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5G NEW RADIO (5G NR) – AIR INTERFACE IN 5G MOBILE NETWORKS

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A b s t r a c t: The fifth generation of mobile networks promises a scalable platform that can effectively provide coexistence between existing services and future 5G services. 5G networks, despite connecting people, will provide interconnection and control between machines, objects and devices. In other words it is an innovation platform that can provide new services, enhance the user experience and connect new industries. The design of 5G not only focuses on improving mobile broadband, but also on providing control over services through ultra-reliable communication links with low latency and connection to massive internet services. At the heart of 5G network there is a new, unified radio interface - 5G New Radio (NR). 5G NR is part of the 3GPP standards defined in Release 15. This paper provides an overview of the specifications defined for standardization of the new generation of mobile networks, describes the key technologies that are subject for analysis about the development of 5G NR and gives a performance evaluation in order to make a comparison with the services we use today. This technology will start a new industrial revolution, providing high communication speeds, extremely low latency, reliable communication and services that have not been possible before.

Key words; 5G NR; millimeter wave; small cells; reliability; massive MIMO; spectral efficiency; latency

5G NR – НОВ РАДИО-ИНТЕРФЕЈС ВО ПЕТТАТА ГЕНЕРАЦИЈА МОБИЛНИ МРЕЖИ

А п с т р а к т: Петтата генерација на мобилните мрежи ветува достижна платфома која ефикасно може да ги мултиплицира постојните сервиси и идните 5G-сервиси. Ваков тип мрежа, покрај тоа што ќе ги поврзува луѓето, ќе овозможи меѓусебна поврзаност и контрола на машини, предмети и уреди. Станува збор за платформа за иновации која може да овозможи нови сервиси, да го зголеми корисничкото искуство и да поврзе нови индустрии. Дизајнот на 5G не се фокусира само на подобрување на мобилниот широкопојасен интернет, туку и на обезбедување контрола врз сервиси преку ултрадоверливи комуникациски линкови со мало доцнење и поврзување на масивни интернет-сервиси. Во срцето на технологијата 5G е нов и унифициран радио интерфејс – 5G New Radio (NR). 5G NR е дел од стандардите 3GPP дефинирани со Release 15. Во овој труд е даден преглед на спецификациите дефинирани за стандардизација на новата генерација мобилни мрежи, опишани се клучните технологии кои се предемет на анализа за развој на 5G NR и направена е евалуација на перформансите со цел да се направи споредба со сервисите што ги имаме и користиме денес. Се предвидува дека оваа технологија ќе ја започне новата индустриска револуција, обезбедувајќи големи брзини за комуникација, екстремно мало доцнење, доверлива комуникација и сервиси кои досега не биле возможни.

Клучни зборови: 5G NR; милиметарски бранови; мали ќелии; доверливост; масивни MIMO системи; спектрална ефикасност; доцнење

INTRODUCTION

Mobile communications are an ever-evolving segment of the communication industry, from simple applications, voice calls and messages, using analog wireless technology, to the evolution of digital technology and previously unimaginable applications. At the heart of this revolutionary change is 3GPP (Third Generation Partnership Project), which has been developing the standards needed for mobile communications for more than twenty years. Since 1998, 3GPP has been developing standards for wireless mobile communications, WCDMA (wideband code-division multiple access), HSPA (high-speed packet access), 4G LTE / LTE-Advanced, and most recently 5G New Radio. With the development of 5G NR standards, in 3GPP Release 15, the performance and functionality of mobile wireless communications reached an unexpected level. Development and implementation of 5G creates a revolutionary change in the way of daily life, providing a wide range of services through the use of intelligent connected platforms. Providing high data throughput, extremely low latency, greater reliability and speeds a hundred times faster than we have had so far, 5G is moving towards commercial reality much faster than expected. Although the first edition of the 5G NR standards is complete, 3GPP is still working on developing NR standards that will fulfill the 5G vision. This evolution is necessary because the expectations of 5G are much higher than exceeding the performance of the LTE network. There are three main categories of services: enhanced mobile broadband (eMBB), ultra-reliable and low latency communication (URLLC), massive machine communications, or massive machine type communications (mMTC). Each category has different requirements in terms of bandwidth, latency, mobility, data speeds and connectivity. With the variety of services provided by 5G and the need for spectral and energy efficiency, the 5G NR must support high level of flexibility. This result in increasing the complexity of the radio system and in order to meet the requirements, the 5G NR, which represents a key part of the 5G network, must be designed to support a set of key technologies. Some of the key technologies are:

- Millimeter waves (mmWave).
- Massive MIMO.
- Beamforming.
- Ultra small cells and heterogeneous networks.
- Scalable OFDM numerology.

STANDARDIZATION OF 5G

Development and maintaining of global technical specifications in order to ensure worldwide interoperability is the task of 3GPP. The fifth generation of mobile networks is defined through a set of requirements and standards. The key requirements for 5G, defined by ITU-R (International Telecommunication Union – Radio communication Standardization Sector), are given in Figure 1.

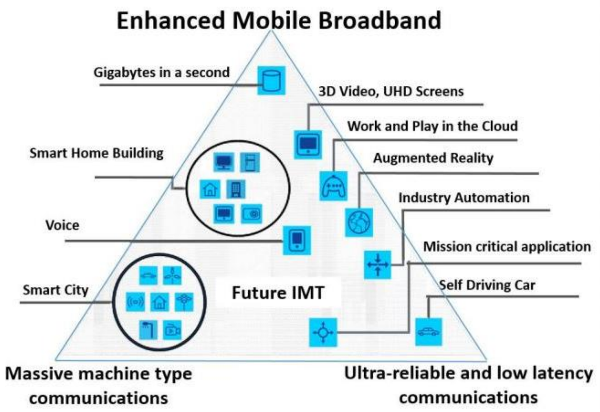


Fig. 1. ITU-R specifications for 5G networks [1]

The need for cost-effective development and interoperability between existing multi-RAT-based networks leads to an unexpected level of complexity in planning of 5G NR network. The standardization of 5G NR is divided into two phases [1]. While the first phase mainly focuses on providing improved mobile broadband and services, the second one provides specifications for high reliability and machine communications.

Release 15: The beginning of 5G

After the introduction of the NSA (Non Standalone) NR 5G Specifications in 2017, a non-standalone radio system, a great effort has been put into completing 3GPP Release 15 – the first complete set of 5G standards. The purpose of the Release 15 is to cover aspects of the SA (Standalone) 5G, with a new radio system complemented by a next-generation core network [2]. The focus of Release 15 is on developing improved mobile broadband, increasing bit rates and network capacity:

- NR "New Radio" and the 5G System Massive MTC (Machine Type Communication) and Internet of Things (IoT);
- Vehicle-to-Everything Communication (V2x);
- Mission Critical (MC) interworking with legacy systems;
- WLAN and unlicensed spectrum;
- Slicing – logical end-2-end networks;
- API Exposure – the 3rd party access to 5G services;
- Service Based Architecture – SBA;
- Improvements in LTE network.

In NR Phase 1, there are common elements between LTE and NR, for example both technologies use orthogonal frequency division multiplexing (OFDM). However, there are also differences as summarized in Table 1.

Table 1A

Differences between LTE and NR

	LTE	NR Pause 1
Frequency of operation	Up to 6 GHz	Up to 52 GHz
Carrier bandwidth	Max 20 MHz	Max 100 MHz (@ >6 GHz Max 1 G Hz (@ >6 Ghz)
Carrier aggregation	Up to 32	Up to 16
Analog beamforming (dynamic)	Not supported	Supported
Digital beamforming	Up to 8 layers	Up to 12 layers
Channel coding	Data turbo coding Control: Convolutional coding	Data LDPC coding Control: Polar coding
Subcarrier spacing	15 Hz	15, 30, 60, 120, 240* kHz
Self contained subframe	Next supported	Can be implemented
Soectrum occupancy	90% of channel BW	Up to 98% of channel BW

The International Telecommunication Union (ITU) has put forth some requirements for 5G that focus on fulfilling three key performance indicators (KPIs):

- >10 Gb/s peak data rates for the enhanced mobile broadband (eMBB),
- >1 M/km^2 connections for massive machine-type communications (MMTC),
- <1 ms latency for ultra-reliable low-latency communications (URLLC).

Release 16 and 17

In Release 16 the focus is mainly on ensuring reliable communication and ultra-low delay in critical applications. Release 16 was completed in July 2020 and consists of:

- 5G System Phase 2,
- Enhancement of Ultra-Reliable (UR) Low Latency Communications (URLLC),
- Industrial IoT,
- Advanced V2X support (Platooning extended sensors, automated driving, remote driving),
- NR-based access to unlicensed spectrum (NR-U),
- 5G Efficiency,
- Integrated Access and Backhaul (IAB),
- Enhanced Common API Framework for 3GPP Northbound APIS,
- Satellite Access in 5G,
- Mobile Communication System for Railways (FRMCS Phase 2).

The most significant improvements of the existing features of Release 16 are in the areas of: Multiple-input, multiple-output (MIMO) through improvements in the algorithms for beamforming, Dynamic Spectrum Sharing (DSS), in order to provide sufficient capacity, Dual Connectivity (DC) mechanisms for rapid deactivation of radio channels in order to save energy, Carrier Aggregation (CA) and User Equipment (UE) for energy saving. Improvements for 5G systems are defined in Release 17 and is expected this release to be completed and adopted during 2021. Release 17 consists of scientific studies on IoT / eMTC. 3GPP (Release 16 and 17) improvements play a key role in expanding the availability and deployment of 5G New Radio and will open a wide range of new applications and use cases in industry and public services.

KEY ENABLING TECHNOLOGIES FOR 5G

In order to enable 5G to become a reality, many ideas have been proposed and analyzed in the last few years. Key technologies that are subject for analysis about 5G development include: millimeter waves, massive MIMO systems, small cell or heterogeneous networks, beamforming, scalable numerology, dual connectivity mechanism, device-centric architecture and full-duplex technology.

mmWave communication

The evolution of wireless communications as well as the increased use of smart devices, is leading to a massive increase in mobile data traffic, creating significant challenges for service providers. With the introduction of many new services offered through new technologies, mobile traffic is expected to increase at a high rate. According to reports from the ITU (International Telecommunication Union), there are predictions that by 2030 data traffic will increase from 10 to 100 times. Existing mobile systems mainly operate in the 3 GHz band and higher frequencies are mainly used for other services, such as satellite applications. Due to the need for larger capacity, as well due to the exhaustion of the bandwidth allocated for wireless communications, or congestion in the UHF and SFH bands there is a need for the new broadband communication networks to use part of the spectrum which was not in use till now. If operators restrict users to the same frequency band from the radio spectrum that we use today, each user will have a limited amount of bandwidth, leading to reduced speeds, unreliable connectivity, and frequent loss of service due to congestion. In order to provide the required data speeds and the required data flow, while avoiding network congestion, new radio systems are designed to operate at higher frequencies. The range of millimeter waves, from the electromagnetic spectrum is defined as the range of wavelengths from 10 millimeters to 1 millimeter. It follows that millimeter waves are longer than infrared or X-rays and shorter than radio waves or microwaves. The same band corresponds to frequencies in the radio band from 30 GHz to 300 GHz, known as the extremely high frequency (EHF) band. Frequencies above 6 GHz have never been used before for wireless communications, so a lot of research has been done about this part of the spectrum [3]. Characteristic for this range of frequencies is that it is only suitable for transmitting data over short distances. The combination of low and high frequencies is crucial for the operation of 5G systems, but it is possible with the help of carrier aggregation or dual connectivity model. Additionally, using massive MIMO systems and small cells, millimeter waves are a key solution for fifth generation mobile networks [4]. One of the most important characteristics of millimeter waves is their ability to transmit large amounts of data. Based on the communication principles, the maximum bandwidth of the signal in wireless communications is about 5 percent of the frequency of the carrier. Therefore, the higher the carrier frequency is, the greater the signal bandwidth will be. In the millimeter wavelength range, 28 GHz and 60 GHz are the most promising frequencies for fifth-generation systems. The advantage of using this kind of propagation is beam width of the signals. Beam width is a measure of how the beam propagates during transmission, starting at the transmitter. Carefully designed antenna allows using microwaves, where they will be focused to have a narrow beam. On the other hand, maintaining a small beam width requires the use of large antennas. However, the use of millimeter waves solves this problem. The use of millimeter waves allows engineers to overcome this problem, because at given antenna size, the beam width can be reduced by increasing the frequency. In this way, small, practical antennas can be used. Until now, only radar systems and satellites have used millimeter waves. Today, with the implementation of the new, fifth generation of mobile systems, their use represents a significant advancement in technology. Although millimeter waves provide a wide range, additional frequencies, very high transmission speeds and large data transmission, millimeter waves also face certain obstacles and disadvantages in their use.

Massive MIMO

MIMO systems are a necessary part of today's wireless systems and in recent years they have been increasingly used in order to achieve high spectral and energy efficiency. Before the implementation and use of MIMO at all, it has been characteristic the use of single input-single output systems, where the flow that can be provided is small and in addition such systems do not provide reliability for large number of users [4]. In order to meet the needs of large number of users, various MIMO technologies have been developed, such as single-user MIMO (SU-MIMO), multi-user MIMO (MU-MIMO) and network MIMO. In any case, these new technologies are not enough to meet the ever-increasing demands. The number of wireless users is constantly growing in recent years and they generate large amount of traffic that the network must deal with as efficiently as possible, ensuring reliable transmission. Initial low frequency band LTE implementations use 2×2 MIMOs in downlink direction (two transmitting antennas at the base station and two receiving antennas on the mobile device) and 1×2 in the uplink direction (one transmitting antenna in the mobile device and two transmitting antennas at the base station). The use of 2×2 MIMO systems is characteristic in the higher frequency bands. Today LTE systems are implemented using 4×2 and 4×4 MIMO and additionally higher order configurations such as 4×4, 8×2 in downlink and 1×4 in uplink direction. The size of the antenna is proportional to the wavelength and this directly dictates the design and configuration of MIMO systems for different frequency bands. LTE Advanced often uses configurations known as full-dimension MIMO (FD MIMO), due to its ability to manage beams in both vertical and horizontal directions.

The current MIMO technologies used in fourth generation networks are not capable to deal with such a volume of data traffic and also with requirements for increasing in speeds and reliability. Therefore, it is considered that the fifth generation networks will use massive MIMO technologies as a potential technology that can deal with the problem of massive amounts of data traffic and users. The extra antennas that massive MIMO uses will help to focus the energy into a smaller region of space and provide better spectral efficiency and throughput [5]. As the number of antennas increases, the radiation, more precisely the rays, become narrower and spatially directed to the user. The beam patterns for different antenna configurations are shown in Figure 2. These spatially focused antenna beams are increasing the throughput for the desired user and reduce the interference to the neighboring users. Smart antennas, defined by 3 GPP specifications, provide significant benefits in terms of power, capacity and coverage in wireless communication systems. By inserting more antennas at the base stations, they will coordinate the transmission, the energy will be focused in one direction and that will improve spectral efficiency. Despite the new advanced technologies specified in Release 15, there is still room to improve the performance achieved with massive MIMO.

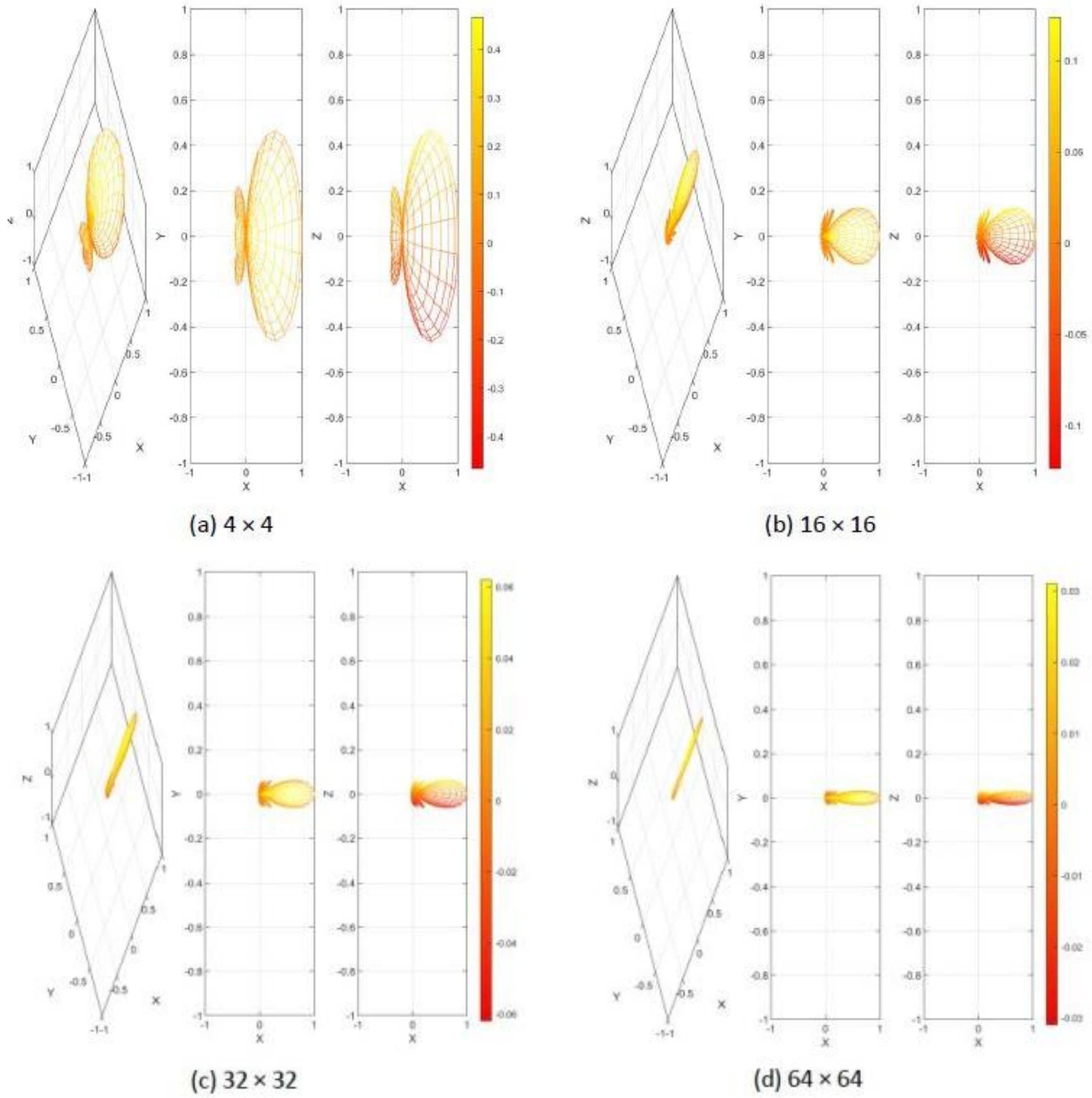


Fig. 2. The beam patterns for different antenna configurations [4]

Uplink transmission

Uplink channels are used to transmit data and pilot signals from the user to the base station. For example, we can assume a massive MIMO system with M antennas at the base station that simultaneously communicate with N (M >> N) single antennas at UE (Figure 3). If the signal transmitted by the user or the deterministic pilot signal to estimate the channel is $x \in$ C^N, the signal received at the base station is given by:

$$y = Hx + n_{uplink},$$

where y $\in C^M$ is the received signal at the base station and H is the channel vector between the user terminal and the base station.

The additional parameter n represents the addition of interference from several transmissions and noise at the receiver. The interference is independent of the user signal x, but it may depend on the channel.

$$n_{uplink} = n_{uplink-interference} + n_{noise}$$

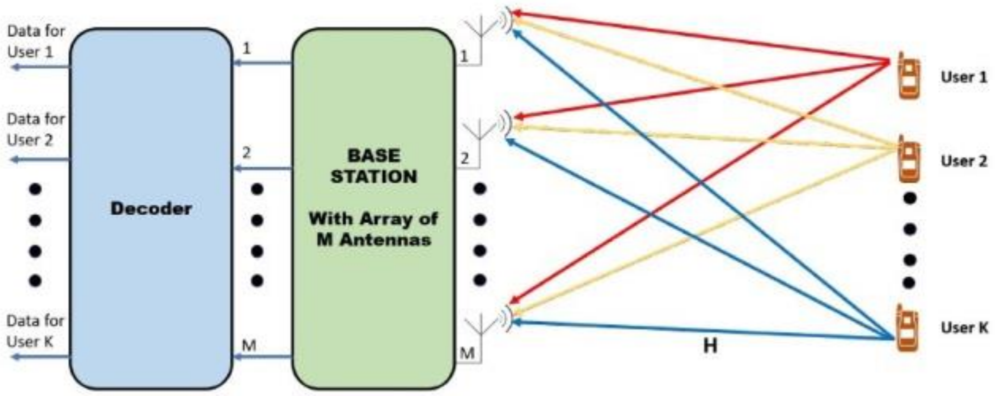
Downlink transmission

Downlink channels are used to transmit data or estimate the channel between the user and the base station (Figure 4). The base station uses training pilot signals to estimate the channel. We can assume a massive MIMO system where the base station consists of M antennas that simultaneously serve N users. The base station sends independent information to multiple users simultaneously. The signal received at k^{th} user is:

$$y_k = h_k x_k + n_{downlink},$$

where x_k is the signal transmitted by base station for user k, h_k is a channel vector between k^{th} user and base station and $n_{downlink}$ is the additional noise which is composed of the noise at the receiver and the interference during downlink caused by transmitting simultaneously to other users.

$$n_{downlink} = n_{downlink-interference} + n_{noise}$$



Fig, 3. UL transmission [4]

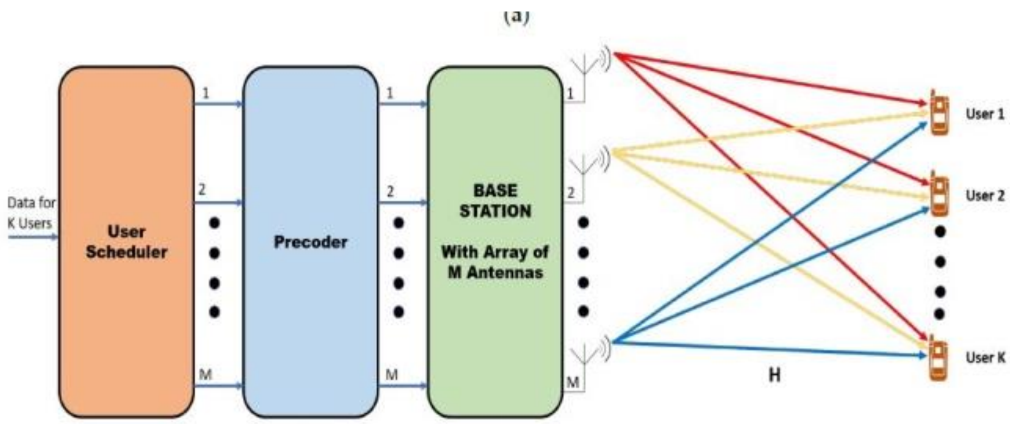


Fig. 4. DL transmission [4]

Challenges in massive MIMO

- Pilot contamination
- Channel estimation
- Precoding
- User scheduling
- Hardware impairments
- Energy efficiency
- Signal detection

Beamforming

Beamforming refers to the ability of the base station to adapt the antenna radiation pattern. This technique allows the base station to find a convenient route to transmit data to the user and reduce interference with neighboring users along the same route. Beamforming as a technique offers many advantages for fifth generation networks. In massive MIMO systems it allows to increase the spectral efficiency and in millimeter waves it helps to increase the data speed. When it comes to MIMO systems, the base station can send data to the user using different paths, in which case the beam-forming technique helps to track the movement of packets and their arrival time, allowing multiple users to send data simultaneously. Often the beamforming as a technique and massive MIMO systems are used together, it can be said that this technique is used in MIMO systems or it is part of MIMO systems. Beam generation mainly uses a large number of antennas in order to control the direction of the rays by properly measuring the magnitude and phase of individual antenna signals from the array. Usually the same signal is sent by several antennas that are at a sufficient distance from each other (at least half the wavelength). At a given location, the receiver would receive several copies of the same signal. Depending on the location of the receiver, the received signals can be in opposite phases, destructively subtracted or constructively added if different copies are in the same phase.

Massive MIMO and hybrid beamforming

The following example shows how implementation of hybrid beamfoming algorithm works on the transmitting side of the MIMO communication system [6].

Multi-user and single-user systems techniques are used as well as channel sounding technique in order to estimate the characteristics of the channel (to get CSI at the transmitter). As the need for higher data speeds and capacity increases, so does the need for efficient utilization of the available spectrum. MU-MIMO systems improve spectral efficiency by allowing transmitters at base stations to communicate simultaneously with multiple mobile stations using the same time-frequency resources. Additionally, as previously stated, massive MIMO systems allow the number of antenna elements at the base station to be very large in order to increase the number of data streams in a suitable cell. The fifth generation of mobile networks uses millimeter waves due to their wide range and antenna arrays in order to reduce propagation losses in this band. Hybrid transceivers are a practical solution because they use a combination of analog and digital beamforming. The following example uses a multi user MIMO OFDM system in order to emphasize the division of the required recoding into digital and analog components in the transmitter. We first define the system parameters (Figure 5), OFDM modulation parameters and the parameters of the transmitting and receiving antenna arrays. Parameters such as: number of users, number of independent flows per user, number of transmitting and receiving antennas, type of modulation and number of OFDM symbols, frequency, mobile station, can be changed in order to obtain a results for the behavior of the system under different conditions.

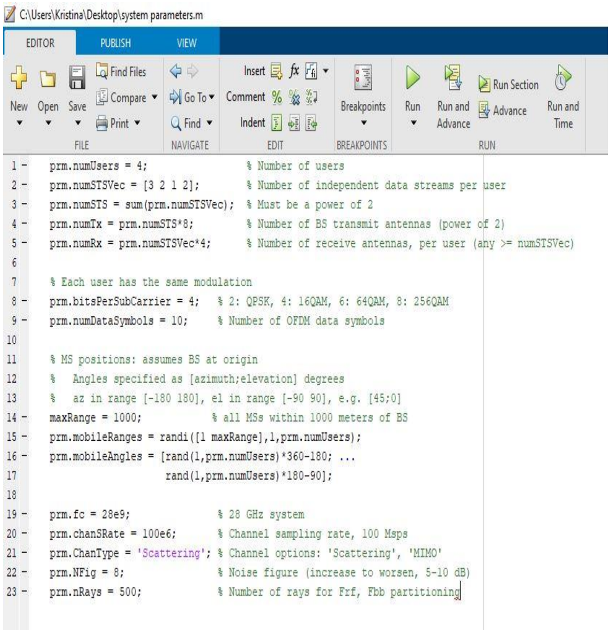


Fig. 5. System parameters

Hybrid beamforming: From the obtained results for the OFDM system we can see that different data flows can be displayed through the main lobes, as shown in Figure 6. By changing the parameters of the system, as changing the number of transmitting antennas, we can see the difference in the main lobe and how it affects the system.

Channel Sounding: For systems with spatial multiplexing, the existence of channel information at the transmitter enables recoding and this maximizes the signal energy to a specific direction. The base station listens to the channel using a reference transmission that the mobile station uses to estimate the channel. The mobile station sends CSI information to the base station in order to calculate the required recoding for the subsequent data flow. For the selected MIMO system, the signal from the base station is sent through all transmitting antenna elements and processed at the receiver. The receiving antenna performs signal amplification, OFDM demodulation and channel estimation in the frequency domain. For multi-user systems, channel estimation is obtained from each mobile station and used by the base station to define the encoding. In the specific example it is assumed that the device sends an accurate estimation.

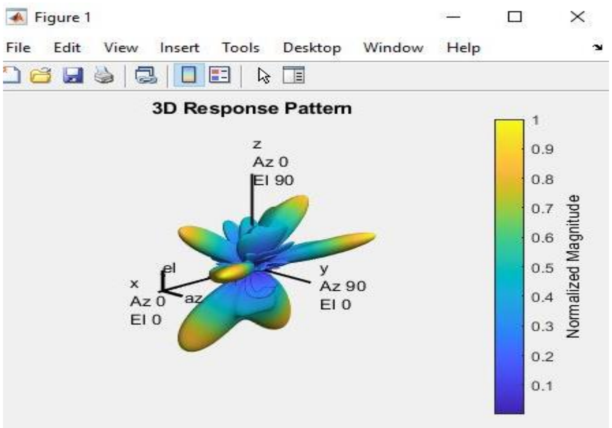


Fig. 6. Hybrid beamforming

The next step is to define the parameters of the transmitter. The process includes channel coding, mapping of bits into complex symbols, merging individual data streams into transmitter streams, baseband recoding, OFDM modulation, and RF analog beam generation for all transmitting antennas in the system. On the receiving side, the MIMO OFDM system is also used, where we have OFDM demodulation, MIMO equalization, QAM demapping and channel decoding. On the receiver side, in order to compensate for the propagation losses, the signal is amplified and additional thermal noise is added. We can calculate the BER (Bit Error Rate) and EVM (Error Vector Magnitude), and the result from simulation is given in Table 2.

Table 2

BER and EVM

	User 1	User 2	User 3	User 4
RMS EVM (%)	0.38361	1.0311	2.1462	1.0024
BER	0.00000	0.00000	0.00000	0.00000
No. of bits	9354	6234	3114	6232
No. of errors	0	0	0	0

From the obtained results it can be concluded that for the modeled MIMO system, the obtained constellation of equalized symbols offers a qualitative assessment of the received symbols. With the help of the calculated bit error rate, a quantitative comparison is given between the actually transmitted bits with the received decoded bits per user. This model takes into account the spatial geometry and location of the antenna arrays at the base station and antennas at UE. Figure 7 shows the constellation diagram for each flow, individually for each user. From results, it is clear that we have improved BER due to the compliance of the mobile station and the direction of radiation of the antennas. This behavior can be significantly worse if the mobile station is out of range of the antenna arrays.

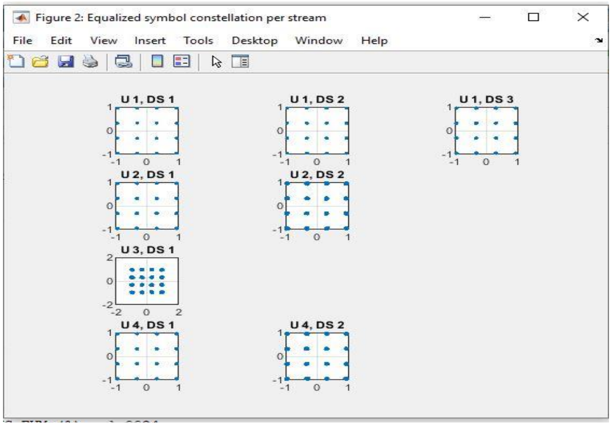


Fig. 7. Constellation diagram for each flow
(The number of users in the example is four and the number of streams per user individually is 3, 2, 1, and 2, respectively.)

It is assumed that the transmitter and the channel are ideal. The channel is characterized by free space path losses and interference from a signal with energy close to the level of the desired signal is added. The model assumes that the transmitter and receiver are ideally positioned, the transmitter is positioned in front of the receiver where the main lobe of the radiation diagram is located. According to the results obtained from the simulation, the differences between the spectrum of the received signal can be clearly seen in Figure 8 and Figure 9, using beamforming algorithm and without beamformig respectively. Beamforming represents the ability to adapt the radiation pattern of the antenna array to particular direction. By focusing signal in a specific direction, beamforming allows to deliver higher signal quality of received signal. Additionally, beamforming can reduce interference from other signals and improve the communication. In presence of strong interference, the target signal may be masked by the interference signal, in these scenarios adaptive beamformers can help Adaptive beamformers preserves the signal arriving along desired direction and tries to suppress signals coming from other directions. Adaptive beamformer is not always able to separate the interference signal from the target signal because the beamformer can suppress the desired signal as well. This happens if the target signal is received along a direction slightly different from the desired one and this is the case in which we should consider another beamforming algorithm.

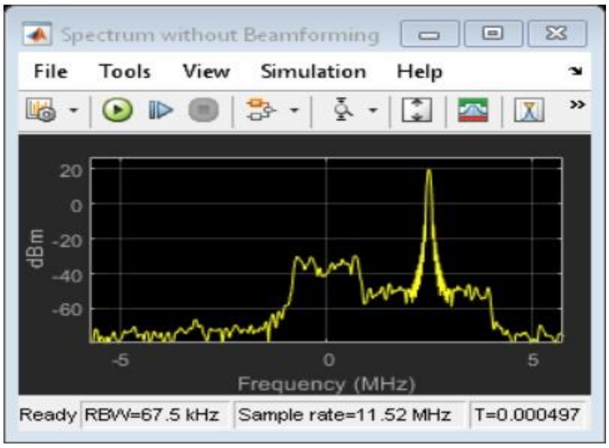


Fig. 8. Spectrum of received signal without beamforming

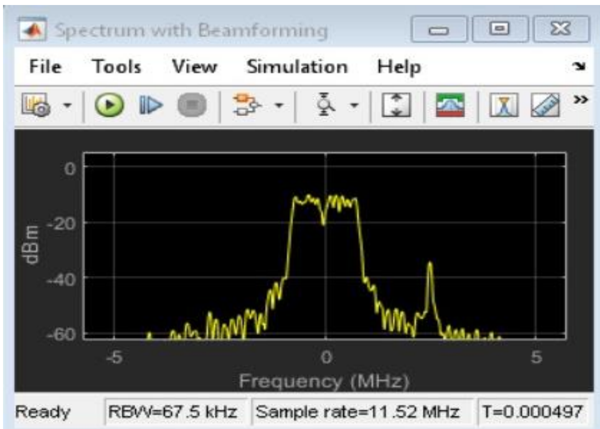


Fig. 9. Spectrum of received signal using beamforming algorithm

Ultra dense network and small cells

The fifth generation of mobile systems works with applications that require high data rates. One of the solutions to get the required speeds is to design the network using small cells. This design, where the systems consist of very close pico cells, results in high spectral efficiency and consumption reduction. Additionally, this solution significantly improves network coverage. However, to implement such a solution in practice, it is necessary to minimize the hardware platform and use small base stations. Small cells are actually small, low power base stations that can be set up at a distance of 100 meters to cover a small geographical area. The cells are so small that they can be placed anywhere. If we use millimeter waves instead of the traditional 6 GHz spectrum, the small cells can become even smaller, they can even be divided into micro cells, femto cells and pico cells (with higher power, which improve coverage in outdoor environments), based on the area which has to be covered and the number of users which have to be served [7]. The simultaneous operation of macro, micro, femto and pico cells is called a heterogeneous network, in which interference management is a key challenge due to the much uncoordinated nature of such a heterogeneous network. However, 3GPP has defined a variety of scenarios and requirements that need to be met to improve the challenges of small cells implementation. In order to overcome network losses, networks that use millimeter waves can be designed using heterogeneous infrastructure that involves the use of a large number of small cells. Atmospheric absorption of millimeter waves significantly increases the isolation of each individual small cell while further enabling the attenuation of background interference from distant base stations. It is about using very small cells (clusters), with dimensions of the order of 200 m, and even smaller. Because of the characteristics of millimeter waves, fifth-generation networks use a method called a small base station as a replacement for the traditional base stations used today (Figure 10). Due to the high frequency, the antennas used to receive millimeter waves are allowed to be very small, resulting in the design of small base stations. With this approach, by using very small base stations, instead of building large base stations, the fifth generation networks will be able to provide coverage to the peripheral areas and additionally to improve the quality of service for end users [9].

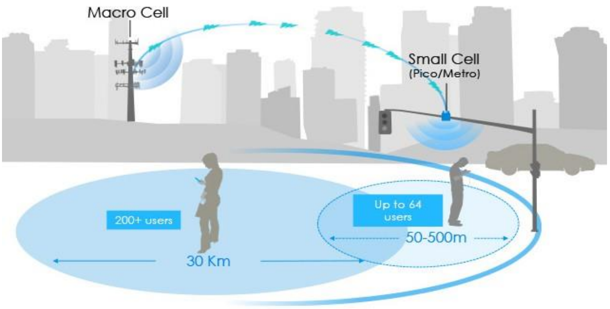


Fig. 10 Small cells implementation

Basic elements for practical implementation of a heterogeneous network are optimization and configuration, especially when the transition in terms of number of cells is very large (from hundreds to a million cells). When implementing small cells, operators also face some challenges. Due to the limited propagation in millimeter waves, the implementation of small cells in 5G systems is dense. The large capacity of millimeter small cells requires more gigabit connections that use a combination of fiber optics, millimeter radio waves in point-to-point connections. On the other hand, the centralization of the base stations enables simplification of the equipment. The effective range of small cells depends on several factors, including whether we have visible, line-of-sight communication, whether the equipment is suitable for outdoor or indoor environment, the type of materials through which the signal must pass to reach indoor equipment, and so on. The implementation of densely distributed cells leads to challenging problems with interference control and mobility management. This requires careful radio planning for the ultra-dense 5G networks.

Scalable OFDM numerology

The new air interface offers functionalities based on OFDM. One of the important features is flexible numerology which refers to the possibility of configuring the parameters of the radio interface depending on the service [8]. This principle of scalable numerology introduces the scalable OFDM distance of sub-carriers and the cyclic duration of prefixes based on the frequency and bandwidth of the carrier. In particular, to simplify the implementation of scalable OFDM numerology, it is proposed to use a number of scaling factors, a common value for the distance between the carriers and a common value for the duration of cyclic prefixes. This simplifies the design of the sampling clock because the duration of the OFDM symbols is inversely proportional to the distance between the subcarriers [9]. Additionally, to simplify the layout and design of the reference signal, it is proposed that the number of OFDM symbols in the subframe to be equal to all shifts values in the subcarriers. This would mean that the distance between the subcarriers would be increased at the expense of shortening the duration of the subframe. The first degree of flexibility is the ability to scale the subcarriers to 15, 30, 60, 120 kHz. Scaling can be done in terms of frequency, spectrum availability and scenarios. For example, a 20 MHz carrier is suitable for external macro networks in the band below 3 GHz, where at higher frequencies it would be necessary to extend the channel to 80, 160 or even 500 MHz. This allows natural scaling of the cyclic prefix, for example in an outdoor environment a 20 MHz macro carrier would have an increased cyclic prefix, while in an indoor environment with small cells at 5 GHz or 28 GHz the cyclic prefix will be short. The second degree of flexibility is in the time domain, with a scalable time interval for transmission. The idea is to adjust the transmission timeline according to the delay requirements. For example, if a 1 ms link needs to be met, we would need to have a short transmission time interval. For high spectral efficiencies, longer transmission time intervals are optimal, such as video streaming where we have a service that is less sensitive to latency. In general, it is necessary to support short and long time intervals for transmission of the same radio at the same time. For the effective support of ultra-confidential services such as public safety, autonomous vehicles, the intention of 5G NR is as soon as it needs to allocate dedicated resources to critical services. Critical services require resources as soon as possible for the duration of the transmission. The mechanisms that enable such needs are still being explored and upgraded.

Dual connectivity

In the 5G networks the development of the radio network is divided into two phases. The first is based on the evolution of LTE and the second is related to the development of NR (New Radio). When it comes to LTE upgrades we mean the functionalities needed to support as many 5G scenarios as possible. On the other hand, NR means complete liberation from the limitations of LTE compatibility, which brings us to the fundamental changes brought by 5G, low latency, flexible separation of carriers and increased capacity (higher bit rates) through the use of high frequencies (millimeter waves) [10]. However, in order to accelerate the development of 5G networks without having to wait for a complete NR system (radio, core network and other necessary components), 3GPP specifies a closely connected LTE-NR system. In such a system a non-standalone version of NR is used in conjunction with LTE using a dual connectivity mechanism where both technologies are connected to the LTE packet core (EPC). This close connection between LTE and NR is called E-UTRAN-NR Dual Connectivity (EN-DC). This is the first case where a DC scenario is enabled for two different 3GPP radio access technologies.

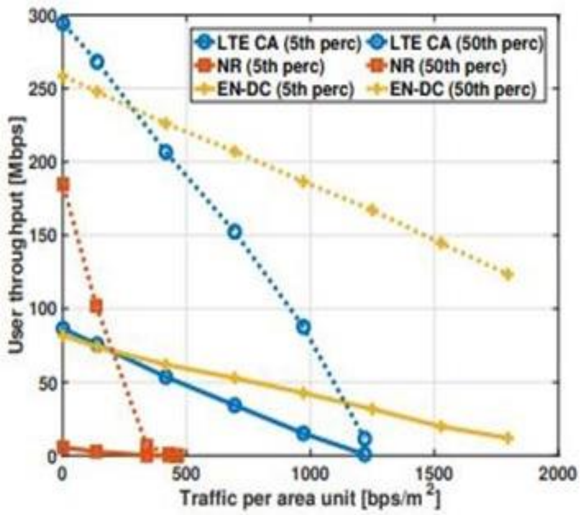
As the components and capabilities of the two networks are different, many challenges need to be addressed to enable the completion of the NR standards. In general, at the development of EN-DC, LTE is the main technology that controls the radio connection of the user device through the air interface, as well as the connection of the control plane to the EPC. On the other hand, NR provides improved capacity for the user device via the air interface and additionally a direct link to the EPC. A series of solutions have been defined that enable the first commercial EN-DC development, where the main element is LTE eNB, and as a second element we have gNB. In this kind of architecture both types of base stations have a direct interface to the existing LTE core for transmitting user data across the user plane. Unlike LTE DC, where there is only one radio control point for transmission, in this case the user device also has a second radio control point or RRC (Radio Resource Control). The advantage of two RRC points in EN-DC for LTE and NR depends on the network configuration. A characteristic of EN-DC is that a set of Signaling Radio Bearers (SRBs) can be used to transmit RRC messages between the eNB / gNB and the user device.

Performance evaluation: Comparison between LTE, NR and EN-DC

In order to validate the performance of a standalone 5G NR network using the EN-DC architecture, a performance analysis was performed using a 5G simulator [10]. This is a scenario with seven base stations, each with three sectors and they are at a distance of 500 meters. The height of each base station is 25 meters and each of them radiates with a power of 43 dBm. The power of UEs is 23 dBm. Both technologies, LTE and NR are used, with LTE being implemented at 2.1 GHz while NR running at 28 GHz. The performance evaluation model uses a band of 20 MHz and 100 MHz for the LTE and NR carrier respectively. Carrier aggregation is used for LTE, where five LTE carriers are aggregated in order to have the 100 MHz band available. The purpose of this selection is to obtain a fair comparison (in terms of bandwidth) between LTE, NR and EN-DC. The distance between the carriers is 15 kHz and the number of OFDM symbols is 14. The transmission time interval (TTI) is 1 ms. The antennas are designed according to the basic parameters given by 3GPP TS 36.814 and 3GPP 38.802 for LTE and NR respectively. The propagation is modeled using a 3GPP SCM model based on an urban macro environment and only DL transmission is considered. The number of user devices per sector is 48 and their distribution is uniform. In order to investigate the average flow that can be achieved and how it varies in relation to different levels of traffic load, several options are compared:

- LTE development: only connection via LTE links is possible. It is considered that aggregation of carriers is enabled where five carriers are used.
- Standalone NR network: NR exists as a standalone technology that provides connectivity for user devices in the coverage area.
- EN-DC development: User devices use dual connectivity between LTE and NR. The user device connects to the NR link while in the appropriate NR coverage and if the device has a better radio link to the NR cell than to LTE. In all other situations the preferred option is LTE.

Figure 11 shows the user flow as a function of the traffic load on the fifth and fiftieth percentiles of the cumulative distribution function. The fiftieth percentile is the average value achieved on average for all user positions, while the fifth percentile represents all users with the lowest flow and this is usually at the edge of the cell (the area with the lowest coverage, lowest signal strength). It has been observed that for users in areas with low signal, compared to other solutions, EN-DC shows the best results. For example, EN-DC can achieve 1750 bps/m^2 in the cells with the weakest coverage, where LTE and NR individual configurations provide around 1200 and 400 bps/m^2, respectively. There is a similar behavior when it comes to users with good coverage, the difference is that the flow that is achieved is much higher. Therefore, the EN-DR network can handle a much larger volume of traffic compared to LTE and NR for any user location. The advantages of EN-DC are not limited only in terms of data speeds, this implementation allows less delay due to the use of the physical level of NR instead of waiting for a full NR system. However, it is important to note that the performance obtained with this model using LTE is not realistic because operators generally do not have as much bandwidth (100 MHz) available in the LTE spectrum.



Fig, 11, Downlink throughput as a function of traffic load [10]

In addition, the frequency used for NR, 28 GHz, makes an additional contribution to the flow achieved. Figure 11 shows that NR data is missing after 500 bps/m^2. This is due to the network load and the lack of radio resources and capacity. According to the results obtained from the scenario where we have the implementation of NR together with LTE, EN-DC offers significant performance improvements in terms of flow that can be achieved in differrent conditions, low and high traffic load. In any case, EN-DC is not a necessary mechanism for stand-alone 5G implementation but is an intermediate point to the 5G eco-system where NR becomes stand-alone technology along with the 5G core network.

CONCLUSION

5G NR is a revolutionary technology that is constantly upgrading, creating a platform that is constantly evolving. The first phase of 5G is characterized by the introduction of a specific air interface for development of various scenarios and flexibility to add functionalities that make this technology compatible for new and still unknown requirements and services. NR is a unified and flexible air interface that supports the three key 5G communication technologies defined by the ITU. From all the researches and analysrs so far, we can conclude that 5G as a technology offers significantly improved data rates and reliable communication with a low delay. In this paper, we describe the specifications defined for the standardization of the fifth generation of mobile networks, followed by a detailed overview of the key components of the 5G NR air interface, where each technology is characterized by its own requirements and offers appropriate communication improvements. Technologies such as mmWave, spectrum sharing, carrier aggregation, dual connectivity, massive MIMO, non-orthogonal multiple access that offer increased spectral efficiency, are still subject of analysis. In this paper, a comparison is made in relation to the services we have and use today and the advantages that 5G offers. As with previous generations of mobile networks, the transition to new technology leads to many opportunities but also challenges, which is why efforts are being made to provide platforms that will ensure a smooth transition to this new era as a combination of existing and previously unimaginable applications.

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