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ELECTRONICS

ANALYSIS OF CHARACTERISTICS AND REQUIREMENTS FOR 5G MOBILE COMMUNICATION SYSTEMS

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One of the main objectives of the fifth generation (5G) mobile communication systems, also known as IMT-2020, is to increase the current data rates up to several gigabits per second (Gbit/s) or even up to 10 Gbit/s and higher. One of the possibilities to consider is the use of higher frequencies in order to enlarge the available bandwidth. Wider bandwidth is necessary to achieve much higher data rates. It should be noted that wireless broadband transmission technologies require frequencies for their development.

The main goal of the research is to investigate the characteristics and requirements of 5G mobile communication systems. The paper provides an insight into deployment scenario and radio wave propagation in frequencies above 24 GHz of IMT-2020.

Keywords: *4G mobile communication, 5G, IMT, mobile service, M2M, radio wave propagation, WRC-19*

1. INTRODUCTION

Mobile broadband traffic is ever increasing, driven by consumer demand for mobile data, improved performance and quality of mobile networks, new technologies, devices, applications and services that introduce advanced ways of usage of mobile service frequencies [1]. In the present paper, the authors investigate the characteristics and requirements of 5G mobile communication systems, also known as IMT-2020. The paper provides an overview of possible architecture, deployment scenario and radio wave propagation in frequencies above 24 GHz.

The paper is organised as follows. The second chapter is devoted to the mobile spectrum estimation for terrestrial International Mobile Telecommunications (IMT).

The third chapter describes the main characteristics and requirements of IMT-2020. The fourth chapter is dedicated to the possible architecture and deployment scenario of IMT-2020. The fifth chapter is devoted to the radio wave propagation in frequencies above 24 GHz. In the last chapter conclusions are drawn.

2. MOBILE SPECTRUM ESTIMATE FOR IMT

It can be estimated that more spectrum resources will be necessary for the future mobile broadband communication systems to support an increasing demand for mobile data traffic. The Report ITU-R M.2290-0 [2] procures a global perspective on the future spectrum requirement approximation for terrestrial IMT in the year 2020. The total predicted spectrum demand for both low and high user density scenarios was calculated to be 1340 MHz and 1960 MHz, respectively, (embracing the spectrum already in use, or planned to be used) at least by the year 2020. The national spectrum demand in some countries can be lower than the estimate derived by lower user density settings and in some other countries national spectrum demand can be higher than the estimate derived by higher user density scenarios. Further estimates [3] expect that global IMT traffic will grow in the range of 10 to 100 times from 2020 to 2030.

To satisfy an increasing demand on mobile data traffic, especially in dense populated areas, it is necessary to develop and introduce next generation of broadband communication technologies – 5G. One of the main goals of 5G technology implementation is to increase the current data rates up to several gigabits per second (Gbit/s) or even more than 10 Gbit/s in hotspot areas. One possibility to conceive is the usage of higher frequencies in order to enlarge the available bandwidth, e.g., to get more than 500 MHz wide frequency blocks [4], which are necessary to achieve such data rate.

Within the framework of WRC-19 agenda item 1.13, in conformity with Resolution COM6/20 (WRC-15), it is planned to conceive identification of frequencies for the prospective development of IMT, including possible additional allocations to the mobile service on a primary basis [5].

3. CHARACTERISTICS AND REQUIREMENTS OF IMT-2020

A. Capabilities of IMT-2020

Goals of future 5G capability development described in Recommendation ITU-R M.2083-0 are summarised in Table 1, where the eight key capability parameters of IMT-2020 are seen [3]. Performance requirements of 5G have to be met but at the same time their execution depends on the usage scenario. The mission-critical communication demands very low latency of a few milliseconds (*ms*), though in this case the needed peak data rate may be much lower than 10–20 Gbit/s.

IMT-2020 will also conceive the Internet of Things (IoT) and M2M by connecting a wide range of smart appliances, machines and other objects without human intervention, in addition to the conventional human-to-human or human-to-machine communication.

Table 1

Capabilities of IMT-2020

Parameter	Key values for 5G
Peak data rate: maximum accomplishable data rate under ideal conditions per user/device (in Gbit/s)	10–20 Gbit/s
User experienced data rate: accomplishable data rate that is available ubiquitously in the coverage area to a mobile user/device (in Mbit/s or Gbit/s)	100 Mbit/s (for wide area coverage, e.g., in urban and sub-urban areas) and 1 Gbit/s (in hotspot cases, e.g., indoor)
Latency: the time contribution of the radio network from when the source sends a packet to when the destination receives it (in ms)	1 ms
Mobility: maximum speed at which a defined quality of service (QoS) and seamless transfer between radio nodes which may belong to different layers and/or radio access technologies can be accomplished (in km/h)	500 km/h (e.g. for high speed trains)
Connection density: total number of connected and/or accessible devices per area unit (per km^2)	10^6 devices/km^2
Energy efficiency: energy efficiency has two prospects: on the network side, energy efficiency refers to the quantity of information bits transmitted to/ received from users, per unit of energy consumption of the radio access network (in bit/Joule); on the device side, energy efficiency refers to quantity of information bits per unit of energy consumption of the communication module (in bit/Joule)	100x greater than IMT-Advanced
Spectrum efficiency: average data throughput per spectrum unit resource and per cell (bit/s/Hz)	3x greater than IMT-Advanced
Area traffic capacity: total traffic throughput served per geographic area (in Mbit/s/m^2)	10 Mbit/s/m^2

Based on the chosen use case or scenario, the importance of certain key capabilities may be significantly different, but generally all key capabilities may, to some extent, be important for most use cases. The relevance of each key capability for massive machine type communication, ultra-reliable and low latency communication, and enhanced mobile broadband usage scenarios is shown in Fig. 1 [3].

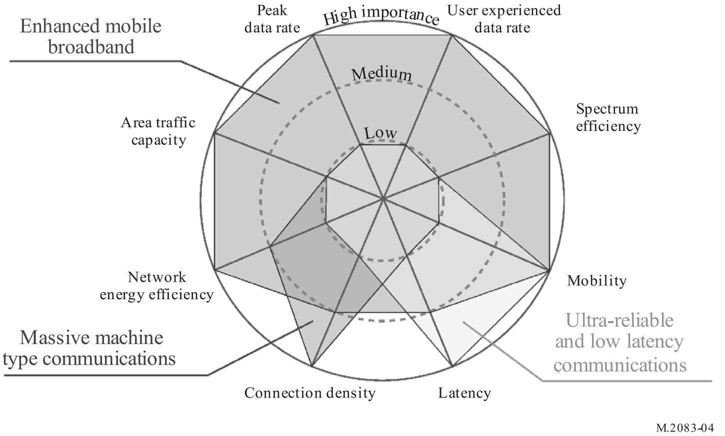

Fig.1. The relevance of key capabilities in different usage scenarios.

As a wide range of 5G requirements are defined, the single radio access configuration would not be enough to support different applications and deployment scenarios. For 5G it is planned to integrate various Radio Access Technologies (RATs) in a single system. In that way enabling a combination and cooperation of different RATs – some already existing (IEEE 802.11p etc.) and others will be designed (future releases of LTE etc.) [6].

B. Timescale for IMT-2020

To support IMT-2020 fluent development, the ITU is planning to complete work on standardisation of IMT-2020 no later than in 2020. The relevant timescale is depicted in Fig. 2 [3]. The European Commission also presented an Action Plan, mentioning plans for commercial 5G launch in 2020 and plans for joint work with industry and the Member States to identify and allocate spectrum for 5G, and organise pan-European 5G trials in 2018 [7]. It is important to specify the exact time when the standards are completed and when deployment may start, when discussing the timelines for IMT-2020.

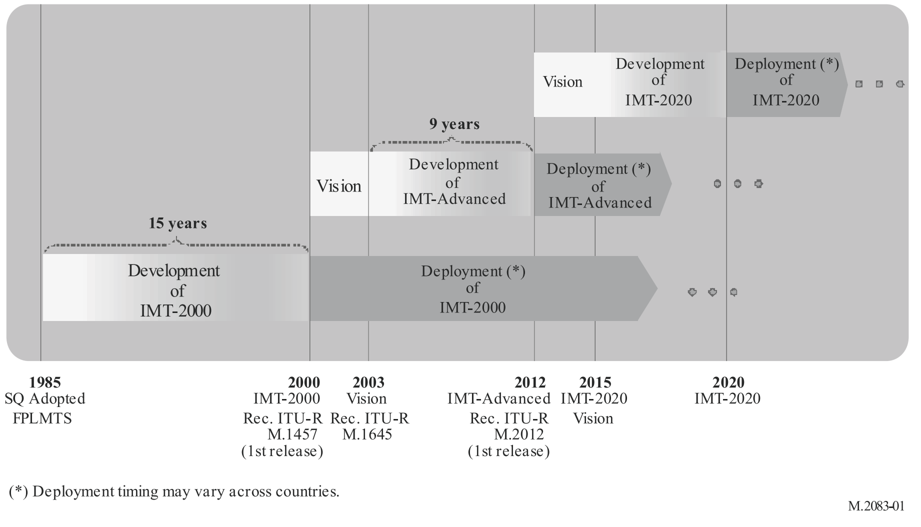

Fig. 2. Overview of timescale for IMT development and deployment.

In the authors' opinion, the 5G signal waveform could be improved, as a result, reducing the unwanted emissions, improving the coexistence in adjacent bands or channels and minimising the requirement for guard bands.

4. ARCHITECTURE AND DEPLOYMENT SCENARIO

According to Ericsson paper [8], LTE will explicate in a way of providing coverage for mobile users. 5G networks will comprise LTE access based on Orthogonal Frequency Division Multiplexing (OFDM) along with new radio interfaces using possibly new techniques, e.g., Filter Bank Multicarrier Transmission technique (FBMC).

A. Architecture of IMT-2020

Deployment architecture of IMT-2020 can be classified into two architecture types: standalone or overlay. The standalone architecture pertains to the network deployment consisting of millimeter wave (mmWave) small cells. The overlay architecture pertains to the network deployment of millimeter wave small cells developed on top of the existing macro networks. In overlay architecture case, the macro cell layer of the existing 4G mobile communication serves mainly for providing coverage, whereas the millimeter wave small cell layer should be used to provide capacity [4].

For mmWave small cells developed using cellular technologies, the typical range is expected to be around 10 m to 200 m under Non-Line-of-Sight (NLoS) circumstances, which is a lot shorter than the range of a cellular macro cell that can be several kilometres wide. Small cells can be deployed both indoors (e.g., femto cells) and outdoors. When deployed outdoors, mmWave small cells are typically deployed at a lower antenna height than a macro cell (on street lamp posts etc.) and with lower transmit power to cover a targeted area. Three categories of mmWave small cell deployment scenarios can be identified: indoor, hotspot, and outdoor [4].

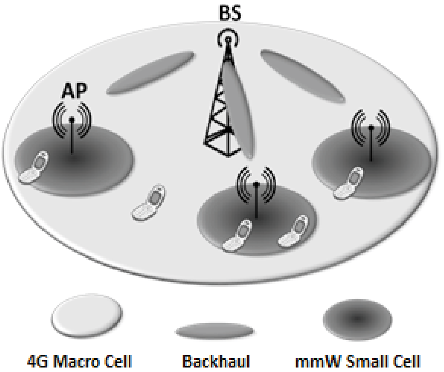

Fig. 3. System architecture proposed for 5G.

The possible system architecture intended for 5G is presented in Fig. 3 [4]. It relies on macro cellular base stations, which provide wide area coverage to mobile users using the existing RATs (e.g., LTE, UMTS) and their enhancements below 6 GHz. The reference system architecture introduces millimeter wave small cells that enable much higher throughput and traffic capacity to low mobility users employing millimeter wave radio access in the frequency bands above 24 GHz.

B. Channel Bandwidth

Maximum capacity of a radio channel for single-input single-output (SISO) scenario can be described by Shannon-Hartley formula. This equation relates the maximum capacity (transmission bit rate) that can be achieved over a given channel to certain noise characteristics and bandwidth. For an *additive white Gaussian noise* of power N the maximum capacity can be calculated by

$$C = B \cdot \log_2\left(1 + \frac{S}{N}\right), \tag{1}$$

where C – the maximum capacity of the channel (bits/s) otherwise known as *Shannon's capacity limit for the given channel*; B – the bandwidth of the channel (Hz);
S – the signal power (W); N – the noise power (W). The ratio S/N is named *Signal to Noise Ratio* (SNR) [9].

It can be recognised that the maximum transmission rate, at which the information can be transmitted without any error, is limited by the bandwidth, the signal level, and the noise level. As the bandwidth *B* tends to infinity, noise power also increases with the increase in bandwidth that is why the channel capacity does not become infinite.

Therefore, the authors assume that bandwidth directly affects channel throughput. For example, in LTE systems different channel bandwidths have a different number of resource blocks (*RB*) used for data transmission, some part of a channel bandwidth is also used for guard bands. It can be concluded that the wider available bandwidth, the higher channel throughput.

One of the benefits of higher frequency adaptation for mobile communications is system capability to implement wide channels. For Frequency Division Duplex (FDD) implementation, a duplex filter is needed. The current development has achieved maximum size of duplex filter to be around 3–4 % of the centre frequency of the frequency band. For better understanding, an example can be given. If the centre frequency is 12.5 GHz, a duplex filter for channel bandwidth of 500 MHz can be used. To cover bandwidth of one 1120 MHz channel or two 500 MHz channels, a duplex filter at 28 GHz can be chosen. In case the centre frequency (*Fc*) × 0.03~0.04 is smaller than the necessary channel bandwidth for specific data rate provision, carrier aggregation is needed to achieve the data rate as shown in Fig. 4 and Fig. 5 [4].

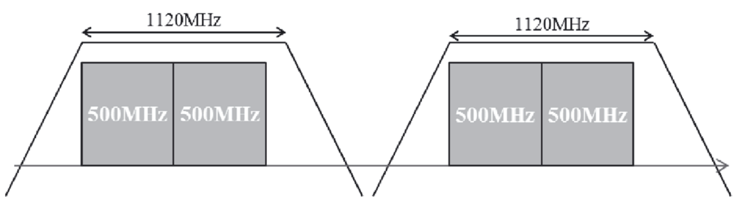

Fig. 4. The number of duplex filters to cover bandwidth to meet the needed data rate in 28 GHz band.

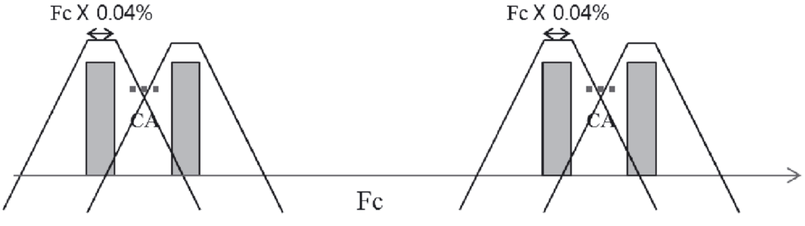

Fig. 5. The number of duplex filters to cover bandwidth to meet the required data rate. F_c where F_c x 0.03~0.04 is less than channel bandwidth to meet the needed data rate.

In the authors' opinion, to achieve objectives set for future IMT-2020 systems, it is necessary to provide contiguous, broad and harmonised frequency bands, which will minimize 5G device complexity and possible interference issues.

5. RADIO WAVE PROPAGATION IN FREQUENCIES ABOVE 24 GHZ

A. Propagation Losses

For outdoor access mobile communications in frequencies above 24 GHz, one of the expected challenges to overcome will be difficulties in propagation conditions. The most evident obstacle is the high path loss of the bands above 24 GHz compared to frequency bands below 6 GHz for traditional cellular use. The Free-Space path loss (Recommendation ITU-R P.525) [10] provides the expected loss (dB) that can be calculated by

$$L_p = 92.4 + 20 \cdot \log f + 20 \cdot \log d, \tag{2}$$

where d – distance between a transmitter and a receiver (km); f – frequency (GHz).

An example can be provided to describe one of the difficulties following higher path loss. In the frequency range from 2 GHz to 28 GHz and 70 GHz additional losses of 22.9 dB and 30.9 dB, respectively, can be anticipated to occur. To compensate these losses, additional means should be taken. For example, one possible way to compensate these losses is to use larger antenna array sizes with higher antenna power gain that uses Multiple-Input Multiple-Output (MIMO) technologies [4].

B. Atmospheric Losses

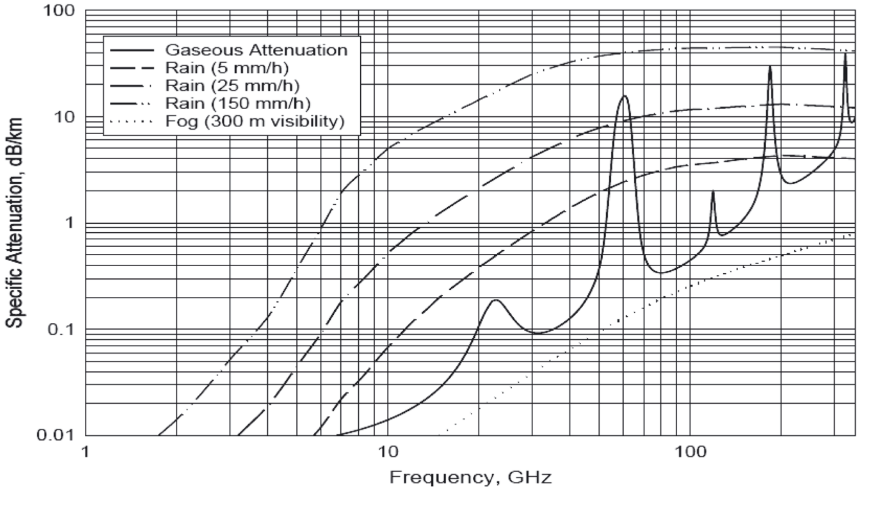

Fig. 6. Atmospheric attenuation versus frequency.

Environmental effects, e.g., gaseous (oxygen and water vapour) absorption, rain loss and foliage loss introduce some other challenges to overcome. Only in rare cases path losses that are caused by snow or fog are significant, in most cases they are only minor challenges. According to ITU-R Recommendation P.837 [11], gas loss is ubiquitous, and as for the rain attenuation, it only occurs for a short period of time. Frequencies that are represented by the peaks in Fig. 6 [4] are the ones most sensible to molecular oxygen and water vapour losses, and following these frequencies should be used where influence of atmospheric attenuation is not significant, e.g., for small cells for indoor usage. In these peak frequency ranges, the reach of interfering signals is also limited by connatural atmospheric loss, allowing for more frequent reuse of carrier frequencies.

C. Antenna Technology

Designing antennas that can operate well enough in distant frequencies at the same time, e.g., both at 700 MHz and 60 GHz is a difficult task; therefore, most likely two separate antennas, each operating at the specific frequency band, will be required. The wavelengths above 24 GHz provide a possibility to put more antenna elements in the restricted area. The antenna technology with the increased number of particular antenna elements can be used to provide high beamforming gain; thus, the incremented path loss of above 24 GHz frequency bands can be mitigated by beamforming techniques with exact pointing direction. The phased array beamforming is used to raise the received signal power by using beamforming gain. Applying narrower beams, greater antenna gains may be achieved [4].

Noticeable advantage of millimeter wave systems above 24 GHz is small size of required antennas, which can be arranged in comparatively small footprint phased arrays for high directivity and beam steering. For 5G communication systems, massive MIMO solutions would be used to compensate additional propagation loss in higher frequencies [12]. Array antennas should be integrated in the terminals or user equipment. In this case, it should be possible since the transmission wavelengths would become smaller. The millimeter wave small cell deployment with much wider bandwidth accessible can provide higher data throughput than the existing macro cell networks.

6. CONCLUSIONS

In the paper, the authors have investigated characteristics and requirements of 5G mobile communication systems. An insight into 5G system deployment architecture and scenario, radio wave propagation in frequencies above 24 GHz of IMT-2020 has also been provided in the paper.

The analysis shows that one of the ways of future IMT-2020 development would be the usage of overlay network architecture, when use of low frequencies below 6 GHz and high frequencies above 24 GHz is coordinated in a complementary manner. In this case, macro cells operating in frequency bands below 6 GHz provide baseline coverage, and capacity improvements are ensured by additional network elements that are to be developed, operating in higher frequency bands above 24 GHz.

The results of the present study have shown that implementation of high frequency bands, even above 24 GHz, remains necessary to ensure that all the performance targets of 5G, e.g., multigigabit per second data rates, are met. Frequencies below 6 GHz are very valuable, especially frequencies below 1 GHz due to their optimal radio wave propagation. IMT technologies produced for deployment in frequency bands above 24 GHz would be rational to use mainly in dense urban environments enabling provision of high data rate services. In the authors' opinion, for the deliberative development of IMT systems it is necessary to timely provide wide and contiguous spectrum resources for implementation of new technologies and services.

The results obtained within the framework of the research can be used by National Regulatory Authorities (NRAs), equipment manufacturers, mobile operators, researchers and other interested parties when planning 4G and 5G mobile services.

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5G MOBILO SAKARU SISTĒMU PRASĪBU UN RAKSTURĪGO PARAMETRU ANALĪZE

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K o p s a v i l k u m s

Viens no piektās paaudzes (5G) mobilo sakaru sistēmu, zināmu arī kā IMT-2020, galvenajiem mērķiem ir palielināt datu pārraides ātrumus līdz vairākiem gigabitiem sekundē (Gbit/s) un pat virs 10 Gbit/s. Lielākus datu pārraides ātrumus var sasniegt, izmantojot radiokanālus ar lielāku frekvenču joslas platumu. Nākamās paaudzes mobilo sakaru sistēmu izmantošana ar platākiem radiokanāliem iespējama augstākās frekvenču joslās. Platjoslas bezvadu pārraides sistēmu attīstībai ir nepieciešami papildu radiofrekvenču spektra resursi.

Pētījuma mērķis ir apskatīt IMT-2020 sistēmu galvenās prasības un to raksturīgākos parametrus. Rakstā apskatīts arī IMT-2020 sistēmu iespējamais izmantošanas scenārijs, kā arī analizēta radioviļņu izplatīšanās virs 24 GHz.

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