5G KPI Targets and Enabling Technologies

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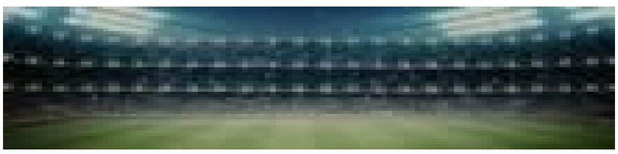
August 2018

Introduction

There is a general consensus that we are heading toward a fully mobile and connected society, which is expected to create huge growth in communication connectivity for human-to-human, human-to-machine, and machine-to-machine applications, as well as data traffic from continuous emergence of new services. The 3rd Generation Partnership Project (3GPP) is currently developing the standard for the fifth generation (5G) of mobile communication networks, which aims to address the communication needs of such a networked society. Unlike earlier generations of the cellular systems, which focused on human-centric services such as voice and streaming of music and video, 5G is designed to provide optimized support for a wide variety of different services. In this white paper, we look at the envisaged usage scenarios and their target performance for 5G systems, and further elaborate the enabling technologies used to achieve the 5G performance requirements.



5G Usage Scenarios and Services

The usage scenarios and services targeted by 5G are grouped into three main categories, as defined by International Mobile Telecommunications (IMT) for 2020 and beyond [1].

Enhanced Mobile Broadband (eMBB)

Enhanced MBB addresses the enhancement of the traditional human-centric services to enable data-intensive services such as streaming of ultra-high-definition (UHD) 3D video and user generated contents. Other possible applications include immersive gaming and interactive services, eg, augmented reality (AR).

Enhanced MBB is expected to provide much improved user data rate compared to existing systems for both wide-area coverage and hotspot areas. For wide-area services, seamless coverage without disruption from mobility is desirable. For the hotspot coverage such as sports arenas, urban areas and transportation hubs, it is essential to provide high volumes of data traffic per area and large numbers of connections in an area.

Ultra-Reliable and Low-Latency Communications (uRLLC)

uRLLC targets mission-critical control-type services such as public safety services and unmanned aerial vehicle (UAV) controls. Other example applications include industrial automation control, self-driving cars, remote robotic surgery, etc. Compared to eMBB services, uRLLC type services require extremely high reliability and low end-to-end latency.

Services such as UAV control also require more precise positioning information that includes altitude, speed, and direction, as well as horizontal coordinates.

Massive Machine Type Communications (mMTC)

mMTC is driven by the development of the internet of things (IoT) and characterized by a massive number of connected devices, each transmitting a relatively low volume of data that is not delay sensitive. mMTC aims at providing a wide range of diversified IoT services. Example applications include smart homes, smart cities, environmental monitoring, internet of vehicles, etc.

This use case demands devices that are low cost and have a very long battery life. Consequently, 5G systems are required to be highly efficient in both resource usage and energy consumptions in order to provide mMTC services effectively.

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It is clear from the above 5G usage scenarios and services that different services will impose different performance requirements, leading to the introduction of a range of performance indicators that are not seen in previous 3GPP systems.

5G Key Performance Indicators (KPIs) and targets

A range of key performance indicators used to characterize the capability of 5G systems are defined in [1] [2] and the targeted values for some of the KPIs are given in [3]. In addition to those shown in Table 1, there are other qualitative KPIs such as UE energy efficiency and network energy efficiency, etc.

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Parameter	Definition	Target value(s)
Peak data rate	*Maximum achievable data rate under ideal conditions per user/ device*	DL: 20Gbps; UL: 10Gbps
Peak Spectral efficiency	*Peak data rate normalised by bandwidth*	DL: 30bps/Hz; UL: 15bps/Hz
User experienced data rate	*Achievable data rate that is available ubiquitously across the coverage area to a mobile user/device*	DL: ≤ 1Gbps UL: ≤ 500Gbps
Area traffic capacity	*Total traffic throughput served per geographic area*	DL: ≤15Tbps/km² UL: ≤ 7.5Tbps /km²
Connection density	*Total number of devices fulfilling a target QoS per unit area*	≤ 100 000/km²
Latency	*The contribution by the radio network to the time from when the source sends a packet to when the destination receives it*	0.5ms ~ 10s
Mobility	*Maximum speed at which a defined QoS and seamless transfer between radio nodes can be achieved*	≤ 500km/h
Mobility interruption time	*Shortest time during which a user terminal cannot exchange user packets with network*	≤ 100 000/km²
Reliability	*The success probability of transmitting a packet*	99.9% ~ 99.9999%

Table 1 Target values for 5G KPIs

Not all KPIs are important for all usage scenarios and the requirements on the KPIs also depend on the deployment environments. For example, user experienced data rate is an important KPI for eMBB type services but less important for mMTC type services. For eMBB applications, the targeted user experienced data rate can be as high as 1 Gbps in downlink and 500 Mpbs in uplink for indoor hotspot environments while 50 Mbps in downlink and 25 Mbps in uplink would be sufficient for rural macro environments. On the other hand, end-to-end latency is extremely stringent for uRLLC type services but can be significantly relaxed for mMTC type services. Consequently, the requirements on some of the KPIs vary hugely depending on the services and deployment environments.

It is apparent from Table 1 that 5G systems are expected to support extremely high peak and user experienced data rate, good spectrum efficiency and mobility support, low latency, and in general, meet very stringent requirements on a wide range of KPIs. This is only possible with a set of innovative enabling technologies.

"…the scalable numerology is a key enabler for 5G networks to achieve trades-offs among quality of service (QoS) requirements, resource efficiency and UE implementation complexity."

5G Enabling Technologies

5G services are expected to be supported by the enhancement of existing 4G systems and the use of new technologies via a new air interface, known as New Radio (NR). In the following sections we describe some of these new technologies and explain how they provide the flexibility to address the varied KPIs.

OFDM-based Waveform with Scalable Numerology

Release 15 of the 3GPP specifications is the first to introduce NR and it adopts the waveform orthogonal frequency division multiplexing (OFDM) with a cyclic prefix (CP) for both downlink and uplink [4]. The discrete Fourier transform spread OFDM (DFT-s-OFDM) with a CP is also optionally supported for uplink transmissions. The term numerology refers to the combination of OFDM subcarrier spacing (SCS) and CP type (ie, normal CP or extended CP). The supported numerologies and frame structure details by NR are summarized in Table 2.

Cyclic Prefix Type	μ	Subcarrier spacing	Number of symbols per slot	Number of slots per frame	Number of slots per subframe
Normal	0	15 kHz	14	10	1
	1	30 kHz	14	20	2
	2	60 kHz	14	40	4
	3	120 kHz	14	80	8
	4	240 kHz	14	160	16
Extended	2	60 kHz	12	40	4

Table 2 NR numerologies and frame structure details

In the frequency domain, multiple SCSs are supported, defined by 2^{μ}×15 kHz where μ takes a value from {0, 1, 2, 3, 4}. In the time domain, one frame has a fixed duration of 10ms and is divided into 10 × 1 ms subframes. Subframes are further divided into a variable number of slots, each containing 14 OFDM symbols. The number of slots in each subframe is scalable depending on the choice of SCSs, as shown in Figure 1. There are 2^{μ} slots in each subframe.

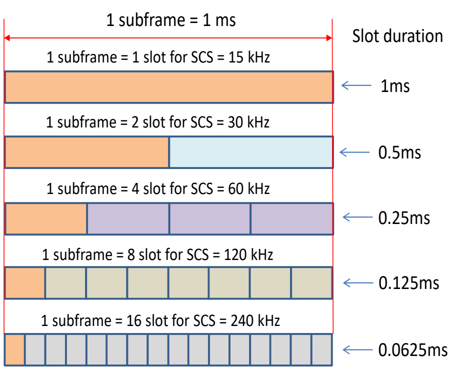

Figure 1 Illustration of 5G NR slot duration scalability

OFDM is well known to be spectral efficient and easy to use with smart antennas. The scalable numerology elevates the advantage of the OFDM waveform in a number of ways. For example, smaller subcarrier spacing and/or a larger CP would provide robustness against channel time-selectivity which may be encountered by high mobility applications. On the other hand, a larger subcarrier spacing means a smaller OFDM symbol duration, which reduces transmission latency. Furthermore, larger subcarrier spacing is used for wider channel bandwidth so that the FFT size scales accordingly and the processing complexity does not increase unnecessarily for wider bandwidth.

The duration of a slot ranges between 1ms and 0.0625ms, and this variability in slot duration accommodates the diverse latency requirements of different use cases. Using slot-based radio resource scheduling, a short slot duration enables fast adaptation to the channel condition and efficiently supports applications with bursty data traffic by assigning resource only when needed. Therefore, the scalable numerology is a key enabler for 5G networks to achieve trades-offs among quality of service (QoS) requirements, resource efficiency and UE implementation complexity.

Advanced Channel Coding

To meet the high peak data rate and low latency requirements of applications such as multimedia UHD streaming and AR/VR services, the channel coding technology used by 5G must support fast processing speed. In general, higher decoder throughput means more power consumption and greater hardware complexity. Both Turbo codes and low density parity check (LDPC) codes (as used by 4G) show performance near the Shannon limit; however, LDPC decoders consume less power than Turbo decoders whilst providing higher performance and higher decoder throughput.

A recent innovation in channel coding has been the discovery of Polar codes, which is the first code family that has been theoretically proven to achieve the Shannon limit. When concatenated with a cyclic redundancy check (CRC), polar codes can achieve a significantly better performance than Turbo codes, especially for short code lengths. Polar codes also have low encoding and decoding complexity. Consequently, Polar and LDPC codes have been standardized as the 5G NR channel coding technologies [4]. Polar codes are used for both uplink and downlink control information as well as master system broadcast information. LDPC codes are used for data as well as other system information and higher layer signaling, including paging information.

Higher Frequency Bands and Wide Channel Bandwidth

One of the solutions to realise the 5G requirements for broadband services in eMBB category is the use of the abundant spectrum available at higher frequencies. Two frequency ranges (FR) are defined for NR operation in 5G Release-15 [5], as shown in Figure 2.

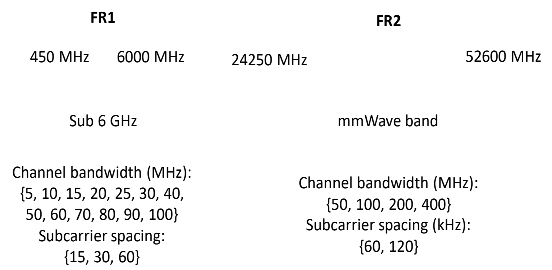

Figure 2 Frequency range and channel bandwidth supported by 5G NR

At higher frequency, the radio signal propagation attenuates quickly, which means smaller cells and more efficient frequency reuse. It is ideal for providing high throughputs in densely populated areas such as indoor hotspots and stadiums. More importantly, antenna elements at higher frequency are smaller and easier to assemble into electrically steered arrays; this enables equipment to direct energy to where it is needed, thus reducing interference and improving performance in dense crowds.

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In a 5G network, the cell channel bandwidth can be up to 100 MHz in FR1 and up to 400 MHz in FR2. Compared with carrier aggregation, ie, combining several smaller bandwidth channels to increase throughput, a wide channel bandwidth provides higher spectral efficiency because it saves resource waste resulting from guard bands.

A UE can be configured to receive and transmit on the whole cell channel bandwidth or just one or more segments of the cell channel bandwidth, known as channel bandwidth parts (BWPs). Up to four BWPs can be allocated to a UE in each of the uplink and downlink directions, and most importantly, the allocation can be done dynamically based on the needs of applications and UE processing capabilities in terms of both hardware and software.

The use of high frequency bands and wide channel bandwidth is one of the key enablers for meeting extreme data throughput requirements of 5G systems. Similarly, channel bandwidth adaptation is a key enabler for achieving spectral efficiency and energy efficiency since a UE need only transmit or receive over a channel bandwidth that is sufficient to meet the QoS of its applications.

> ***"A set of new enabling technologies introduced via the NR interface provide the foundation for 5G systems to achieve the diverse performance requirements in an effective manner."***

Massive MIMO

Massive multiple-input multiple-output (MIMO) combined with higher frequency bands, at which larger antenna array size becomes more practical, is another key enabler for achieving peak data rates.

The 5G NR air interface has been optimized for TDD operation, because this enables accurate and timely estimation of channel conditions, which is an essential factor in realising the full benefits of smart beamforming. TDD operation makes use of the channel reciprocity to schedule downlink transmissions using uplink sounding reference signals. The flexible uplink/downlink configuration within a slot means that the network can adapt resource assignment and antenna configuration quickly to provide optimal services.

By using antennas intelligently, both network capacity and coverage can be vastly improved. For example, spatial multiplexing exploits multiple channel paths and treats these paths as different channels so that multiple streams of data can be transmitted simultaneously using the same radio resource. To achieve high spectral efficiency, multiple data streams can be sent to multiple users simultaneously using the multi-user MIMO (MU-MIMO) configuration, or multi-layer data streams can be sent to a single user in the single-user MIMO (SU-MIMO) configuration to meet the required peak data rate for broadband applications. On the other hand, beamforming can be used to achieve spatial selectivity, ie, signals to antenna elements are processed so that signals from antenna elements are combined constructively at a particular receiving angle. The smart beamforming configuration can be used to extend the coverage area and achieve the required antenna gain in a desirable direction while minimizing interference from/to other cells and users. By enhancing cell-edge throughput via beamforming, 5G is able to provide a more uniform mobile broadband user experience and also enable 4G cell sites to be reused for 5G services at higher frequency bands for system operators.

Conclusion

The performance requirements from 5G services are extremely diverse and stringent. Compared to earlier generations of cellular systems, more KPIs are required to characterise the capability of the 5G system. The initial release of the 5G specifications targets three main service areas: eMMB, uRLLC and mMTC. These services will enable mobile communication technologies to penetrate into broader industries and fields. A set of new enabling technologies introduced via the NR interface provide the foundation for 5G systems to achieve the diverse performance requirements in an effective manner.

Reference

[1]. Recommendation ITU-R M.2083: IMT Vision - "Framework and overall objectives of the future development of IMT for 2020 and beyond" (September 2015).

[2]. 3GPP TS 38.913 “Study on Scenarios and Requirements for Next Generation Access Technologies”

[3]. 3GPP TS 22.261 “Service requirements for the 5G system”

[4]. 3GPP TS 38.211 “NR; Physical Channels and Modulation”

[5]. 3GPP TS 38.104 “NR; Base Station (BS) radio transmission and reception”

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MAC Ltd has an established track record of successfully designing products and sub-systems for wireless communications applications. Its development skills are focussed on the application of digital signal processing to wireless physical layer designs, but this encompasses the full range of product development activities from requirements capture, through architectural design, algorithm development and simulation, board layout, software development, regression testing, EMC compliance testing, documentation and training.

In addition MAC Ltd uses its radio knowledge and expertise combined with analysis, modelling and simulation know how to support its customers with the evaluation of competing or emerging technologies (including assessments of the intellectual property contained therein), and applies the same proven techniques to solve all manner of technical issues encountered by customers who design, deploy, operate and use all types of public and private radio communications systems.