5G New Radio: Next Generation Radio Access Network

Olalekan Peter Adare
Chalmers University of Technology
Gothenburg, Sweden
peterad@student.chalmers.se

Haitham Babbili
Chalmers University of Technology
Gothenburg, Sweden
haitham@student.chalmers.se

***Abstract*—The mobile network is an ever-growing one, thanks to more demand in the services it offers. The major services are classified as voice, video, and data. Demand for various new services as off-shoots of multimedia and data services, as well as new use cases, have pushed for a major change in the existing network technology and infrastructure. This has led to optimized solutions for the use of the wireless channel. The 5th generation new radio (5G NR) will address a variety of usage scenarios which mainly include enhanced or extreme mobile broadband, very low-latency communications and interconnection of a massive number of devices, or the internet of things (IoT). It will leverage key technology features like ultra-lean transmission, better support for low latency applications, more advanced antenna technologies, and spectrum flexibility which covers the use of both the high-frequency bands, inter-working with the low-frequency bands. The aim of this report is identifying the driving forces behind 5G NR and the benefits of the technology. It also gives a concise but yet detailed look into the 5G NR, as put forward by 3GPP, covering standards, design, and deployment.**

I. INTRODUCTION

5G new radio (NR) is the access air interface of the 5G network. The air interface is the radio frequency part of the radio access network, between the mobile device and its base station. It is the use of the wireless channel to connect mobile devices, mobile stations, and, generally, user equipment to the base station. This is generally referred to as the air-interface. There are several base stations make up the network which are geographically spread out. This helps to achieve expected service coverage and handoff of service from one base station to another, thus enabling service accessibility even with mobility. 5G NR offers a unified and more capable air interface than previous generations in the mobile access technology. It has been designed with an extended capacity to enable next-generation user experiences, empower new deployment models, and deliver new services. This is to be achieved with very high data rates in the wireless space, with superior reliability and very low latency. 5G NR covers flexible bandwidth use with specific modulation schemes, channel coding, waveform generation, network slicing, MIMO, improved frame structures, numerology, hybrid automatic repeat request (HARQ), and duplexing. The combination of all these makes it to be better than the previous generations. 5G will expand the mobile ecosystem into new realms. It will improve most industries, including safer transportation, remote healthcare, precision agriculture, digitized logistics, and much more. The previous generations,1G, 2G, 3G, and 4G, all led to 5G, which is designed to provide more connectivity than was ever available before. Going forward, 5G will serve as the foundation for other newer technologies. It will focus on the breakthroughs to support the expansion and enhancement of mobile internet and the Internet of Things (IoT). The future 5G mobile applications defined by the International Telecommunication Union (ITU) in June 2015 are categorized into three types. They are enhanced mobile broadband, massive machine type communication, and ultra-reliable and low-latency communication [1].

II. PRE-5G COMMUNICATION

The telecom operators basically have been offering voice, video, and data services, over varying architectures and technological standards. Building a wireless mobile communication system started in early in the 1980s with first-generation (1G), second-generation (2G) in the 1990s, and third generation (3G) in 2000. 1G was only analog voice service, while 2G was for better digital voice and new data services. 3G was a unified architecture for voice, video and data, but with reduced capability. It was built on wideband code division multiple access (WCDMA) networks used to increase packet data performance. It was upgraded with the advent of High-Speed Packet Access (HSPA/HSPA+) into what was regarded as 3.5G, or 3.75G. There has been a push for an All-IP network, like the internet, which is the biggest network in the world. The internet can be accessed from both wired and wireless media.

Every generational mobile technology came with a number of limited features and availability until the 4th generation Long Term Evolution (LTE) mobile network was released in 2009. The LTE mobile network offered very high speed for down-link and up-link of data as compared to the previous generations and wider coverage area than before. 4G now opened the door for an enormous amount of applications connected to the mobile network such as Device-to-Device Communication, vehicle-to-vehicle communication, remote-controlled drones and massive machine-type communication. Cloud computing networks were growing as well, and they could be hosted on the 4G network also. The features that came with 4G LTE are spectrum flexibility, multi-antenna techniques and densification. The use of 4G LTE is more than just for mobile networks. The 4G LTE network designed for a baseline of 100Mbps for the down-link. Higher data rates can be achieved depending on the later improvements made. In addition to the reduced cost of newer technologies and low data rates (10 – 100 kbit/s), a larger number of devices can now connect to the network. It is predicted that there will be 160 exabytes per month by the end of 2024. This will come with more need for ultra-low latency, in the order of nanoseconds and milliseconds, as well as high connection density and reliability, especially with IoT, making one-third of the new subscriptions for the network to be for machines[1,2].

III. 5G NEW RADIO

5G NR is a new radio access technology (RAT), was developed by 3rd Generation Partnership Project (3GPP) for the fifth generation (5G) mobile networks. It was designed to be the global standard for the air interface of 5G networks. RAT is the underlying physical connection method for a radio-based communication network. 5G also uses OFDM, a spectral efficient technique already being used by WiMAX, LTE, and IEEE 802.11 (Wi-Fi). The three major applications enabled by 5G NR are enhanced mobile broadband (eMBB), or extreme mobile broadband (xMBB), ultra-reliable and low-latency communication (URLLC) and massive machine type communication (mMTC) [3]. Figure 1 shows the three key components of the 5G NR and defined requirements.

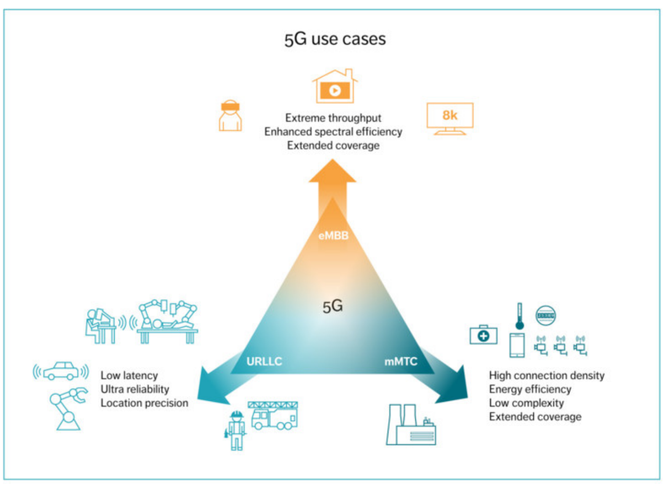

Fig. 1. 5G NR use cases[4].

eMBB/xMBB facilitates people-to-people exchange as a fundamental requirement for mobile communications. eMBB focuses on both larger and flexible bandwidth than 4G, leading to a tremendous improvement of a user's perceived experience and quality of experience (QoE). Higher data rates can always be achieved by increasing the bandwidth in use and increasing the modulation schemes. mMTC promotes the internet of things (IoT) and other vertical industries, that will bring about a large number of wireless sensor networks, thereby putting a new demand network access quantities and power consumption efficiency. Additionally, uRLLC revolves around industry automation, telemedicine, smart grids, and other vertical industries that require high reliability and low latency use cases. Consequently, the key features of 5G NR encompass ultra-lean carrier design, scalable orthogonal frequency multiplexing (OFDM) based air-interface, use of massive MIMO and beam-forming, usage of sub 6GHz, and mmWave spectrum, and scalable numerology. Several of technological solutions released and standardized over the years have actually made 5G NR a reality [1].

NR's operation will be from low to very high bands: 0.4 – 100Ghz, with the possibility for standalone operation in unlicensed bands. It offers ultra-wide bandwidth up to 100MHz bandwidth in wireless bands less than 6GHz, and up to 400MHz in wireless bands above 6GHz. It will also offer various sets of different numerologies, for optimal operation in different frequency ranges[1, 2]. There is a limitation to the available bandwidth in sub-6GHz bands because they are already in use by other wireless technologies. To get higher bandwidth in these bands, it will require frequency re-farming, which means re-purposing of frequency bands that have historically been allocated for other mobile services [1,3,5].

The 5G system architecture is created to support data connectivity and services enabling deployments to use techniques such as network function virtualization (NFV) and software-defined networking (SDN). The 5G performance requirement is higher than that of 4G, including the capability to support between 100Mbps to 1Gbps user experience speed, 1 million connections density per square kilometer, millisecond-level of end-to-end latency of less than 10ms, Tbps level of traffic flow density per square kilometer and mobility of up to 500km/h. All of these make up the top three (3) key performance indicators of the 5G network (user experience, connection density, and latency). Meanwhile, 5G is required to improve the efficiency of network deployment and operation and maintenance. To compare with 4G, the spectrum efficiency improved between 5 to 15 times, and the cost efficiency improved more than a hundred times [5,6].

IV. 5G STANDARDIZATION AND SPECIFICATIONS

Like the generations that have come before, 5G standardization is spearheaded by 3GPP. The 3GPP standardization is an open and contribution-driven process, bringing together (telecommunications) companies from all over the world in order to establish an international standard for mobile technologies.Release 15 of the 3GPP specifications started in March 2017 and ended in June 2018. It contains the first complete specification of 5G NR. Since then, newer requirements and other use cases have given rise to releases 16 and 17. This makes it reasonably technology and location neutral. Earlier standards offered a co-existence of 5N NR and 4G LTE networks, where every resource is centrally managed by the 4G evolved packet core (EPC) node. NR relies on the existing 4G LTE network for mobility and initial access.This is the standardization of non-standalone (NSA) NR, which was intended to be used in early commercial deployments. Then, the standalone (SA) version was released to operate without relying on 4G LTE [7(6),8(13)].

Through the guided releases of 5G, 3GPP has made NR compatible with future innovations. NR achieved forward compatibility by self-contained and well-confined transmissions. Self-containment means that data in a slot and a beam is decodable without dependency on other slots and beams. Well-confined transmissions are the approach of keeping transmissions confined in time and frequency domains to allow future inclusion of new types of transmissions in parallel with with the existing backhauling transmission technologies [7(6)].

V. 5G NR Design

Empirically, to increase the data rate is to increase the bandwidth of the system, supported by a given modulation technique. The key principles behind the 5G NR design are flexibility, ultra-lean design, and forward compatibility. The flexibility of deploying NR uses a wide range of frequencies and different deployment types (macrocells, microcells, picocells), with diverse use cases covering eMBB/xMBB, mMTC and uRLLC. The physical layer components of NR are flexible and scalable. The 5G network is divided into access and core networks. The access network consists of the gNodeB (gNB) which is the wireless access base station of the 5G network. The 5G NR consists of a set of gNodeBs which all connect to the 5G core network (5GC)as shown in figure 1. It differentiates between the network architecture of 4G LTE and the 5G networks. It also points out the basic interconnection between the mobile network nodes [9].

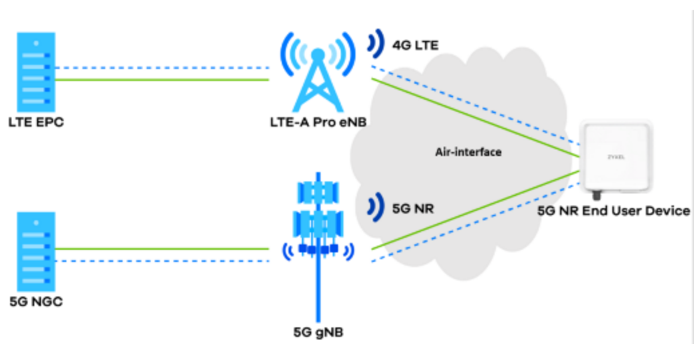

Fig. 2. Simplified 4G LTE and 5G NR Network[10].

The main technology components of the NR physical layer are modulation schemes, waveform, frame structure, reference signals, multi-antenna transmission and channel coding. There is a wide range of QAM based modulation orders including OFDM waveform with scalable numerology, low-density parity codes (LDPC) codes with rate-compatible structure, polar codes, and frame structure with flexible slot durations. Numerology is the sub-carrier spacing used in OFDM. The reference signals can be beamformed in both frequency domain and time domain, and with pre-conceived densities. There are also varying multi-antenna techniques with flexible channel state information acquisition and reporting framework. NR core specifications support any bandwidth from 1.4 to 20 MHz. Data is transmitted as symbols, and a symbol is coded collection of bits. One OFDM slot is comprised of 14 symbols. Figure 2, shows the NR frame structure and the duration for each subframe. Modulation scheme offers the number of symbols and the number of bits per symbol that can be coded into a constellation. QPSK, 16QAM, 64QAM, and 256QAM, with the same constellation mapping as in LTE, are supported. Numerology is about the channel spacing. NR supports scalable numerologies to address different spectrum, bandwidth, deployment, and services. Sub-carrier spacing (SCS) of 15, 30, 60, 120 kHz is supported for data channel [7,9].

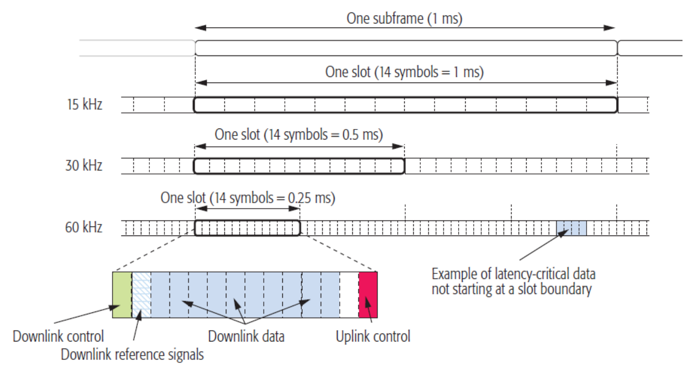

Fig. 3. 5G NR frame Structure [3].

Basically, cellular networks are designed to transmit certain signals at regular intervals even when there is no data to transmit to any user and this is called ”always-on”. Examples of such specific signals are reference signals, synchronization signals, and system broadcast information. Ultra-design concept is to reduce the “always-on” transmissions. The network should transmit signals only when necessary. The reference signals are used for tracking, synchronization, channel state information, demodulation and sounding, for both uplink and downlink information. The NR ultra-lean design is to significantly improve network energy efficiency, and reduce network operational expenses. This then reduces interference in high traffic load situations. The ultra-lean design also enhances the forward compatibility of NR because it is hard to modify the “always-on” transmissions without degrading the performance of legacy devices. NR offers four (4) main reference signals. They are demodulation reference signals, phase tracking reference signals, sounding reference signals, and channel state information reference signals. These signals are only transmitted when necessary, making NR design ultra-lean. NR has no cell-specific reference signals; synchronization and broadcast signal are sent every 20 ms [6,7,9].

VI. 5G NR Services

This is brief overview of the service categories of 5G NR

A. eMBB

eMBB is a service in 5G NR that require high bandwidth to serve high resolution video, virtual and augmented reality and live steaming. Several technologies at the physical layer were introduced to maintain eMBB. This includes high order modulation transmission, higher bandwidth and carrier aggregation, cell densification and massive MIMO transmission. Beside these technologies, some techniques from 4G LTE have been developed to improve spectrum efficiency and utilize all the capacity of the spectrum such as mmWave communication and spectral localization [1,11].

B. mMTC

mMTC is a key service of NR which supports high volume of IoT devices. This means that virtually any intelligent device, that can be connected to internet, will be supported by the NR. mMTC related services include sensing, parking, building management, tagging, smart metering, and monitoring. These require high connection density and better energy efficiency. Narrowband internet of things (NB-IoT) is a good fit mMTC services. NB-IoT offers advantages such as low power consumption, reduced operation cost, and improved coverage. NR specifications will bring new capabilities to existing NB-IoT. To maintain NB-IoT, virtual networks and spectrum slicing has been used together with non-orthogonal spreading sequence. This further helps to manage the possibility of having more mMTC devices than the network can initially support[11].

C. URLLC

URLLC is designed to support services that are latency-sensitive and highly reliable such as autonomous driving, factory automation, industrial internet, smart grids and telemedicine. Low latency allows a network to be optimized for processing large amounts of data with minimal delay in the order of 1ms or less. Therefore, the networks need to adapt to a broad amount of changing data in real time. URLLC requires a quality of service (QoS) that is totally different from the mobile broadband services. Latency is defined as on the basis of end-to-end communication. The physical layer plays an important role to achieve ultra low latency and reliability. This is achieved by first reducing the system overhead in term of channel access, user schedule, and allocation of resources. Then with advanced channel coding schemes, the packet error probability is reduced, the re-transmission of packets is reduced and reliability is improved. Also, the transmission of URLLC packets is given high QoS priority, and are being transmitted as soon as they are generated. The design of URLLC involves components like integrated frame structure with reduced overhead, improved channel estimation accuracy, efficient control, data resource sharing, grant-free based uplink transmission, and advanced channel coding schemes. The goal is therefore to reduce latency and still ensure 99.999% reliability of the network [5,11].

VII. SPECTRUM ALLOCATION FOR 5G NR

Frequency bands for 5G NR are separated into two different frequency ranges. First, there is frequency range 1 (FR1) that includes sub-6GHz frequency bands. Some of these are bands traditionally used by previous standards, but which have been extended to cover potential new spectrum offerings from 410 MHz to 7125 MHz. The other is frequency range 2 (FR2) that includes frequency bands from 24.25 GHz to 52.6 GHz. Bands in this range, which is referred to as the millimeter-wave (mmWave) range, have shorter coverage but higher bandwidths are available than in the bands in FR1.mmWaves have a very high free space attenuation and penetration loss. This limits its coverage and ability to serve indoor users. The combination of FR1 and FR2 gives NR the advantage of wider coverage and bandwidth, than any pre-existing wireless technology. This caters for both indoor and outdoor users, irrespective of the use case.

5G NR supports the use of all available spectrum types and spectrum bands. This encompasses the licensed spectrum (exclusive right), unlicensed spectrum (shared use), and shared spectrum (new shared spectrum paradigms). Spectrum sharing unlocks more spectrum possibilities, new deployment scenarios, and increased spectrum utilization, with higher efficiency. Spectrum can be shared both horizontally and vertically. This is defined as frequency division duplex (FDD) and time division duplex (TDD). NR mainly uses dynamic TDD. The benefits of the 5G NR TDD self-contained slot structure is a much faster, more flexible TDD switching, with better spectrum utilization and a guaranteed bandwidth [3,9,12].

VIII. 5G AND 4G LTE COEXISTENCE

The frequency spectrum is a limited resource and so efficient utilization must be promoted. This can be achieved by spectrum sharing which can be static or dynamic. Static spectrum sharing means that there will be a dedicated carrier frequency for each wireless access technology within the same band. It is transparent to the UE but not too spectrally efficient. The data rate increases with bandwidth. Any current or future technology deprived of bandwidth will not meet its goal. This gave rise to a dynamic approach, called dynamic spectrum sharing (DSS). Overlapped and non-overlapped LTE and NR carrier frequencies transition is more efficient for 5G and 4G coexistence.

The DSS concept is based on the flexible design of the NR physical layer. It makes it possible for NR signals to be transmitted over unused LTE resources. With LTE, all the channels are statically assigned in the time-frequency domain, whereas the NR physical layer is extremely flexible for reference signals, data, and control channels. This allows for dynamic configurations that will minimize a chance of collision between the two technologies.

One of the main concepts of DSS is that only 5G users are made aware of it, while the functionalities of the existing LTE devices remain unaffected i.e. LTE protocols in connected or idle modes [7,9,12].

Spectrum re-farming for 4G LTE bands is not best solution to expand the coverage of 5G NR. Re-farming low band carriers from 4G without a corresponding increase in 5G devices penetration might lead to congestion of the remaining LTE carriers, degrading indoor coverage for LTE users who still represent the majority of the subscriber base. This co-existence between 5G and 4G LTE can thus be considered as a flexible re-farming solution [7,12].

IX. DEPLOYMENT MODES OF 5G

3GPP has defined possible deployment modes to integrate elements of different generations in different configurations with 5G. They are broadly divided into two modes: standalone (SA) and non-standalone (NSA). An SA scenario uses only one radio access technology (5G NR or 4G LTE radio cells) and the core networks are operated alone. Data and control information are handled by the 5G network. An NSA scenario combines NR radio cells and LTE radio cells using dual-connectivity to provide radio access and the core network may be either 4G Evolved Packet Core (EPC) or 5GC [13]. For this option, the 5G control information is carried by the 4G LTE network, while the data traffic is carried by the 5G NR network. This is to enable a smooth upgrade of the existing network to support 5G services seamlessly. Figure 3 below shows the diverse deployment options for SA and NSA, detailing the entities for both the access and core networks respectively.

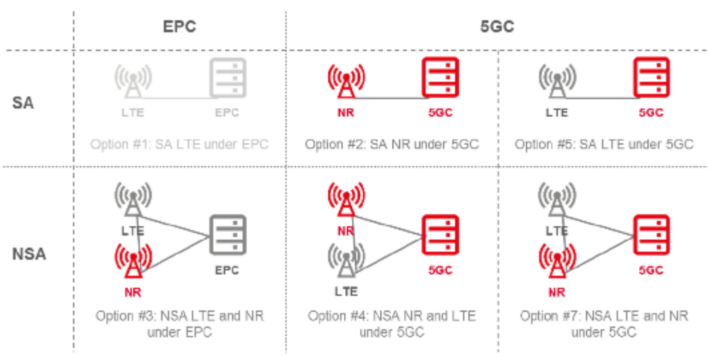

Fig. 4. 4G LTE and 5G NR Deployment Options [13]

X. BENEFITS OF 5G NR

NR will enable the network to support adaptive bandwidth.Varying data rates for different applications are made possible. Key benefits of NR will include more capacity for wireless users, improved interconnection among users, and enhanced speed of data rates. Because of these end-user benefits, 5G NR is destined to benefit the day-to-day life.5G NR offers many use cases, which are the benefits of this innovation.

The use of various band across the frequency spectrum increases both data rate and network coverage. Home broadband penetration is greatly increased, even with the advent of unlicensed frequency for the NR technology.IoT can be better achieved with the interconnection of devices for varying purposes. This covers V2V communication, self-driving cars, drones, and other later intelligent devices. It has also become a platform for telemedicine, improved agricultural management, and for other industrial purposes. Multimedia services such as virtual reality and augmented reality are also seamlessly supported. Multimedia-related services helped in pushing for an increase in the possible data rates offered by the wireless network [8].

XI. CONCLUSION

5G NR offers a wide range of use cases and is expected to lead to significant socio-economic benefits. The three key components have been maturely achieved. 3GPP approved the highly anticipated standalone 5G NR specifications in June 2018. NR offers very high and flexible bandwidth, which guarantees high data rates. It also gives a better coverage for mobile services for both urban, sub-urban and rural areas. It is a foundation for IoT which creates new business opportunities, new revenue streams and improved control of operation processes. 5G NR can co-exist with the 4G LTE network both riding on the legacy backhaul transmission network. SDN and NFV have introduced the logical and more efficient use of the mobile network to support many use cases, services, deployments, and future possibilities. The 5G NR is the beginning of the future of the mobile communication network.

REFERENCES

[1] Ericsson AB., J. PEISA, P. PERSSON, S. PARKVALL, E. DAHLMAN, A. GRØVLEN, C. HOYMANN, D. GERSTENBERGER, February 2020, 5G New Radio Evolution, IEEE Communications Standards Magazine. pp 2-14, December 2017

[2] S. Parkvall, E. Dahlman, A. Furuskär, and M. Frenne. "NR: The New 5G Radio Access Technology", IEEE Communications Standards Magazine, pp. 24-30, December 2017

[3] Qualcomm Technologies, Inc. Making 5G NR a reality Leading the technology innovations for a unified, more capable 5G air interface. pp 2-63,September, 2016

[4] Ericsson AB., A. A. Zaidi, R. Baldemair, M. Andersson, S. Faxér, V. Molés-Cases, Z. Wang,"2017-07 [online] Available at ericsson.com/en/reports-and-papers/ericsson-technology-review/articles/designing-for-the-future-the-5g-nr-physical-layer

[5] Qualcomm Technologies Inc. Expanding the 5G NR ecosystem.[online] https://www.qualcomm.com/media/documents/files/expanding-the-5g-nr-ecosystem-and-roadmap-in-3gpp-rel-16-beyond.pdf ,pp 3-25, September 2018

[6] Amitabha Ghosh, Nokia, "5G New Radio (NR): Physical Layer Overview and Performance", IEEE Communication Theory Workshop 2018. pp 2-37, May 2018

[7] Huawei Technologies., Alexander Serbin, "On the roads to 5G: theory and practice". ITU Seminar. pp 2-18, May 2018

[8] Ericsson AB., Shiv K. Bakhshi, Ph.D. "5G and standards: managing complexity, ensuring interoperability". Ericsson presentation. pp 2-18, February 2018

[9] 3GPP publication. The 5G Evolution: 3GPP Releases 16-17.[online], https://www.5gamericas.org/wp-content/uploads/2020/01/5G-Evolution-3GPP-R16-R17-FINAL.pdf pp 22-27, Jan 2020.

[10] ZYXEL [online] https://www.zyxel.com/solutions/5g-nr-service-provider-20200115-082732.shtmlsn-nsa

[11] H. Ji, S. Park, J. Yeo, Y. Kim, J. Lee and B. Shim, "Ultra-Reliable and Low-Latency Communications in 5G Downlink: Physical Layer Aspects," in IEEE Wireless Communications, vol. 25, no. 3, pp. 124-130, JUNE 2018, doi: 10.1109/MWC.2018.1700294.

[12] Qualcomm Technologies Inc., "What can we do with 5G NR Spectrum Sharing that isn't possible today?" Available at https://www.qualcomm.com/media/documents/files/new-3gpp-effort-on-nr-in-unlicensed-spectrum-expands-5g-to-new-areas.pdf, pp. 4-32, December 2017

[13] GSMA publication, Road to 5G: Introduction and Migration. pp 6-27, April 2018