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5G NEW RADIO: REQUIREMENTS, CHALLENGES AND OPPORTUNITIES

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Abstract- New research directions bring basic changes in the designing of the future generation 5G. 5G New Radio (5G NR) gets a special attention, due to its importance in responding to the necessary requirements for 5G deployments such as: the performance, the flexibility, the scalability and the efficiency in the mobile networks.
This perceivable article highlights the most recent and the newest substantive design choices, the requirements and the challenges to overcome in the 5G NR area. this review paper focuses on identifying the fundamental technologies in the 5G NR design, and the feature of each tech, by synthesizing high quality researches.
We begin by defining the characteristics of the new spectrum. Using this framework, we evaluate the changes that will bring to the 5G NR namely: the beam forming processing, initial/random access procedure, waveform structure.
The work item of 5G NR is still ongoing, therefore, this article does not provide a final solution, but it transmits the latest vision of the future architecture.

Index Terms- 5G, 5G NR,mmWave communication, MIMO, Beam forming, Initial access, random access, New waveform, OFDM.

I. INTRODUCTION

Since more the existing technologies expand, businesses and consumers expect to see more opportunities in the future technology, this one has to be faster and have the ability to accomplish many services. The fifth generation of mobile network will operate the major fields of industries, such as: healthcare, education, transportation, smart homes and entertainment. Industrials and researchers started to clarify the 5G architecture after many experiences and resources. The 5G design includes a set of new and effective technologies that will be used in its networks which are presented in [1-6].

The first set of 5G standards, Release 15, was delivered in December 2017, marking a significant milestone on the way to the deployment of the future generation, and there still many advancements to be accomplished to meet all the necessary requirements. Release 16 will be finalized at the end of 2019, and the commercial deployment of the 5G mobile network will be launched in 2019 - 2020 according to the 3rd Generation Partnership Project (3GPP) [7]. The latter is a collaboration between several telecom partners, which aims to develop a set of globally applicable standards for 5G.

Initially, 5G will be made available through improvements in LTE, LTE-Advanced and LTE Pro technologies. Afterward, it will be followed by a significant step-up with the introduction of a new air interface (5G NR). The release validated on December 2017 is for Non-Standalone 5G NR (NSA), It uses the existing LTE radio and core network. The standalone 5G NR (SA) mode was to be completed by September 2018 but was also finished early, in June 2018. It implies full user and control plane capability using the new 5G core network architecture. Fig. 1. presents the SA and NSA 5G NR Operations.

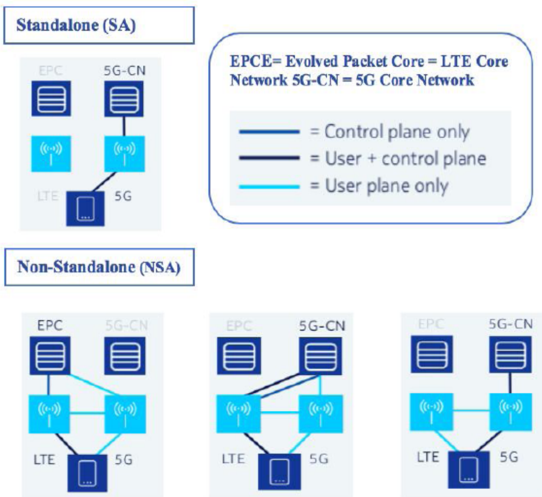

Fig.1. SA and NSA 5G NR Operations

In this survey paper, we present an overview of the fundamental technologies integrated in the 5G NR, we also highlight the phase one of 5G standardization, namely Release 15. The remainder of this review-paper is organized as follows.First, we introduce the signal propagation characteristics in the new spectrum, which is considered the key to enable the 5G. From that point, we describe the Massive MIMO beamforming proceeding in this new spectrum range. Then, we explain the procedure of the Initial / random access in the 5G NR. After that, we detail the structure of the new waveform. Finally, we conclude by mentioning our future work in this area.

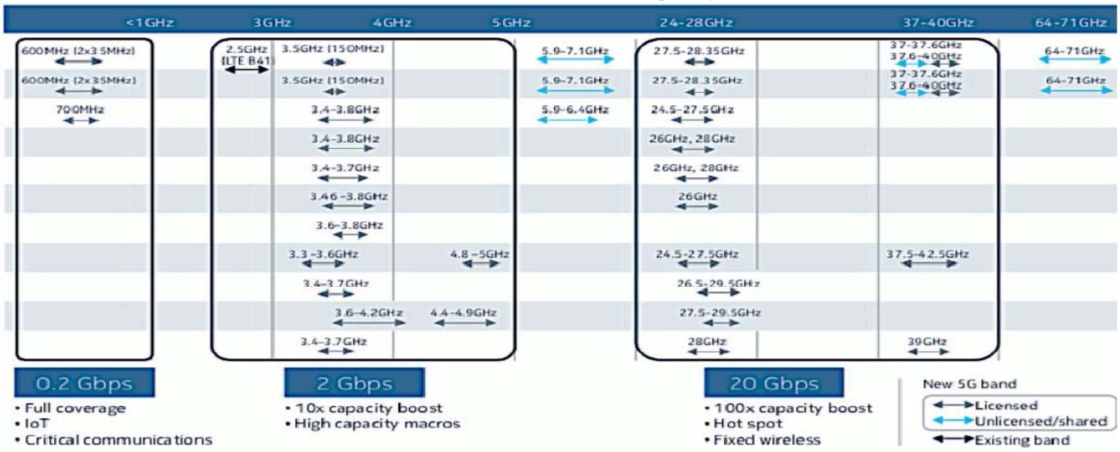

Fig.2. [8]: Available frequency bands in the world

II. NEW SPECTRUM

Nowadays, technological devices are using very specific frequencies on the radio frequency spectrum [3KHz - 6GHz]. As the number of electronic devices is highly increasing, the actual frequencies are starting to get overcrowded. This complication causes overdue services and dropped connections. To solve this issue, it is required to transmit signals on new frequency bands which called centimeter waves [3GHz - 30GHz] and millimeter waves [30GHz - 300GHz].

This Technology is considered the enabling key of the next generation. On the one hand, this new range of spectrum is needed to furnish a combination of 5G requirements, that is to say: high data rates, high capacity and ultra-high reliability. On the other hand, mmWave communications is the key to provide multi-gigabit used in new services. Using new spectrums involve an emergent evolution towards 5G NR.

In the initial stage, the principal worldwide spectrum options for 5G network are: 3.3 – 4.9 GHz, 24-28 GHz, and 39 GHz. More information about the global licensed and unlicensed spectrum are detailed in Fig. 2[8].

A. Measurement results

Creating a new generation of mobile network begins with understanding the channel characteristics of radio access technology (RAT) [9].

The successful and the most important project in the world in taking measurements and developing an advanced channel model is mmMAGIC project (mm-wave based Mobile radio Access network for fifth Generation Integrated Communication), It took 24 months and it was co-funded by the European Commission’s 5G PPP program, bringing together major infrastructure vendors (Samsung, Ericsson, Alcatel-Lucent, Huawei, Intel, Nokia), major European operators (Orange, Telefonica), leading research institutes and universities (Fraunhofer HHI, CEA LETI, IMDEA Networks, Universities Aalto, Bristol, Chalmers and Dresden), measurement equipment vendors (Keysight Technologies, Rohde & Schwarz) and one SME (Qamcom) [10].The measurements and simulations obtained in this project were done in different environments, and in certain frequencies. Detailed information about the mmMAGIC project is presented in [9].On the other hand, researchers and academia have led manymeasur ement campaigns. Some of the latest and the most important researcher projects are presented in [11-20]. Those studies are done in different frequencies (15 GHz, 28 GHz, 38 GHz, 60 GHz, 73 GHz), in various scenarios (urbanenvironment, dense environment), in order to reaching some objectives (pathloss models, interference characteristics, signal coverage, and the multipath propagation).

B. Channel characteristics

The accomplished measurements (that were carried out in different frequencies, various scenarios and across dissimilar materials), demonstrate that the new spectrum has some challenges to overcome. The shortcomings that those new frequency bands face are: high pathloss, higher sensitivity to obstacles, and finally the decreased diffraction [21].

The attenuation of rain and atmospheric gases: The effects of rain, atmospheric gases or molecular are the principal factors that influence in the propagation loss in the mmWave communications. Full simulation studies, which demonstrate the effects of those factors, are presented in [22-25].

The sensitivity to obstacles: Another important issue for using mmWave is the penetration loss experienced by radio propagations traversing diverse objects (e.g., humans, buildings and furniture).

In higher frequency bands, human blockage has a major interest. The human body can cause strong shadowing for the radio signal, in some cases it can block the communication link [26-29].

On the other hand, mmWave communications suffer from penetration loss in crossing solid materials (e.g. glass, drywall, brick wall, wood, buildings...) [30], or vehicular [31].

The decreased diffraction: The phenomena of the diffraction are decreasing while the frequency increases in outdoor scenarios, but it has less impact above 10 GHz [32]. For indoor scenarios, diffraction loss has fewer effect due to reflection and transmission between walls [33].

C. Deployment of Different Bands

The choice of the deployment environment of this new generation is conditioned by the criterion of the new spectrum characteristics. Measurements studies conduct us to think about the cells characteristics of the 5G network. One of the important key aspects that characterizes the 5G architecture is deploying macro cells and small cells, and assuring the Cooperation between those two kinds. In this scenario, macro-cells provide wide area coverage while small base stations provide high data rates (Fig. 3).
Thus, it's essential to develop cooperation in multicast scenarios [34].

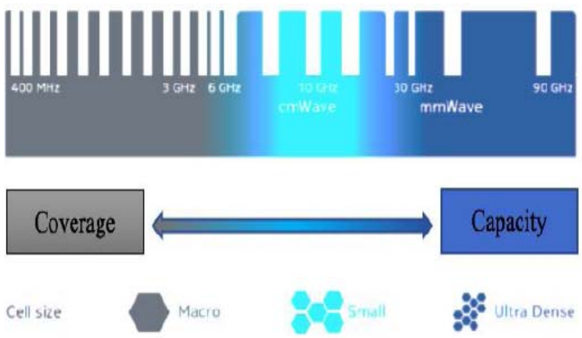

Fig.3. Cells characteristics in different bands

III. MASSIVE MIMO BEAMFORMING

A. Massive MIMO

Massive multiple input multiple output (MIMO) makes a big progress in wireless systems, it has been employed in the current 4G network, and it has demonstrated its efficiency. This antenna technology for wireless communication used a multiple number of controllable antennas. In 2017, it has been deployed 4X4 MIMO which supports 32 antennas at the base station, this configuration is called Full-Dimension MIMO. In the mmWave bands, a base station can support hundreds of antennas. At low frequency the signal has significantly better propagation characteristics than the higher frequencies. This criterion affects the MIMO technology deployments (Fig. 4). An analyzed architecture of a MIMO system, used in the next generation, is presented in [35].

The main role of Massive MIMO is limiting pathloss by using high antenna gain, which implicate improving coverage (by 6dB - 9dB) [8]; to be precise, the antenna gain is controlled by the output power, the amount of antenna elements and the number of transceivers. In addition to that, MIMO takes an important part in limiting interference by using High Order Spatial Multiplexing. An interesting process for improving MIMO Multiplexing, which can ameliorate mmWave channel throughput, is studied in [36]. In [37] authors demonstrate the effectiveness of the massive MIMO device over the air (OTA) Radio Frequency (RF) by many tests and measurements.

To overcome all the propagation issues that mmWave can face, namely: sensitivity to blockage, penetration losses and diminished diffraction, a cluster network concept is envisioned where a set of coordinated access points (APs), that will fit in small boxes that are easy to install, work together to furnish omnipresent coverage through AP diversity [38]. In the scenario of blockage, one AP will rapidly handoff the user device to another AP in the cluster. Those Handoffs may be done while changing orientation, hand movement or moving obstacles.

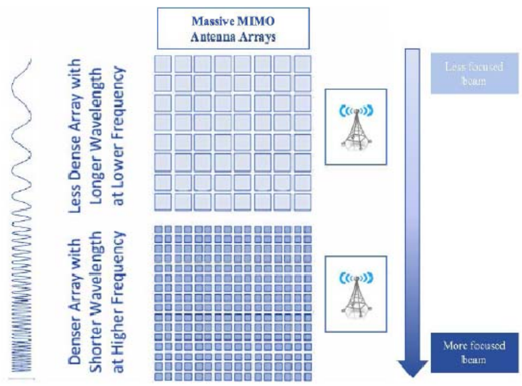

Fig.4. MIMO deployment in different frequencies

B. Beamforming

The implementation of MIMO can be executed in diverse way, the implication of beamforming is a special technique used to join multiple antenna elements to condense the power in a specific direction, and also upgrade the signal to noise plus interference ratio (SNIR). Moreover, the beamforming can remove the interference, some designs for this objective are presented in [39] [40]. Beamforming is especially gainful for progressing cell-edge performance. The antenna system needs to dynamically steer the beam to the user devices in the cell area to insure the full coverage from a single radio and antenna. A proposed beamforming technique which assuring atmospheric coverage is developed in [41].

Advanced beamforming techniques can track the user. The paper [42] proposes a beam tracking robust mechanism for mobile mmWave communication systems which considered the system throughput and handoff probability. It is important to mention that the efficient adaptive beam tracking algorithms need to be employed for both base station (BS) and user equipment (UE) in order to be accurately aligned with acceptable latency.

The most enticing means to steer antenna beams in mmWaves is the electronically steered array (ESA), also called phased array. Phased arrays necessitate active phase control of the antenna elements. The size of the array belongs on the application or the deployment scenario, in other words, it will vary according to the system gain. Phased arrays can be designed round divers RF architectures. Phase steering can take place at RF (analog beamforming), baseband (digital beamforming), or a combination of baseband and RF (known as a hybrid beamforming). The realization of the full digital beamforming in mmWave based MIMO systems, is complicated due to the high cost and power consumption of the RF chains. Thankfully, the hybrid beamforming is suggested to rise above these limitations by separating the beamforming process between the analog and digital domains [43] [44] (Fig. 5).

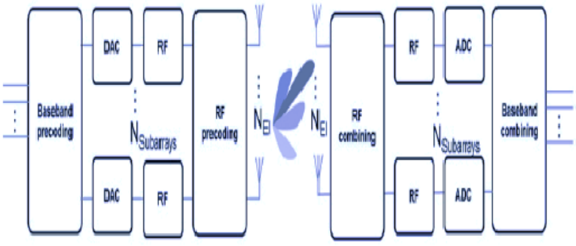

Fig.5. Hybrid beamforming design for 5G NR

Fortunately, 5G NR can also leverage user equipment (UE) antenna diversity to get over the issue of hand-blocking [45]. The attractive work in [46] proposes a novel and highly configurable system design for 5G cellular UE, which is the distributed phased arrays based-MIMO (DPA-MIMO), this topology furnishes a solution to human body blockage. Depending on the hand position habits while using phones (or tablets) and his impact in the high frequencies studied in [47]; an efficient solution of placing BF modules in the phone devices is proposed in [46]; More precisely, it is mandatory to position BF modules (BFM) at the central part of the mobile device, top two corners and bottom two corners. As a result, the beamforming technique can be used in device to device communication (D2D), a novel scheme for this objective is presented in [48].

IV. ACCESS IN 5G NEW RADIO

A. Initial access

Initial access is the proceeding done by a device to find a cell to camp on, to get the needful system information, and to request a linking through random access [49].

Owing to the propagation difficulties in mmWave bands, 5G NR defined new initial access design for beamforming that will utilize beam scanning (or beam-sweeping), so that the base station can identify the strongest beam and establish the convenient connection (Fig. 6). Therefore, Beamforming technology has a fundamental role in 5G NR and especially in the initial or random access, either for user plane or control plane, which can be performed at the transmitter side or receiver side.

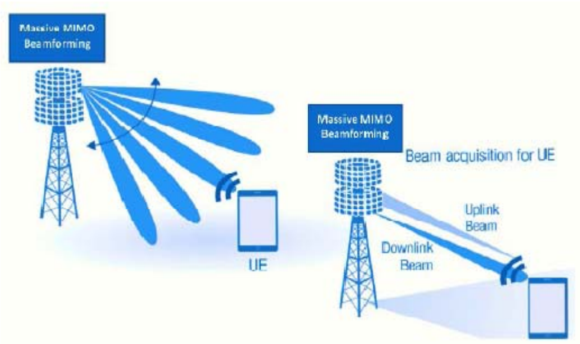

Fig.6. Initial access design for beamforming

Different initial access protocols are studied in [50]. In order to choose the best initial access technique, a comparison analysis of several design is detailed in [51].

5G NR inserted the synchronization signal block (SSB), which is role is to support the multi-beam process in high frequency scenarios. The SSB is repeated within a synchronization signal (SS) brust set (confined to a 5 ms slot), which is potentially used for beam-sweeping transmission. For the initial cell picking, the UE adopts a default SS burst set periodicity of 20 ms, at that time the UE can obtain the physical cell identity. It is worth to mention that SS consists of primary SS (PSS) and secondary SS (SSS). SS achieves downlink synchronization in both time and frequency domain. NR SSS is produced by using BPSK modulated sequence of length 127. PSS and SSS together can be used to indicate a sum of 1008 different physical cell identities.

SSB is made up of a primary synchronization signal (PSS), a secondary synchronization signal (SSS), and a physical broadcast channel (PBCH), the lately one carries the fundamental system information. PSS, SSS and PBCH are transmitted together, so they all have the same periodicity. In addition to that, PSS, SSS, and PBCH of the same SSB share the same single antenna port. It is important to mention that the beams applied to an SSB are transparent to the UE, since it sees the equivalent SSs and PBCH after precoding and/or beamforming operations, that are up to the network implementation [52] (Fig. 7). The subcarrier spacing of SSB can be 15 or 30 kHz in FR1 and 120 kHz or 240 kHz in FR2 (More information about Frequency range are given in Table 1).

Table 1: Frequency range

Frequency range (FR)	FR1	FR2
Frequency band	[450 MHz – 6 GHz]	[24.25 GHz – 52.6 GHz]
Type	Sub 6 GHz	mmWave

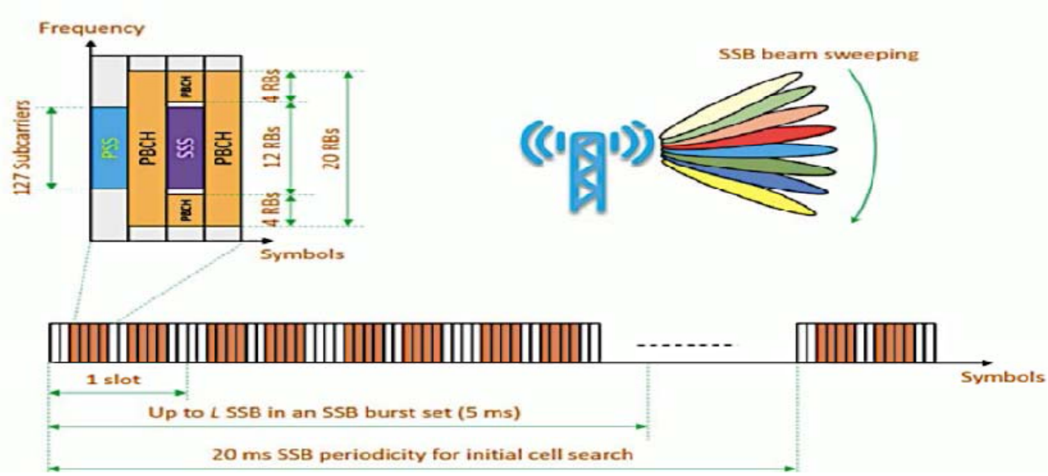

Fig.7. [53]: Illustration of SSB

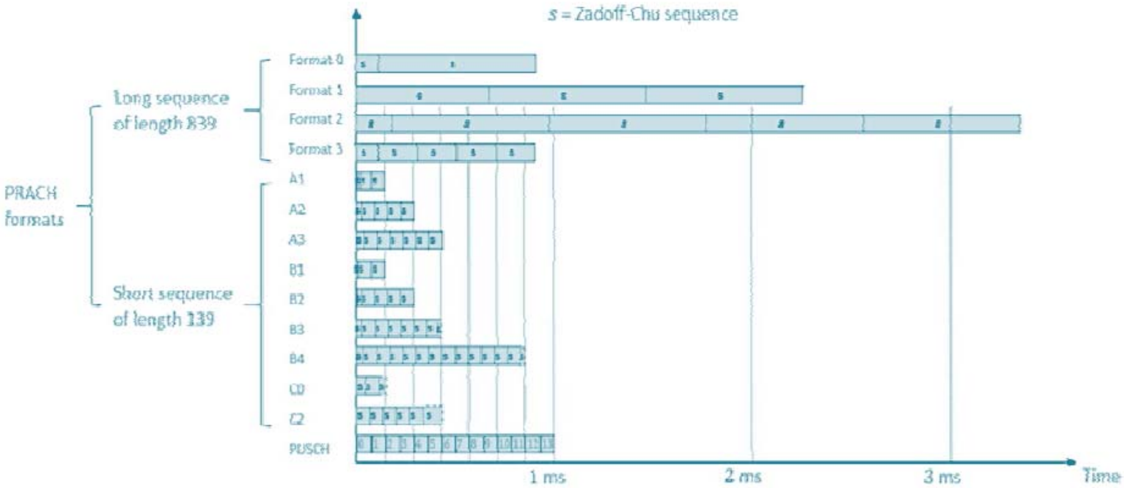

Fig.8. PRACH formats

B. Random Access

Similar to LTE, 5G NR will also use Zadoff-Chu (ZC) sequences. The ZC sequence is used for generating NR random-access preambles, it is known to have an ideal autocorrelation property, including constant amplitude before and after Discrete Fourier Transform (DFT) operation, zero cyclic auto-correlation and low cross-correlation. This makes it appropriate for many applications such as the random-access preamble of the Physical Random-Access Channel (PRACH).

The paper [54] presents more details about ZC sequence design for random access, while the letter [55] proposes Improved ZC Sequence detection under unknown multipath.

The PRACH transmits a random-access preamble from a UE to the base station, in order to indicate a random-access attempt and to assist the base station to adjust the uplink timing of the UE, among other parameters.

NR random-access preamble supports two types of sequence lengths with different format configurations, dissimilarly to LTE. This choice was taken in order to handle the wide range of deployments for which 5G NR is designed.

The first type which is long sequence of length 839, four preamble formats are introduced. These formats can only be used in FR1; thus, it is principally targeting large cell scenarios. The formats have a subcarrier spacing of 1.25 kHz or 5 kHz. The second type which is short sequence of length 139, nine different preamble formats are supported. These formats can be used in both FR1 and FR2. The formats have subcarrier spacing of 15 or 30 kHz for FR1 and 60 or 120 kHz for FR2 (a detailed scheme is presented in Fig. 8) [53].

This new design has many advantages. The first benefit is the support of analog beam-sweeping during PRACH reception. The second one is allowing the base station receiver to use the same fast Fourier transform for random-access preamble detection and data. The third plus is the robustness, performed by the short preamble format, against time varying channels and frequency errors.

V. NEW WAVEFORM

A. Numerology

5G is designed to provide a wide diversity of services, by performance waveform parameters flexibly. The insertion of the flexibility in the waveform decreases latencies, improves reliability and QoS. This pliability was provided by coexisting of numerologies, each numerology consists of a set of parameters defining the frame structure of the waveform [56-58]. The flexible numerology in NR is different from numerology in LTE. In spite of the advantages of this flexibility it introduces new challenges in the manner waveforms are built and operated.

NR permits contemporaneous multi-numerology utilization. In the literature [59–62], Multi-numerology structures that were included in the 3GPP 5G NR standardization were elaborated.

NR takes up a flexible subcarrier spacing of $2^{\mu} \times 15\ KHz$(μ=0, 1,...,4) scaled from the staple 15 kHz subcarrier spacing in LTE (Table 2).

Table 2: Numerology in 5G NR

Numerology	Subcarrier spacing	slots per subframe	Slot length
0	15 kHz	1	1ms/2^1=1 ms
1	30 kHz	2	1ms/2^2=500us
2	60 kHz	4	1ms/2^4=250 us
3	120 kHz	8	1ms/2^8=125µs
4	240 kHz	16	1ms/2^{16}=15,25ns

At lower frequencies, below 6 GHz, where the large cells are deployed, subcarrier spacings of 15 kHz and 30 kHz are suitable. In contrary to higher frequencies, where the phase noise issue becomes serious, NR supports 60 kHz and 120 kHz for data channels and 120 kHz; whereas 240 kHz is for the SSB used for initial access.

B. Frame structure

One frame (10 ms) contains ten subframes (1 ms for each one) and every slot own 14 OFDM symbols, this is similar to LTE; this choice is taken in order to facilitate NR and LTE coexistence. The augmentation of the numerology increases slots in a subframe; as a consequence, increasing the number of symbols sent in a given time. In addition to that, while the frequency growth, the slot duration decreased (as shown in Fig. 9).

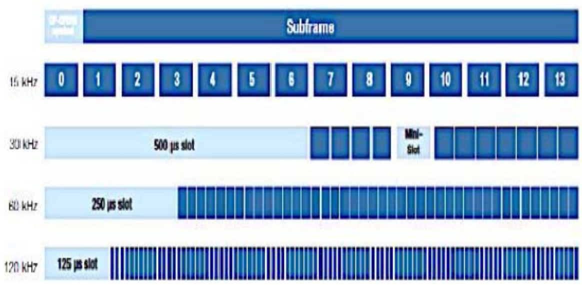

Figure 9: Slots within a subframe

Slots can be DL, UL, or flexible. As a result, the network can dynamically balance UL and DL transmission. Thus, it is a key to optimize traffic for different service types [63].

NR allows transmission to start at any OFDM symbol and endure only as many symbols as required for the communication; in other word, scheduling works perfectly in a slot. This kind of slot (also known as a mini-slot) transmission can facilitate in getting a very low latency for crucial data as well as reduce interference. A summarize of all this discussion is presented in Fig. 10

C. Optimized OFDM modulation

Compared with other waveforms, orthogonal frequency division multiplexing (OFDM) technology is the excellent candidate which can be adopted, due to its advantages such as low complexity, low cost, easy integration with MIMO, and plain channel estimation [65]. In addition to that, OFDM is able to provide a more optimum parameter choice for each service group by permitting multiple parameter configurations, and hence better overall system efficiency.

After studies and evaluation of all the waveform proposals, 3GPP agreed to adopt OFDM with a cyclic-prefix (CP) for both DL and UL transmissions, in order to maximize mobile broadband capacity [66]. On the other hand, 5G NR is able to use discrete Fourier transform (DFT) spread OFDM in the uplink to ameliorate coverage. A single carrier (SC) based waveform is preferred to be used for bands above 40 GHz; in order to: increase power efficiency, allow efficient beamforming and decrease switching overhead [67].

A new transmission scheme based on OFDM mechanism considering the characteristics of mmWave communication has been proposed in [68]. Case study of hybrid beamforming design for OFDM-based systems with large-scale antenna arrays is studied in [69], which demonstrate the efficiency in using all those elements in the mmWave communication.

CONCLUSION AND FUTURE TRENDS

This paper aims to offer a comprehensive overview of the state-of-the-art development of 5G NR, we have studied the evolution that will bring to the 5G networks. The idea gotten from this work describes the importance of optimizing this new radio due to its value in supporting extreme and diverse requirements for capacity, availability and latency.

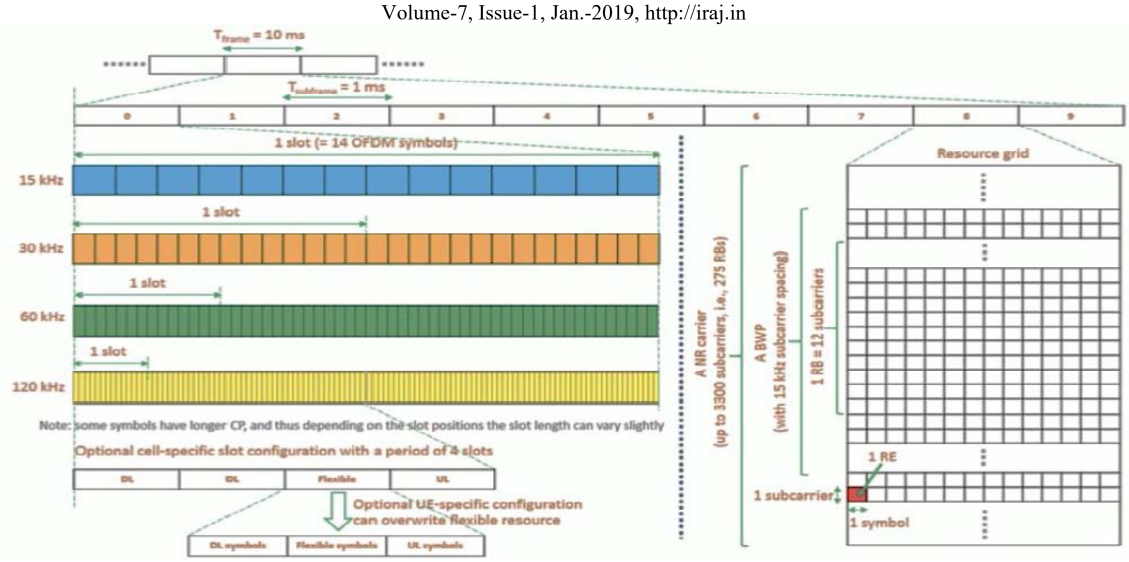

Fig.10. [64]: Structure of frame and slots in different frequencies

While academics and industrials are currently working on what will define 5G wireless networks, a proposed technology will take its place in the future 5G deployments, this technology is known as "Network slicing". This new tech creates virtual network segments for the various use cases within the same network in order to support multi-service [70]. Limited researches were carried out in this area; therefore, it presents the objective of a future work.

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