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Explanation and Analysis of 5G NR: the New Radio-Access Technology

Grigor Mihaylov[1*], Teodor Iliev[2] and Ivaylo Stoyanov[2]

[1]University of Telecommunications and Post, Sofia, Bulgaria
[2]University of Ruse "Angel Kanchev", Ruse, Bulgaria

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Abstract

Fifth-generation mobile communications discussions began around 2012. In many discussions, the term 5G is used to refer to new technology for accessing 5G radio. However, 5G is often used in a much broader context, not just in terms of specific radio access technology, but rather in a wide range of new services designed to be activated by future mobile communications.
3GPP has initiated the development of a new radio access technology known as NR (New Radio). In the fall of 2015, a seminar was held in which the work of sledding was carried out and the technical work began in the spring of 2016.
One of the main features of NR is a significant extension of the spectrum in which radio access technology can be used. Unlike LTE, which introduces support for licensed spectrum at 3.5 GHz and unlicensed spectrum at 5 GHz, NR maintains a licensed radio frequency operation from less than 1 GHz to 52.6 GHz, with expansion to unlicensed spectrum also planned.
Along with the NR, ie the new technology to access 5G radio, 3GPP is also developing a new 5G core network called 5GCN. New technology to access 5G radio will connect to 5GCN (5Gcn core network). However, 5GCN will be able to provide connectivity for LTE development.

Keywords: Mobile Network, 5G, Radio Access Network.

1. Introduction

The growth in mobile traffic is mainly due to the proliferation of mobile devices and the rapid adoption of hungry mobile devices – especially smartphones. The rate of increase of mobile data traffic is much higher than the number of voice calls. Global mobile voice traffic has been outpaced by mobile data traffic, with the extrapolation of this trend for the remainder of the decade showing that global mobile traffic will increase by 1000x from 2010 to 2020. An important factor behind the huge growth in mobile traffic is the increasing demand for mobile traffic. Modern multimedia applications such as Ultra-High Definition (UHD) and 3D video, as well as an extenedreality and immersive experience. [1]

In addition to the 1000x increase in traffic, the increasing number of connected devices is another challenge for the future mobile network. It is envisaged that in the future, the connected society will be connected to each other - under the umbrella of the Internet of Everything (IoE), where tens to hundreds of devices will serve each person. This upcoming 5G cellular infrastructure and its support for big data will allow cities to be smart. The data will be generated everywhere by humans and machines and will be analyzed in real time to extract useful information, habits and preferences of people on the state of traffic on the streets, as well as monitor the health of patients and elders. Mobile communications will play a key role in ensuring efficient and safe transport, allowing vehicles to communicate with each other or with the road infrastructure to alert or even assist drivers in the event of invisible hazards, paving the way for autonomous vehicles. This type of machine-to-machine communication requires very tight latency (less than 1 ms), which creates additional challenges for the future network. [2]

2. Material and method

As shown in Figure 1, 5G will be a truly cohesive system supporting a wide range of mobile voice and multi-gigabit Internet applications for D2D and V2X communications, as well as proprietary machine type communications (MTC) and public safety applications. MIMO will be incorporated into Base Stations (BS) to further increase data speed and capacity at the macro-cellular level. The system's performance in terms of coverage, capacity and energy efficiency (Ee) will be further enhanced in "dead" and hot spots through relay stations, deployment of small cells or landing on WiFi; mmWave connections will be used to redirect relay and/or small BS cells. D2D communications will be supported by macro-BS, providing the control plane. Smart grid is another interesting application for 5G that

* E-mail address: gregmihaylov@gmail.com
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allows the power grid to work more reliably and efficiently. Cloud computing can potentially be applied to radio access network (RAN) and mobile users, which can form a virtual set of resources that can be managed by the network. Bringing cloud apps to the end user reduces communication latency to support real-time applications. [3]

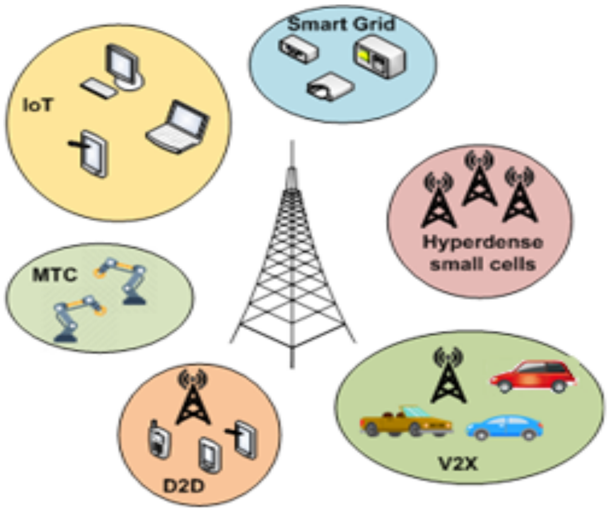

Fig 1. 5G System architecture

The overall architecture of the radio access network and the architecture of the core network (CN) has been revised, including the separation of functionalities between the two networks. The RAN is responsible for all radio-related features of the entire network, including scheduling, radio resource management, retransmission protocols, coding and multiple antenna arrays. [4]

The core 5G network is responsible for non-radio related features, but is required to provide a complete network This includes, for example, authentication, boot functionality, and end-to-end connection setup. Handling these functions individually instead of integrating into RAN is useful because it allows multiple radio access technologies to be served by the same core network. However, the NR radio access network can connect to LTE (long-term evolution) core network, known as the Evolved Packet Core (EPC). [5]

The 5G core network is based on the EPC with three new areas of improvement over the EPC: service-based architecture, network partitioning support and control plane / user plane separation.

The service architecture is at the heart of the 5G core. This means that the specification focuses on the services and functionality provided by the core network and not on nodes as such. This is natural, since the core network today is often very virtualized with the functionality of the core network running on common computer hardware.

Network plane is a term commonly used in the context of 5G. A network plane is a logical network that serves a particular business or client's needs and consists of the necessary architectural features based on services that are configured together. For example, a network segment can be set up to support mobile broadband applications with full mobility support similar to what LTE provides, and another plane can be set up to support non-mobile applications, which is critical for the industry and automation. These parts will be implemented on the same physical core and radio networks, but from an end-user application point of view, they appear to be independent networks.

The separation between the control plane / user plane is emphasized in the architecture of the 5G core network, including the independent scaling of the capacity of both. For example, if more control plane capacity is required, it should be easy to add without affecting the user plane. [6]

2.1 5G NR PHY layer

Like any wireless technology, the physical layer forms the backbone of 5G NR. NR layers must support a wide range of frequencies (from below 1 GHz to 100 GHz) and various deployment options (pico cells, microcells, macrocells). There are user centered and machine oriented use cases with extreme and sometimes conflicting requirements. Contingencies with new requirements may also be available in the future. To successfully meet these challenges, 3GPP is developing a flexible physical layer for NR. Flexible components can be properly optimized with an accurate understanding of the propagation of radio waves and hardware imperfections across networks and devices. This is a challenge, because these features are less understood. NR is the first technology for mobile access to the millimeter wave frequency band (up to 100 GHz) targeted to the GHz bandwidth and enables massive multi-antenna systems. [7]

In 3GPP terminology, the base station is the deployment of a logical network node for radio access. The 5G NR radio node is called 3GPP Next Generation Node (gNB). It is important to emphasize that gNB is a logical device, not a physical execution base station. The base station can be implemented in various ways based on a standardized gNB protocol.

The protocol architecture of the NR can be divided into the control plane architecture and the user plane architecture. The user plane provides user data, while the control plane is the primary responsibility for setting up connectivity, mobility and security. Figure 2 illustrates the protocol stack of the user plane, divided into the following layers: the physical (PHY) layer, the MAC layer, the RLC layer, the PDCP protocol layer packet, and the Service Data Adaptation Protocol (SDAP) layer. [8]

- The SDAP layer processes the mapping between QoS and radio carriers. IP packets are matched to radio channels according to their QoS requirements. A radio channel can be considered as a pipe that transmits Internet Protocol (IP) packets over a network and receives priority as defined by the QoS requirement.
- The PDCP layer is the primary responsibility for compressing / decompressing the IP header, rearranging and detecting duplicate records, encrypting / decrypting, and protecting integrity. The compression mechanism reduces the number of bits for transmission over the radio interface. Encryption prevents data loss and ensures message integrity. Rearranging and duplication mechanisms allow serial transmission of data and removal of duplicate data units.
- The RLC layer primarily performs correction of errors through automatic request (ARQ), segmentation / re-segmentation of IP packets compressed in the header, and sequential delivery of data units to higher layers.
- The MAC layer is primarily responsible for error correction through a hybrid ARQ (HARQ) mechanism and uplink and downlink planning. The scheduler controls the assignment of physical time-frequency resources for uplink and downlink transmission. The MAC layer also takes care of data multiplexing between multiple component carriers when carrier aggregation is used.

- The PHY layer processes coding / decoding, modulation / demodulation, multi-antenna processing, and mapping signals to physical time-frequency resources.

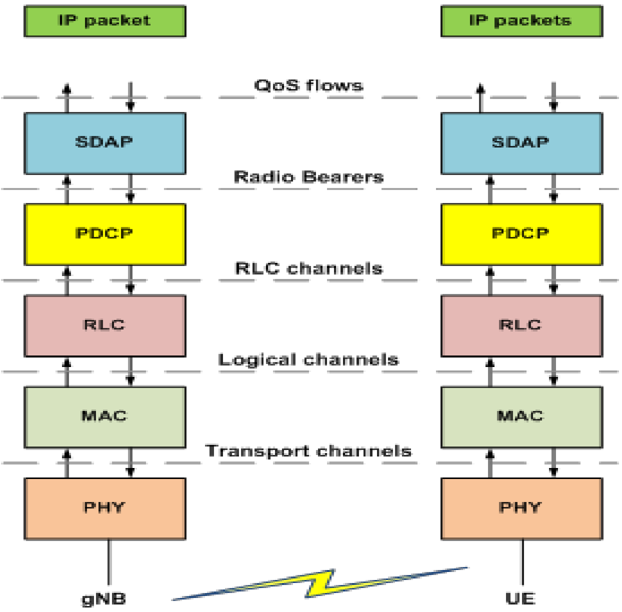

Fig 2. 5G NR User-plane protocol stack

The control board is mainly responsible for signaling control for connection setup, mobility and security.

2.2 Modulation

Control signaling originates from either a core network or an RRC layer in gNB. The RRC layer's core services include systematic information delivery, virtual memory messaging, security management, including key management, signal transmission, cell selection, QoS management, radio detection and recovery. RRC messages are transmitted using the same PDCP, RRC, MAC, and PHY layers as the user. In addition, the π / 2-BPSK is activated to allow an additional peak to reduced power average and a power ratio increases the amplifier at lower operating data speeds for massive machine-type communications (mMTC) services. [9]

Table 1. 5G NR scalable numerology

OFDM numerology	**15 kHz**	**30 kHz**	**60 kHz**	**120 kHz**
Frequency band	*0.45-6 GHz*	*0.45-6 GHz*	*0.45-6 24-52.6 GHz*	*24-52.6 GHz*
OFDM symbol duration	*66.67 μs*	*33.33 μs*	*16.67 μs*	*8.33 μs*
Cyclic prefix duration	*4.69 μs*	*2.34 μs*	*1.17 μs*	*0.59 μs*
OFDM symbol wit CP duration	*71.35 μs*	*35.68 μs*	*17.84 μs*	*8.91 μs*
Max. BW	*50 MHz*	*100 MHz*	*200 MHz*	*400 MHz*

Since NR will cover a wide range of applications, it is likely that the range of supported modulation schemes will be expanded. For example, 1024 QAM may become part of the NR specification because point-to-point relaying already uses modulation orders higher than 256 QAM.

2.3 Multiple antennas

Multi-antenna techniques are important in LTE, but in NR they play a more fundamental role in system design. Expanding the spectrum of mobile communication to include millimeter waves has led to the design of NR beam forming an analog beam to achieve sufficient coverage. In addition, multi-antenna techniques are critical to meeting the requirements of 5G performance and traditional cellular frequency bands.

Advances in active antenna technology allow the digital control of a large number of antennas, called multiple input multiple output (MIMO). This allows for higher spatial resolution when processing multiple antennas, which can give higher spectral efficiency. To this end, NR provides better multi-user MIMO (MU-MIMO) support and interoperability. A new channel state information (CSI) framework has been developed to allow greater flexibility in transmitting reference signals and to enable higher spatial resolution. This framework also provides a more economical system design and facilitates adaptation to different applications and the introduction of new features in future versions of NR. [10]

For higher frequencies, obtaining coverage is the main challenge, not achieving high spectral efficiency. The reason for this is that transmission losses when inherited transmission techniques are used are significantly higher, while there is a large bandwidth in the millimeter spectrum. To overcome higher transmission losses and to provide sufficient coverage, the beam forming is useful, especially in accordance with line of sight conditions (LoS). With current hardware technology, analog beam generation is expected to prevail in millimeter waves. Therefore, procedures for assisting analogue beam generation in both gNB and EU have been developed already in NR. Unlike previous generations of mobile communications systems, NR supports beamforming not only for data transmission but also for initial access and broadcasting of signals. [11]

2.4 Simulator overview

The simulator was developed by Qamcom Research & Technology AB. Initially, it was developed within the framework of the EU-funded mmMAGIC project to assess the performance of various waveforms in the general environment. This is a MATLAB-based open source level simulator, including several waveforms and a geometric stochastic channel supporting emulation of channels up to 80 GHz. In Fig. 3 is presented a functional diagram of the used simulator. [12]

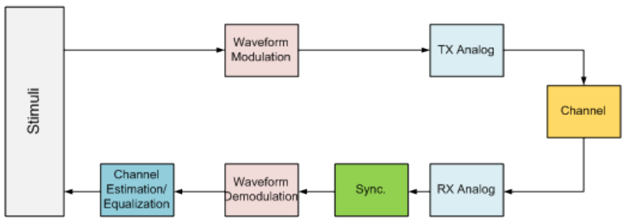

Fig 3. Block diagram of used simulator

The stimuli module sends (receives) QAM symbols to be modulated (demodulated) by the waveform modulator (demodulator). The modulated signal passes through analogue modules in the transmitter (Tx) and the receiver (Rx) and to the radio channel. Analogue module Tx adds hardware disturbances, such as nonlinearity of power amplifier (PA), phase noise (PN) and carrier frequency offset (CFO) to transmitted signal. The transmitted signal then experiences propagation delay, Doppler effects, and interference caused by the channel model. After the radio channel, the received signal is additionally distorted by the additive white Gaussian noise (AWGN) and PN, which are produced in the analog Rx module (before demodulation). At the receiver, synchronization of time and frequency is first performed. The synchronized signal is transformed into the frequency (subcarrier) domain from the waveform demodulator. An evaluation and alignment of the channel is then performed. [12]

3. Results and discussion

The phase noise of the oscillator is a multiplicative noise. It causes random signal rotation and destroys the orthogonality of waveforms with multiple carriers. For a multi-carrier waveform, PN causes a common phase error (CPE) and inter-carrier interference (ICI). While the first represents the total phase rotation of the entire subcarrier, the latter refers to interference for each subcarrier, caused by all the others. CPE can be easily corrected using scattered pilots, while ICI can be difficult to eliminate. Fig. 4 and Fig. 5 show the symbol error rate (SER) performances of different waveforms in terms of PN without and with CPE correction, respectively.

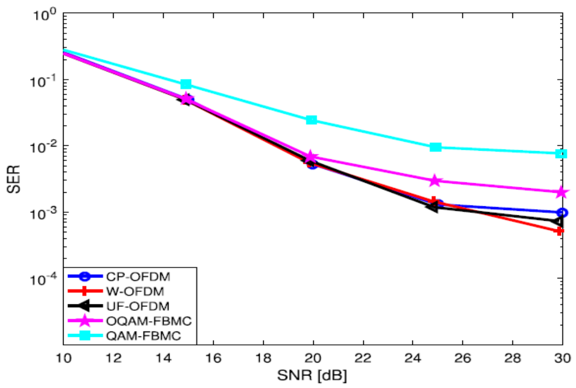

Fig 4. SER performances of different modulations in terms of PN without CPE correction

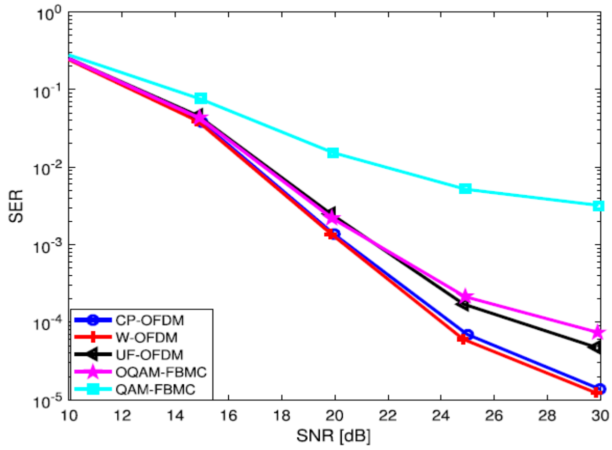

Fig 5. SER performances of different modulations in terms of PN with CPE correction

4. Conclusions

It is clear that NR is a very flexible platform capable of developing in a wide range of directions and an attractive path to future wireless communication. NR evolution will bring additional capabilities and further boost productivity. Additional capabilities will not only provide better performance in existing applications but will also be open or even motivated by new application areas.

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