivering better core network flexibility

5G will efficiently support a wide variety of services and mobile devices; for example, smartphones and tablets initially, and gradually new classes of devices such as VR glasses, health monitors, mission-critical robotics, and connected vehicles that may have very diverse capabilities, performance, and efficiency requirements. A key enabler is network slicing, which allows the creation of virtual network segments for the support different use cases and tenants within the same 5G Core access and core network.

To achieve optimized energy and spectral efficiency, different end-to-end logical networks with isolated properties are instantiated and operated independently, enabling operators to offer dedicated network slices to different customers and applications to meet their requirements exactly. Through network slicing, the more flexible network will create new business models and revenue opportunities; at the same time, providing both traditional operators as well as enterprises and verticals the ability to deliver new value-added services.

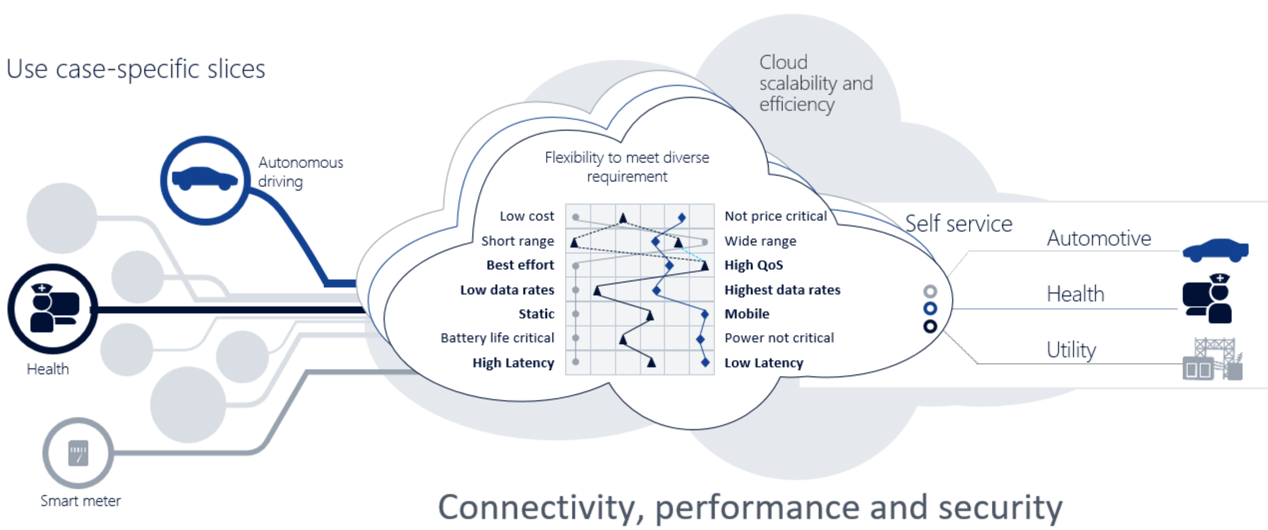

Figure 7: Network slicing overview

Driving toward early 5G NR eMBB deployments in 2019

With the work on 5G NR Release 15 specification well under way, the ecosystem is preparing for initial 5G NR deployments to start in the 2019 timeframe. Early 5G NR networks will leverage the Gigabit LTE coverage foundation and focus on enhancing performance and efficiency for eMBB use cases utilizing licensed spectrum in both sub-6 GHz and mmWave. To make 5G NR a reality, new 5G NR radio access network (RAN) must be deployed, and new generation of mobile devices must also be available to support 5G NR RAN.

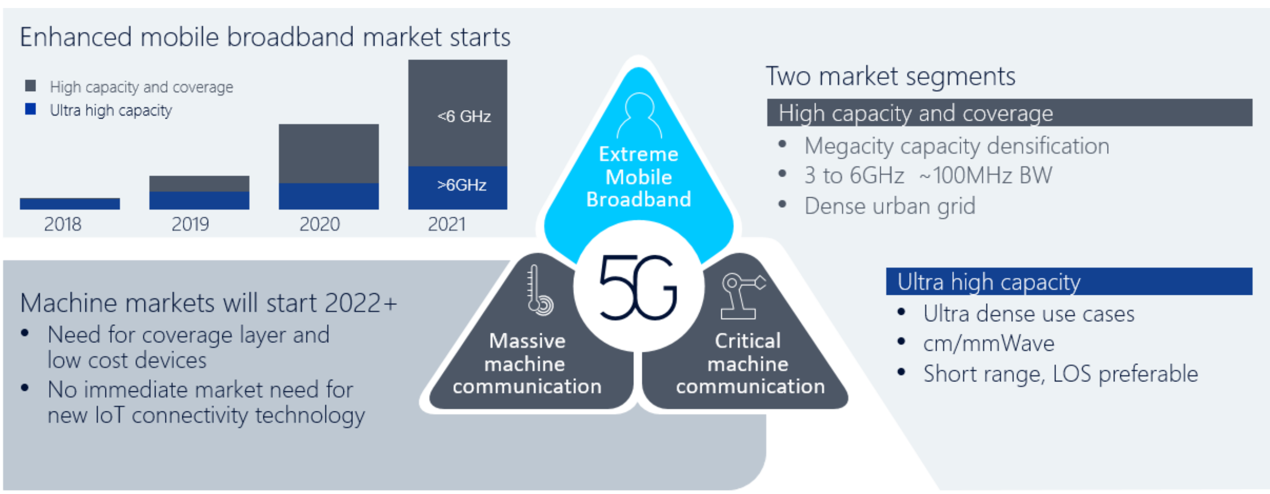

Figure 8: Initial 5G deployments will focus on enhanced mobile broadband services

Leveraging existing LTE infrastructure

To accelerate 5G NR deployments, 3GPP Release 15 has defined several evolutionary architectural and deployment configurations that will allow the new 5G NR RAN to build upon the existing LTE infrastructure. This proposed configuration is called a Non-Standalone (NSA) mode, where the new 5G NR RAN will leverage the existing LTE EPC in dual-connectivity mode with existing LTE RAN. Mobile devices supporting the NSA configuration will have two real-time parallel radio connections to the EPC: one via 5G NR and one via LTE. This is particularly practical if the LTE network uses lower band and the 5G NR network uses higher band with more capacity but is limited in initial coverage. Release 15 will also define a longer-term deployment configuration called Standalone (SA) mode, where both the core and access network will be based on the new 5G standard (i.e., with 5G NR RAN and 5G NGC). Both SA, and NSA are being selected by different carriers for their early deployments.

There are advantages and implications to each configuration; for instance, while NSA deployments only require operators to focus on investing in the 5G NR RAN, the overall performance may still be limited due to the LTE EPC. On the other hand, SA deployments require the investment on both a new core and access network, but allows the operators to deploy new services based on 5G NR without impacting existing services already deployed in LTE. Given ubiquitous deployments of LTE, the most likely NSA solution adopted for initial deployments is with LTE as prime, leveraging 5G NR as a secondary carrier with the LTE EPC core. If NGC is later deployed, an operator may choose to upgrade the LTE RAN (i.e., eLTE) to utilize the upgraded NGC for both LTE and 5G NR.

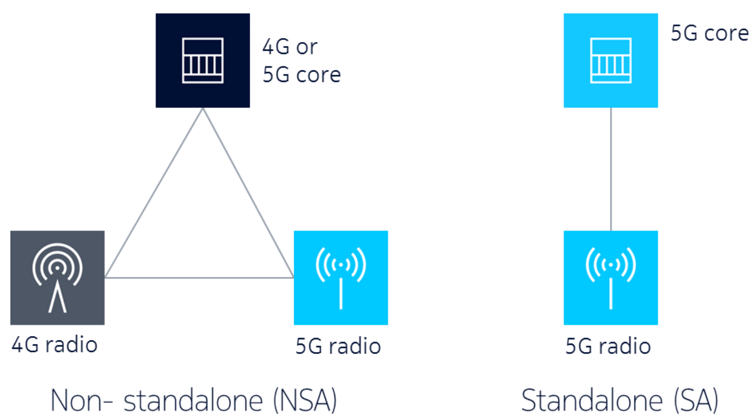

Figure 9: 5G Deployment configurations – NSA vs. SA

Enabling mobile devices supporting 5G NR

While it is important to start deploying 5G NR networks as soon as possible, device availability will also play an integral role in driving early 5G adoption. As inferred in previous sections, initial 5G NR mobile devices will also need to support LTE, especially Gigabit LTE, for its coverage foundation.

We expect the initial 5G NR enabled device form factors to be higher-end smartphones and data-centric tablets (vs. massive IoT that will be driven by LTE IoT in this timeframe), and 5G will continue to ride the display size, thinness, battery and processing power curves of the mobile industry as it proliferates into the mass market. These display-centric devices will be well suited to target eMBB applications to better support the increasing and more efficient use of videos for consumers.

At Mobile World Congress 2017 in Barcelona, QTI announced the Qualcomm® Snapdragon™ X50 family of 5G modems that will support 5G NR in sub-6 GHz and mmWave spectrum with integrated Gigabit LTE multimode. The Snapdragon X50 is expected to be available to support the first large-scale 5G NR trials and commercial network launches starting in 2019.

Nokia will be deploying 5G NR early and has adopted 5G NR as part of its 5G FIRST offering with commercial deployments expected in 2019, following initial trials with selected operator clients during 2018.

To accelerate mmWave deployments, QTI has developed mmWave prototype in the smartphone form factor, and Nokia has developed Nokia AirScale 28 GHz 5G Active Antenna[9] for the gNodeB – illustrated below.

Figure 10: Qualcomm® 5G NR mmWave prototype in smartphone form factor (left), Nokia AirScale 28 GHz 5G Active Antenna (right)

9 Design is subject to change

Reusing existing LTE cell sites for 5G NR mmWave

To date, mmWave has been considered only useful for short-range applications or carefully engineered point-to-point links, with line-of-sight (LOS), such as wireless backhaul for mobile networks or for fixed applications. This is due to the robustness challenge of the higher path loss and susceptibility to blockages, even from small objects like leaves. With recent advancements in antenna design and RF processing techniques, 5G NR mmWave is being designed for mobility by also utilizing reflected, non-line-of-sight (NLOS) signals to supplement the LOS signals. In addition, intelligent beamforming, beam-tracking and switching, and close integration with LTE and 5G NR sub-6 GHz will effectively mobilize the mmWave for mobile devices like smartphones.

It turns out that 5G NR mmWave can be deployed more economically than most assume today. QTI recently conducted a study on mmWave coverage by modelling mmWave in actual LTE networks in dense metropolitan areas — the initial target of 5G NR mmWave — to see if co-siting 5G NR mmWave with existing LTE infrastructure can provide sufficient outdoor downlink coverage for early use cases (a study for indoor mmWave coverage is also underway). The findings were encouraging and concluded that by co-siting 5G NR mmWave at existing LTE macro and outdoor small cells (e.g., outdoor small cells used for LAA), it is possible to achieve significant outdoor downlink coverage, even exceeding 80% in one city example, but even in the 40% range for cities only relying on co-siting with macro outdoor sites at high-traffic, hotspot areas.

Of course, actual achievable outdoor downlink coverage via co-siting will depend heavily on the city, operator, and frequency used to deploy mmWave. Nevertheless, this study sufficiently confirmed that existing LTE cell sites in major cities can be easily leveraged as a viable and reasonable place to start 5G NR mmWave deployments for outdoor coverage and provide a significant capacity boost. Given that most of the indoor coverage and capacity is currently served from the outdoor base stations, and mmWave does not typically penetrate indoor, mmWave will still help indoor capacity by offloading outdoor capacity from the outdoor sub-6GHz that can now better serve indoor users. Additional indoor mmWave capacity can be achieved by deploying complementing indoor mmWave small cells.

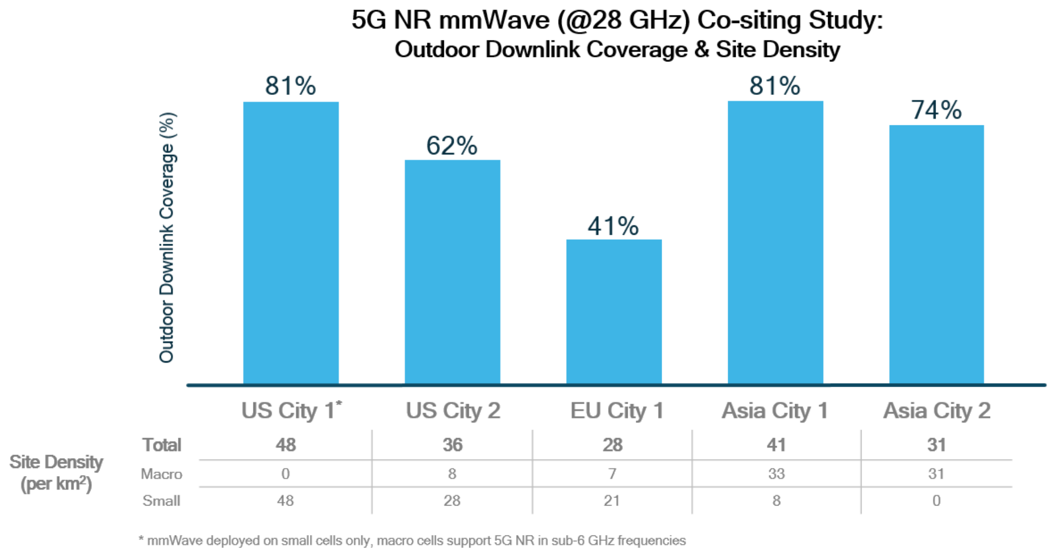

Figure 11: Achieving significant outdoor downlink coverage by co-siting with LTE

Continued LTE evolution in the 5G NR era

While 5G NR will elevate the mobile broadband experience, and provide much more capacity, proliferating 5G NR networks everywhere will take time; meanwhile, existing LTE networks will deliver the coverage foundation as part of the 5G platform. Gigabit LTE will continue to evolve when 5G NR launches in 2019, bringing further enhancements that will provide a more consistent experience for users that move between LTE and 5G coverage areas. It is expected that many of the 5G NR features will propagate back into existing LTE networks, including the support for ULL, massive MIMO and URLLC capabilities. It is also worthwhile to note that the mobile expansion into new verticals will continue to drive LTE growth in the foreseeable future. For instance, the continued LTE IoT evolution (both eMTC and NB-IoT) will be essential to connect the massive IoT in the 5G era, as 5G NR based IoT design is only expected in Release 16 or later.

As previously discussed, new 5G NR deployments can leverage existing LTE infrastructure, and this provides an opportunity for operators to refresh LTE equipment to increase overall LTE efficiency by further reducing size and power consumption as well as introducing new features. All in all, continued enhancements to LTE networks will be essential to enable a truly ubiquitous Gigabit-class mobile experience that is consistent outside 5G NR deployments.

Leveraging 5G as the platform for future innovations

This paper mainly focused on the initial eMBB deployments, but the potential for 5G is much broader. Other 5G capabilities, from URLLC to mMTC[10], will enable many emerging and new applications that are yet to be completely defined or even known today.

When 4G LTE was initially being conceived in 2004[11] few imagined the transformations that modern smartphones brought and the expansion of LTE to new areas such as unlicensed spectrum and IoT. Very different from the initial design philosophy for LTE that solely focused on an all-IP architecture for mobile broadband, 5G is being designed with flexibility and scalability in mind to provide a unifying connectivity platform that will ultimately connect virtually everything.

5G will evolve to also support a variety of diverse services. On one hand, it will further extend the mission taken on by LTE IoT (eMTC and NB-IoT) to connect efficiently the massive Internet of Things, and on another, it will also address the untethering of many emerging mission-critical services and new opportunities in the enterprise and industrial IoT areas.

The flexible framework, self-contained TDD subframe, and network slicing are just some examples of how 5G NR is being designed with forward compatibility in mind, so it can easily support future services that are unknown today. For instance, many niche use cases today are envisioned to become mainstream 5G NR use cases in the longer term, such as 6-DoF[12] immersive VR/AR experiences that will demand both low latency and high capacity as VR/AR form factor progresses. The automotive requirements will become a key use case not only for mission-critical C-V2X, initially for enhanced road safety and evolving to better support future autonomous vehicles, but also to enable immersive in-vehicle media consumption. All in all, we are only at the dawn of the 5G era, and we expect the continued 5G evolution to unlock even more value in the next decade and beyond.

[10] Massive Machine-type Communication
[11] At the 3GPP workshop on LTE in November 2-3, 2004
[12] 6 Degrees of Freedom