ФОРМИРАНЕ НА КАНАЛА ПРИ 5G МРЕЖА, ИНОВАТИВНИ ХАРАКТЕРИСТИКИ

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Резюме: *Новото поколение мобилна система 5G, известна като NR – new radio, подобрява работата на потребителя със системата и обезпечава нарастващите изисквания за висока скорост, голяма честотна лента и качество на услугата. Настоящият документ представя в детайли формирането на канала и нивото на подобрения, към цялостната производителност.*

Ключови думи: *Формиране на канала, високоскоростни комуникации, комуникационен модел*

CHANNEL FORMING OF 5G, INNOVATIVE FEATURES

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Abstract: *New generation of mobile system 5G known as NR – new radio improves user experience and covers the increasing demands on high speed, large bandwidth and quality of service. The present paper presents in details the channel forming and the level of improvements it brings to the overall performance.*

Key words: *Channel formation, high-speed communications, communication model.*

INTRODUCTION

The advent of 5G technology marks a significant milestone in the evolution of wireless communication, promising to revolutionize various sectors through enhanced connectivity, speed, and reliability. As the fifth generation of mobile networks, 5G is designed to surpass its predecessors by offering higher data rates, reduced latency, and massive device connectivity, thus paving the way for new applications and services [1]. Central to these advancements are the innovative features of 5G, including the use of millimeter waves, massive MIMO (Multiple Input Multiple Output), and beamforming technologies, which collectively contribute to its superior performance [2]. Channel formation in 5G is a critical area of study, as it directly influences the efficiency and effectiveness of data transmission. The implementation of sophisticated techniques such as dynamic spectrum sharing, network slicing, and edge computing are instrumental in optimizing channel utilization and enhancing overall network capacity [3]. Understanding these mechanisms is essential for leveraging 5G's full potential in addressing the increasing demand for high-speed internet and the proliferation of Internet of Things (IoT) devices. Moreover, the deployment of 5G networks introduces significant challenges and opportunities for innovation. The necessity to manage higher frequency bands and more complex signal environments necessitates advancements in channel modeling and propagation analysis. These developments are crucial for achieving the promised improvements in connectivity and service delivery [4].

This paper explores the formation of 5G channels, delving into the innovative features that distinguish it from previous generations and examining the implications for future technological advancements.

1. KEY FEATURES OF 5G, NEW RADIO SIGNAL FORMATION IN CONTRAST WITH LTE

The transition from Long-Term Evolution (LTE) to 5G technology brings a host of improvements and new features designed to meet the demands of modern connectivity. One of the most notable enhancements is the substantial increase in data rates. While LTE typically offers peak download speeds of up to 1 Gbps, 5G can achieve speeds exceeding 10 Gbps, thanks to the use of wider frequency bands, including millimeter waves (mmWave), and advanced modulation techniques [5].

Another key feature of 5G is its significantly reduced latency. LTE networks typically have latencies of around 30-50 milliseconds, whereas 5G aims to reduce this to as low as 1 millisecond, enabling real-time applications such as autonomous driving and augmented reality [6]. This is facilitated by edge computing and network slicing, which allow for more efficient data processing and resource allocation.

Massive MIMO (Multiple Input Multiple Output) is another major advancement in 5G, allowing for the use of a large number of antennas at the base stations to improve spectral efficiency and capacity. In contrast, LTE systems use conventional MIMO configurations with a limited number of antennas, typically up to 8×8 MIMO [7].

Beamforming is also extensively utilized in 5G to direct signals more precisely to users, thereby enhancing coverage and reducing interference. LTE systems use simpler beamforming techniques, which do not offer the same level of precision and efficiency [8].

The transition from Long-Term Evolution (LTE) to 5G New Radio (NR) technology represents a significant leap in wireless communication capabilities. While LTE, introduced with the 4G standard, has been the backbone of high-speed mobile internet, 5G NR offers groundbreaking advancements in data rates, latency, capacity, and reliability. These improvements are driven by innovations such as the use of millimeter-wave (mmWave) frequencies, enhanced Multiple Input Multiple Output (MIMO) systems, and sophisticated beamforming techniques

Orthogonal Frequency-Division Multiplexing (OFDM) is the modulation scheme used in both LTE and 5G NR. In LTE, the received OFDM signal can be expressed as (1):

$$S_l^{p\mu}(t) = \sum_{k=-\left\lfloor\frac{N_{RB}^{DL}N_{sc}^{RB}}{2}\right\rfloor}^{-1} a_{k^{(-)},l}^{(p)}\, exp[j2\pi k\Delta f(t - N_{CP,l}.T_s)] + \sum_{1}^{k=\lfloor N_{RB}^{DL}N_{sc}^{RB}/2\rfloor} a_{k^{(+)},l}^{(p)}\, exp[j2\pi k\Delta f(t - N_{CP,l}.T_s)] \qquad (1)$$

In 5G NR, the received OFDM signal is similar but often involves more complex channel models due to the use of massive MIMO and beamforming. The received signal y(t) can be represented as (2):

$$S_l^{p\mu}(t) = \sum_{k=\left\lfloor N_{RB}^{\mu}N_{SC}^{RB}/2\right\rfloor}^{\left\lceil N_{RB}^{\mu}N_{SC}^{RB}/2\right\rceil-1} a_{k',l}^{p,\nu}\, \exp[j2\pi k\Delta f(t - N_{CP,l}.T_s)] \qquad (2)$$

where

$$0 \le t < (N_{\mu} + N_{CP,l}^{\mu}).T_S\,,\; N_{\mu} = 2048\ .k.2^{-\mu}\,,\; N_{\mu} = 2048 \times 64 \times 2^{-\mu} = N_{\mu} = 2048 \times 64 \times \frac{1}{2^{\mu}}$$

$$N_{CP,l} = \begin{cases} 512k.2^{-\mu}\ \textit{extemded cycle prefix} \\ 144k.2^{-\mu} + 16.k\,, \textit{normal cycle prefix}\ l = 0 \text{ or } 1 = 7.2^{\mu} \\ 144.k.2^{-\mu}\ \textit{othewise} \end{cases},$$

In LTE, the waveform generation equation (1) is split in two parts to remove the point located at DC location. In NR(5G), DC removal is not required and the full IFFT equation is combine into one (2).

To form the channel it is necessary to perform a transport precoding accordingly. As mentioned above, unlike LTE NR has two options for UL Waveform. One is CP-OFDM equivalent to DL waveform and the alternative is DFT-s-OFDM which is same as LTE UL waveform. Transform Precoding is the first step to create DFT-s-OFDM waveform as highlighed below. Whether UE need to use CP-OFDM or DFT-s-OFDM is determined by following RRC Parameter. The Uplink UL precoding scheme is presented in fig. 1

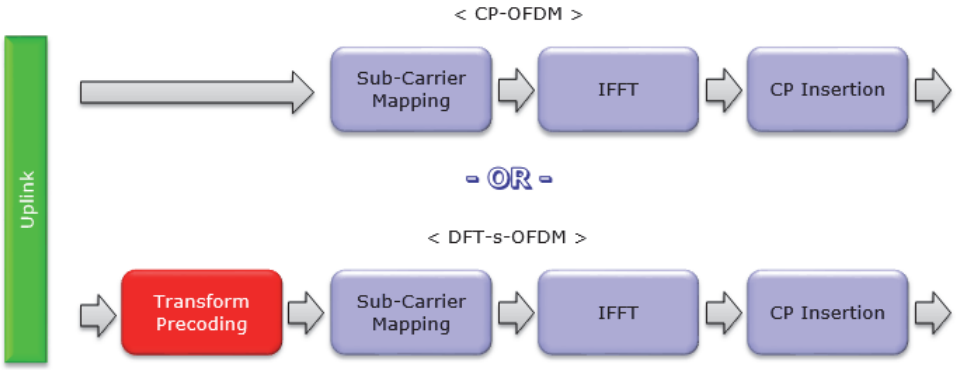


Figure 1. Precoding scheme for UL

In term of functionality, Transform Precoding is performed to spread UL data in a special way to reduce Peak-to-Average Power Ratio - PAPR of the waveform. In terms of mathematical expression the transform precoding can be represented as a form of Discrete Fourier Transform.

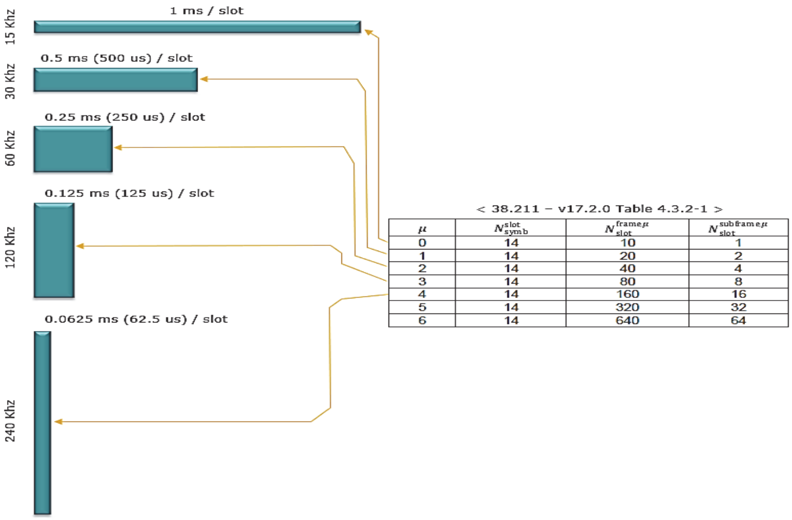
2. NR CHANNEL FORMING AND FRAME STRUCTURE

5G technology brings not only faster data rates and lower latency but also introduces an entirely new frame structure designed to efficiently manage the diverse range of wireless devices and applications prevalent today. This document delves into the intricacies of the 5G frame structure and its role in enabling the seamless functioning of our increasingly interconnected world. The 5G frame structure is engineered to be more flexible than its predecessor, LTE, to meet the stringent requirements of modern applications such as autonomous vehicles, the Internet of Things (IoT), and high-speed video streaming. Unlike the rigid design of earlier networks, the 5G frame structure adapts to the specific needs of each application, enhancing overall network efficiency.

A critical feature of the 5G frame structure is its method of time-frequency resource allocation. Time-frequency resources are divided into resource blocks, which are further subdivided into resource grid elements. This subdivision allows for an optimal distribution of network resources, ensuring faster and more reliable connectivity for users. The network can thus cater to diverse connectivity demands, providing high-speed connections for streaming 4K video while simultaneously maintaining the low-latency connections required for autonomous vehicles. The 5G frame structure is based on a slot and symbol-based design, which enables dynamic adjustment of time slot durations according to service requirements. Data-intensive services may receive longer slots, while services requiring quick response times, such as remote surgery or smart factories, may be allocated shorter slots. This adaptability enhances the efficiency and responsiveness of the 5G network. The 5G frame structure also introduces the concept of mini-slots, which allows for even faster response times for specific applications. In critical situations where a fraction of a second can make a significant difference, mini-slots ensure the prompt delivery of vital information. (For detailed information on mini-slots, please refer to the separate note provided.). Additionally, the 5G frame structure incorporates both self-contained and non-self-contained subframes. This feature provides another layer of flexibility, permitting different data transmission methods based on the specific requirements of the application. Consequently, this approach helps maintain the quality of service and further reduces latency.

The term numerology refers to the set of parameters that define the physical layer structure, specifically, the subcarrier spacing, symbol duration, and cyclic prefix length in an OFDM system. Comparing to LTE numberology (subcarrier spacing and symbol length), the most outstanding diffrence you can notice is thet NR support multiple different types of subcarrier spacing (in LTE there is only one type of subcarrier spacing, 15 Khz).

According to the numerology, different slot lengths can be used to utilize the frame structure as shown in fig. 2.



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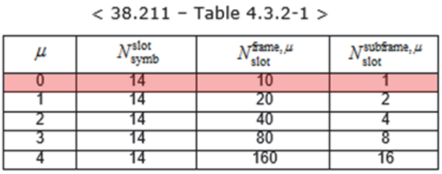
μ	N_{symb}^{slot}	$N_{slot}^{frame,\mu}$	$N_{slot}^{subframe,\mu}$
0	14	10	1
1	14	20	2
2	14	40	4
3	14	80	8
4	14	160	16
5	14	320	32
6	14	640	64

Figure 2. Slot length according to the numerology

In 5G New Radio (NR), multiple numerologies, which refer to different waveform configurations such as subcarrier spacing, are supported. These numerologies result in variations in the radio frame structure. Despite these variations, the duration of one radio frame and one subframe remains constant across all numerologies. Specifically, a radio frame always has a length of 10 milliseconds, and a subframe consistently measures 1 millisecond. To accommodate the different physical properties associated with each numerology, the number of slots within a single subframe is adjusted. This adaptation is necessary to ensure the efficient use of the radio spectrum and to meet the diverse requirements of various applications. Another parameter that varies with numerology is the number of symbols within a slot. However, this variation is not directly related to numerology but rather to the slot configuration type. For slots with a normal Cyclic Prefix (CP), each slot contains 14 symbols. In contrast, slots with an extended CP contain 12 symbols. Thus, the 5G/NR frame structure maintains a consistent temporal framework while allowing flexibility in the number of slots and symbols per slot to accommodate different numerologies and slot configurations. This flexibility is essential for optimizing performance across a wide range of applications and services. An example of the frame structure for normal CP and numerology index 1 is shown in fig. 3.



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μ	N_{symb}^{slot}	$N_{slot}^{frame,\mu}$	$N_{slot}^{subframe,\mu}$
0	14	10	1
1	14	20	2
2	14	40	4
3	14	80	8
4	14	160	16

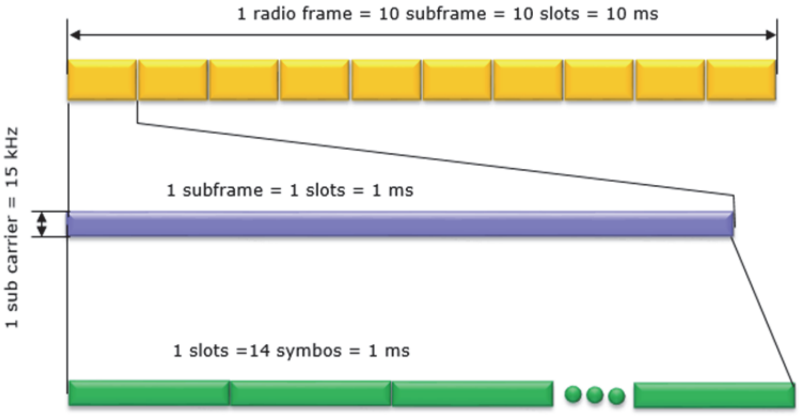
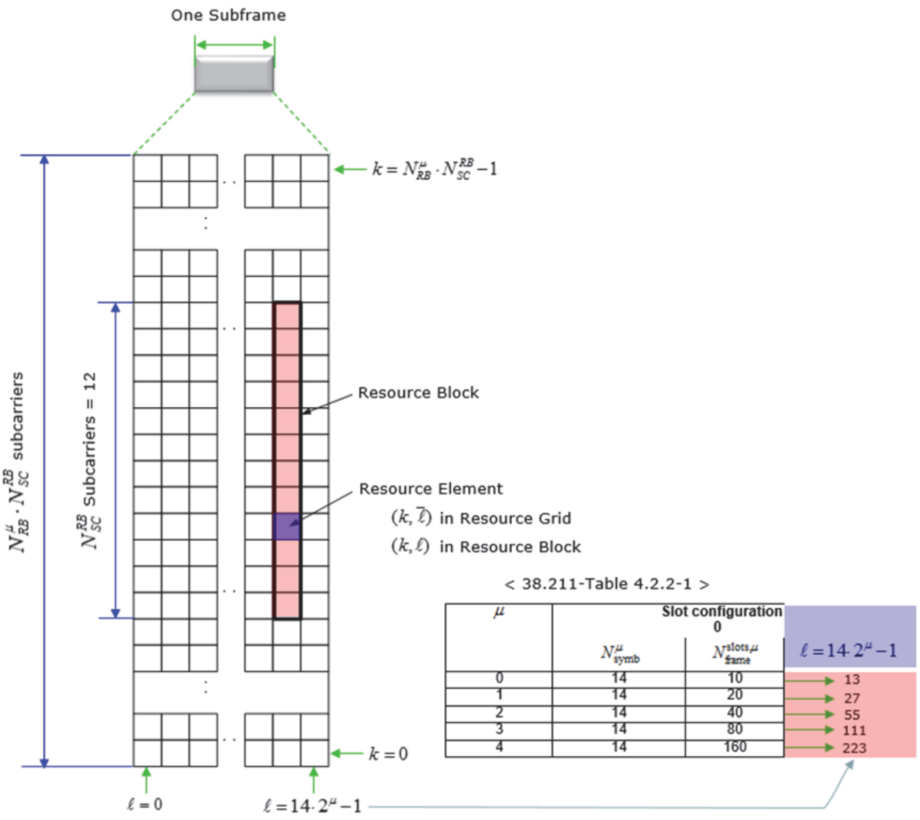


Figure 3. Sample frame structure for normal cyclic prefix μ=1

After the frame structure has been specified, then the resource grid has to be assembled – fig. 4.



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μ	Slot configuration 0		
	N_{symb}^{μ}	$N_{frame}^{slots,\mu}$	$\ell = 14 \cdot 2^{\mu} - 1$
0	14	10	13
1	14	20	27
2	14	40	55
3	14	80	111
4	14	160	223

Figure 4. NR resource grid

The resource grid for New Radio (NR) is defined with specific parameters that exhibit similarities to the LTE resource grid at first glance. However, the physical dimensions, such as subcarrier spacing and the number of OFDM symbols within a radio frame, vary in NR based on the numerology employed. The maximum number of resource blocks (RBs) for both downlink and uplink in NR differs from LTE. The following outlines the maximum number of RBs that can be configured through the Radio Resource Control (RRC) message and the Downlink Control Information (DCI). It is important to note that the actual required RF bandwidth may be slightly wider than the maximum number of RBs to account for the necessary guard band. For a precise estimation of the RF spectrum and bandwidth requirements, refer to the specific guidelines on RF bandwidth calculation. This flexibility in the NR resource grid allows for efficient utilization of the available spectrum, catering to the diverse requirements of modern wireless communication applications. The maximum number of resource blocks (RBs) for both downlink and uplink in NR differs from LTE. The following outlines the maximum number of RBs that can be configured through the Radio Resource Control (RRC) message and the Downlink Control Information (DCI). It is important to note that the actual required RF bandwidth may be slightly wider than the maximum number of RBs to account for the necessary guard band. For a precise estimation of the RF spectrum and bandwidth requirements, refer to the specific guidelines on RF bandwidth calculation.

The NR resource grid's flexibility is a cornerstone of 5G technology, enabling efficient spectrum use and adaptable resource allocation. By varying subcarrier spacing, the number of slots per subframe, and the number of symbols per slot, the NR resource grid can meet diverse performance requirements across multiple applications. The structured and mathematically rigorous framework ensures high efficiency and adaptability in modern wireless communication systems, supporting everything from high-speed data transfer to low-latency critical applications.

CONCLUSION

The 5G frame structure represents a significant advancement in wireless communication, offering unprecedented flexibility and efficiency. By dynamically adapting to the needs of various applications, it ensures optimal performance across a wide range of use cases. This adaptability is crucial in meeting the demands of modern connectivity, from high-speed video streaming to the low-latency requirements of autonomous systems, ultimately supporting the seamless operation of our interconnected world.

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