Chapter 3

Spectrum Usage for 5G Mobile Communication Systems and Electromagnetic Compatibility with Existent Technologies

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Additional information is available at the end of the chapter

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Abstract

The increased demand of consumers on services in the mobile broadband environment with high data rate and developed mobile broadband communication systems will require more spectrum to be available in the future. New technologies as well as the existing services require frequencies for their development. In this chapter, we investigate the available and potential future mobile terrestrial radio frequency bands (5G)—worldwide and in Europe. An insight into the mobile spectrum estimate is provided. Characteristics and requirements of IMT-2020, future possible IMT frequency bands, and examples of 5G usage scenarios are also addressed in the chapter. Electromagnetic compatibility evaluation methods are provided mainly focusing on existent mobile technologies below 1 GHz where also 5G technologies will be developed in the future. It is stressed that the radio frequency spectrum is a limited national resource that will become increasingly precious in the future.

Keywords: 4G mobile communication, 5G, electromagnetic compatibility, frequency band, international mobile telecommunications (IMT), IoT, international telecommunication union (ITU), M2M, mobile service, radio wave propagation, spectrum planning, WRC-19

1. Introduction

5G referred to as IMT-2020 in ITU-R terms is the next generation of mobile communication technologies. IMT systems are now being evolved to provide diverse usage scenarios and applications such as enhanced mobile broadband (eMBB) communication, massive machine-type communication (mMTC), and ultrareliable and low-latency communication (URLLC) requiring larger contiguous blocks of spectrum than currently available bandwidth to realize those applications.

5G aims to provide high data rates, low latency, seamless coverage, low power, and highly reliable communications. Used cases under consideration include enhanced mobile broadband communications, but also machine-to-machine (M2M), Internet of Things (IoT), home and industrial automation and applications, etc. expected to respond to requirements from vertical sectors (e.g., utilities, automotive, railways, public protection). 5G is planned to be deployed around the world by 2020.

The potential usage scenarios shown in **Figure 1** have different operational and technological requirements.

Different players from various verticals, i.e., different industries, can be brought together using the 5G concept. The network capabilities are intended to match the requirements of the different vertical players.

The first 5G specification in 3GPP Release 15 is planned to be available by the end of 2018 and will address the more pressing commercial needs. The second release, 3GPP Release 16, planned for March 2020, will address all used cases and requirements. There is an ongoing work on development of new radio access technology targeted for completion by the end of 2017.

3GPP has been working to standardize the 5G-NR (New Radio) specification. In March 2017, 3GPP decided to accelerate the timescale in order to finalize the *non-stand-alone* mode by March 2018. This mode will operate in parallel with 4G long-term evolution (LTE) to provide boosted data rates. The *stand-alone* 5G mode is planned for completion in September 2018. This accelerated timescale will facilitate 5G network trials in the early 2018.

In general, 5G technologies will describe the following characteristics: high-frequency operation, very wide bandwidth, massive beam forming, and interworking with LTE. ITU will complete its work for standardization of IMT-2020 no later than the year 2020 [2].

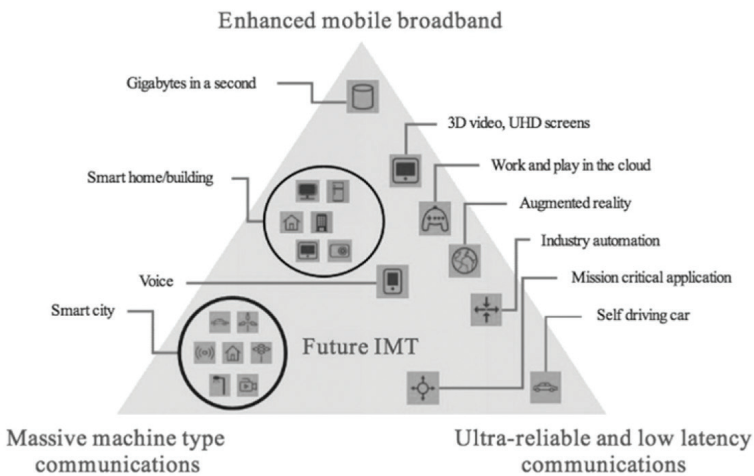

Figure 1. 5G usage scenarios according to ITU-R Recommendation M.2083-0 [1].

From a spectrum management's point of view, one of the main innovations brought by 5G is its capacity not only to handle broadband mobile communications as in the previous generations but also to cover the needs from a range of sectors, the so-called "verticals."

2. Mobile spectrum estimate for terrestrial IMT

The ITU terms for 3G and 4G are IMT-2000 and IMT-Advanced accordingly. The term IMT-2020 is adopted for 5G. Collectively, they are known as IMT [3]. IMT systems have contributed to global economic and social development.

With the mobile data traffic, increasing more spectrum resources will be necessary for the future mobile broadband communication systems. The Report ITU-R M.2290-0 provides a global perspective on spectrum requirement estimate for terrestrial IMT in the year 2020. The predicted total spectrum requirement for both low and high user density scenarios was calculated to be 1340 and 1960 MHz (including the spectrum already in use or planned to be used) at least by the year 2020 [4]. In some countries, national spectrum requirement can be lower than the estimate derived by lower user density settings, and in some other countries, national spectrum requirement can be higher than the estimate derived by higher user density settings. The mobile traffic forecast is presented in **Figure 2**.

It is assumed that for the year 2020, the median traffic growth will fall in between the lowest and highest growths, anticipating at least 25-fold traffic growth ratio in 2020 compared to 2010. Other estimates [1] anticipate that global IMT traffic will grow in the range of 10–100 times from 2020 to 2030.

An option for increasing data rates is the development of small cells and the combination of the capacity of unlicensed bands (e.g., 2.4 GHz, 5 GHz) with the capacity of a licensed

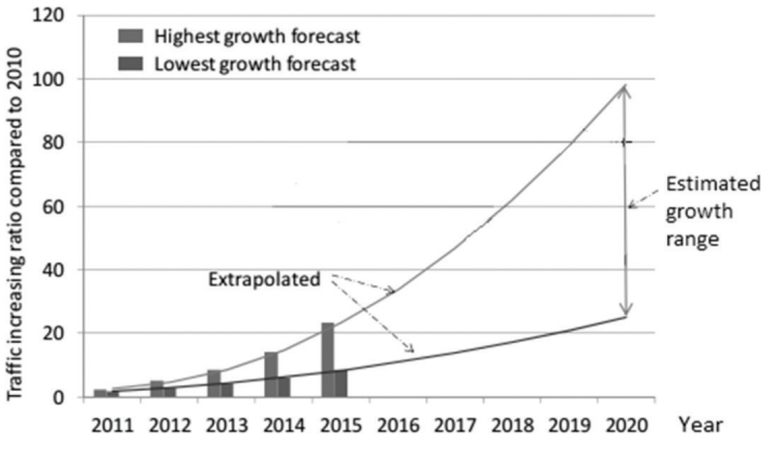

Figure 2. Mobile traffic forecasts toward 2020 by extrapolation according to the Report ITU-R M.2290-0.

frequency block [5]. Another option is carrier aggregation, which enables to increase data rates, but its complexity is exponential with the number of possible combinations of frequency bands used; spectrum sharing is also possible as a solution.

Another option is to develop and introduce the next generation of broadband communication technologies (5G) [6]. Authors presume that 5G base stations in the future will be connected by fiber optical lines or microwave backhaul links as an alternative solution. Huge investment in fiber is needed in order to realize the 5G vision.

3. Characteristics and requirements of IMT-2020

According to the Ericsson paper [7], LTE will evolve in a way that recognizes its role in providing ubiquitous wide area coverage for mobile users, and 5G networks will incorporate LTE radio access, based on orthogonal frequency division multiplexing (OFDM), along with new air interfaces.

Millimeter wave cells are very small, and they could be deployed mainly in dense urban areas or indoors delivering greater capacity. In the long term, it is expected that all devices that benefit from network connectivity eventually will become connected through M2M communications in the future.

According to Recommendation ITU-R M.2083-0, goals of future development of 5G capabilities are summarized in **Table 1**, which include IMT-2020 capability eight key parameters [1].

Performance requirements must be met but at the same time depend particularly on the used cases or scenario. The key capabilities of IMT-2020 are presented in **Figure 3** compared with those of IMT-Advanced.

In the enhanced mobile broadband scenario, peak data rate, user-experienced data rate, area traffic capacity, mobility, energy efficiency, and spectrum efficiency all have high importance in comparison to connection density and latency.

Parameter	Key value for 5G
Peak data rate	10–20 Gbit/s
User-experienced data rate	100 Mbit/s (for wide area coverage, e.g., in urban and suburban areas) and 1 Gbit/s (for hotspots, e.g., indoor)
Latency	1 ms
Mobility	500 km/h (e.g., for high-speed trains)
Connection density	106 devices/km^2
Energy efficiency	100x more than IMT-Advanced
Spectrum efficiency	3x more than IMT-Advanced
Area traffic capacity	10 Mbit/s/m^2

Table 1. 5G target capabilities.

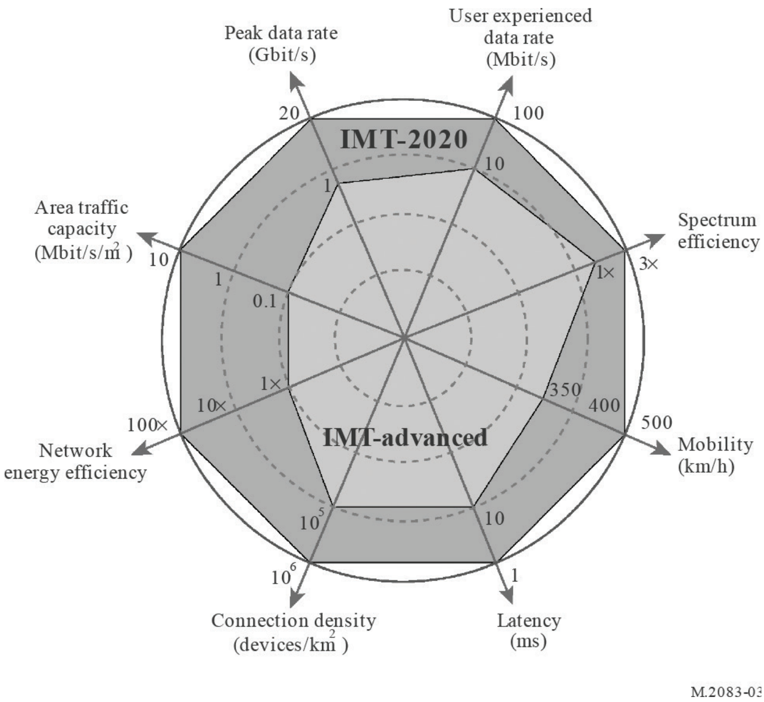

Figure 3. Enhancement of key capabilities from IMT-Advanced to IMT-2020.

In some low-latency communications and ultrareliable scenarios, low latency is of the highest importance, e.g., in order to enable the safety critical applications. Such capability would be required for some high mobility uses as well, e.g., in transportation safety, while, e.g., high data rates, might be less important.

The high connection density is needed in the massive machine-type communication scenario to support large number of devices in the network that, e.g., may transmit only occasionally at low bit rate and with zero or very low mobility. A low-cost radio device with long operational lifetime is of great significance for this usage scenario.

4. Future possible IMT frequency bands

In order to encourage increased data traffic capacity and to enable the transmission bandwidths needed to encourage very high data rates, 5G will extend the range of frequency bands used for mobile communications. This includes new radio spectrum below 6 GHz, as well as spectrum in higher frequencies.

For wireless communications, lower frequencies provide better coverage. Currently, almost all countries use spectrum below 6 GHz for IMT systems. Spectrum relevant for 5G wireless access therefore ranges from below 1 GHz up to approximately 100 GHz.

Frequency bands identified for IMT in the RR (MHz)	World Radiocommunication Conference (WRC)	Licensed mobile frequency bands in CEPT countries (MHz)
450–470	WRC-07	450–457.5 / 460–467.5
470–608	WRC-15	—
614–698	WRC-15	—
694–960	WRC-2000, WRC-07, WRC-12	694–790
		790–862
		880–915 / 925–960
1427–1518	WRC-15	1427–1518
1710–2025	WARC-92, WRC-2000	1710–1785 / 1805–1880
		1900–1920
		1920–1980 / 2110–2170
		2010–2025
2110–2200	WARC-92	1920–1980 / 2110–2170
2300–2400	WRC-07	2300–2400
2500–2690	WRC-2000	2500–2690
3300–3400	WRC-15	—
3400–3600	WRC-07	3400–3600
3600–3700	WRC-15	3600–3800
4800–4990	WRC-15	—

Table 2. Spectrum already identified for IMT.

High frequencies, e.g., those above 10 GHz, can only serve as a complement to lower frequencies and will mainly provide additional system capacity with very wide transmission bandwidths for extreme data rates for dense deployments. Spectrum use at lower-frequency bands will remain the backbone for mobile radio communication networks in the 5G era, providing excellent ubiquitous wide area connectivity.

4.1. Spectrum below 6 GHz

Besides achieving high data rates, it is also necessary to guarantee wide area coverage and outdoor to indoor coverage in 5G. Therefore, spectrum below 6 GHz forms a very important part of the 5G spectrum solution. Until now in Europe, more than 1200 MHz of spectrum for mobile broadband in the frequency range from 694 to 3800 MHz was harmonized.

For providing ubiquitous coverage in next-generation (5G) or pre-5G networks, the important role will be of LTE (4G) bands already harmonized below 1 GHz, including particularly the 700 and 800 MHz band, in order to enable nationwide and indoor 5G coverage. The 450 MHz band, which harmonized conditions for LTE use in the band currently is under development in the European Conference of Postal and Telecommunications Administrations

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Frequencies to be studied until WRC-19 for possible identification to IMT (GHz)	Primary allocations to radiocommunication services in RR in ITU regions (including WRC-15 results)	Comments
24.25–27.5	Earth exploration-satellite (space-to Earth), fixed, fixed-satellite (Earth-to-space), inter-satellite, mobile, radionavigation, space research (space-to-Earth)	Frequencies have already allocation to the mobile service on a primary basis in RR
37–40.5	Earth exploration-satellite (Earth-to-space), fixed, fixed-satellite (space-to-Earth), mobile, mobile except aeronautical mobile, mobile-satellite (space-to-Earth), space research (Earth-to-space), space research (space-to-Earth)	
42.5–43.5	Fixed, fixed-satellite (Earth-to-space), mobile except aeronautical mobile, radio astronomy	
45.5–47	Mobile, mobile-satellite, radionavigation, radionavigation-satellite	
47.2–50.2	Fixed, fixed-satellite (Earth-to-space), fixed-satellite (space-to-Earth), mobile	
50.4–52.6	Fixed, fixed-satellite (Earth-to-space), mobile	
66–76	Broadcasting, broadcasting-satellite, fixed, fixed-satellite (space-to-Earth), inter-satellite, mobile, mobile-satellite (space-to-Earth), radionavigation, radionavigation-satellite	
81–86	Fixed, fixed-satellite (Earth-to-space), mobile, mobile-satellite (Earth-to-space), radio astronomy	
31.8–33.4	Fixed, inter-satellite, radionavigation, space research (deep space) (space-to-Earth)	Frequencies may require additional allocation to the mobile service on a primary basis in RR
40.5–42.5	Broadcasting, broadcasting-satellite, fixed, fixed-satellite (space-to-Earth)	
47–47.2	Amateur, amateur-satellite	

Table 3. Possible new spectrum for IMT in frequencies above 24 GHz.

(CEPT), in author’s opinion will also play a significant role for enabling wide coverage for services of next-generation mobile networks in Europe. Frequency bands currently identified for IMT in the ITU Radio Regulations (RR) are presented in **Table 2**.

The *priority* frequency band suitable for the introduction of 5G use in Europe even before 2020 with wide channel bandwidths (50–100 MHz and more) could be 3400–3800 MHz band, noting that this band is already harmonized for mobile networks in Europe. This frequency band has the ability to put Europe at the forefront of the 5G or *pre*-5G deployment.

4.2. Spectrum above 6 GHz

5G envisages very high data rates, which will need much larger bandwidths than ever before. Those very high data rates may only be found in higher frequency bands (above 6 GHz). To deliver higher data rates and lower latency, there is an expectation that new wireless solutions at higher frequencies—millimeter wave (*mmWave*) bands—will be deployed. Therefore, implementation of frequency bands even above 24 GHz remains needed to ensure all the performance targets of 5G, e.g., multi-gigabit per second data rates. Implications of very low-latency drive to millimeter wave deployments with their highly directive antennas and small cell sizes.

The 2015 World Radiocommunication Conference (WRC-15) decided the following frequency bands 24.25–27.5 GHz, 31.8–33.4 GHz, 37–43.5 GHz, 45.5–50.2 GHz, 50.4–52.6 GHz, 66–76 GHz, and 81–86 GHz as presented in **Table 3** to study for possible identification to IMT (aimed for 5G) at WRC-19.

Europe identified 26 GHz as a *pioneer* frequency band for early European harmonization, as it provides over 3 GHz of contiguous spectrum and has the greatest potential to be a globally harmonized band.

The 31.8–33.4 GHz (referred to as 32 GHz) and 40.5–43.5 GHz (referred to as 40 GHz) bands were also identified as priority bands for study in the CEPT.

5. Examples of 5G usage scenarios

According to the recent ITU theoretical assessment, simulations, measurements, technology development, and prototyping described in the Report ITU-R M.2376-0, utilization of bands between 6 and 100 GHz is feasible for studied IMT deployment scenarios and could be considered for the development of IMT for 2020 and beyond [6].

It is expected that LTE will develop in a way of providing wide area coverage for mobile users. 5G networks will include LTE access based on OFDM along with new radio interfaces using possibly new techniques, e.g., filter bank multicarrier (FBMC) transmission technique.

5.1. IMT-2020 architecture

Deployment architecture of IMT-2020 can be classified into two architecture types: *stand-alone* or *overlay*. The stand-alone architecture refers to the network deployment consisting of millimeter wave (*mmWave*) small cells. The overlay architecture refers to the network deployment of mmWave small cells developed on top of the existing macro-cell networks (LTE, etc.). In overlay architecture case, the macro-cell layer of the existing 4G mobile communication serves mainly for providing coverage, whereas the mmWave small cell layer should be used to provide capacity [6] as shown in **Figure 4**.

For mmWave small cells explicated using cellular technologies, the typical service range is expected to be around 10 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 provide several kilometers. The 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, on building walls, in parks, etc.) and with lower transmit power to cover a targeted area. For mmWave small cell deployment, scenarios can be identified three categories: indoor, hotspot, and outdoor [6].

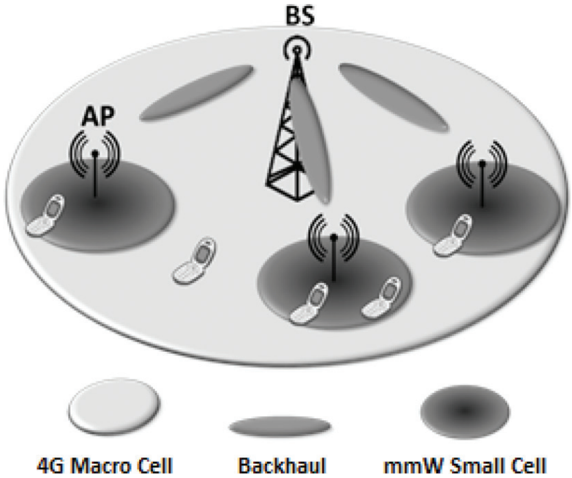

Figure 4. System deployment architecture proposed for 5G.

5.2. Channel bandwidth

For single-input/single-output (SISO) scenario, the maximum capacity of a radio channel can be described by Shannon-Hartley formula. This formula 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 the N, the maximum capacity can be calculated by

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

where C is the maximum capacity of the channel (bits(s)) otherwise known as *Shannon's capacity limit for the given channel*, B is the bandwidth of the channel (Hz), S is the signal power (W), and N is the noise power (W). The ratio S/N is named *signal-to-noise ratio* (SNR) [8].

It can be perceived that the maximum transmission data rate, at which the information can be transmitted without any error, is limited by the bandwidth, the signal level, and the noise level. With the increase in bandwidth, the noise power also increases; that is why the channel capacity does not become infinite. By using wider channels, increasing the number of antennas, and reducing interference, it is possible to increase the capacity.

One of the benefits of higher-frequency adaptation for mobile communications is system capability to implement wide channels.

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

In the 5G era, FDD will remain the main duplex scheme for lower-frequency bands. However, for higher-frequency bands—especially above 10 GHz—targeting very dense deployments, TDD will play a more important role.

In author's opinion, 5G wireless access may be realized by the improved LTE systems for existing spectrum in combination with new radio access technologies that primarily target new spectrum [2].

5.3. Antenna technology

Antennas that can operate well enough in distant frequencies at the same time, e.g., at between 450 MHz, 700 MHz, and 26 GHz, are 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. 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. Greater antenna gains may be achieved applying narrower beams [4].

For 5G communication systems, massive MIMO (*multiple-input and multiple-output*) solutions would be used to compensate additional propagation loss in higher frequencies [2] and to minimize interference. 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.

5.4. 5G development scenarios

The 5G radio access is based on the evolution of LTE and the other one on New Radio (NR) access. In the LTE-5G, enhancements will continue to enable it to support as many 5G requirements and used cases as possible. Unlike the LTE-5G, the NR-5G is free from backward compatibility requirements and thereby able to introduce more fundamental changes, such as targeting spectrum at high (mmWave) frequencies. However, NR is being designed in a scalable manner so it could eventually be migrated to frequencies that are currently served by LTE.

The process of making LTE-5G involves a variety of enhancements and new features in 3GPP Release 14 and Release 15. The most significant ones are enhancements to user data rates and system capacity with FD MIMO (*full-dimension multiple-input multiple-output*), improved support for unlicensed operations, and latency reduction in both control and user planes. FD MIMO is a technology that arranges the signals transmitted to antennas in the form of virtual beams that are able to power multiple receivers in three dimensions. It is expected that this technology significantly will increase spectrum efficiency.

In authors' opinion, LTE along with NR-5G will continue to play a major role in mobile communications for many years to come.

6. Electromagnetic compatibility studies with existent technologies

The 2019 World Radiocommunication Conference (WRC-19) will take place over 4 weeks, from 28 October to 22 November 2019. The Conference will address a number of questions within the radiocommunication sector, and consideration of spectrum for 5G above 24 GHz is expected to feature heavily through the Resolution of WRC-19 Agenda Item 1.13.

In the framework of WRC-19 Agenda Item 1.13, identification of frequency bands 24.25–27.5 GHz, 31.8–33.4 GHz, 37–43.5 GHz, 45.5–50.2 GHz, 50.4–52.6 GHz, 66–76 GHz, and 81–86 GHz for the future development of IMT will be considered, including possible additional allocations to the mobile service on a primary basis, in accordance with Resolution 238 (WRC-15) [9].

Compatibility studies must be carried out in each frequency band, and each band must balance with the requirement of other existing services and allocations. Any identification of frequency bands for IMT should take into account the use of the bands by other services (to protect existing services) and the evolving needs of these services. WRC-19 Agenda Item 1.13 states to conduct and complete in time for WRC-19 the appropriate sharing and compatibility studies, taking into account the protection of services to which the band is allocated on a primary basis.

Spectrum sharing will be an important element to facilitate the requirements of 5G, and the development of new technological solutions in higher-frequency ranges, such as the more extensive use of MIMO technique, may provide more opportunities for sharing but also challenges for National Regulatory Authorities (NRAs).

In the future, there may be a need to adapt the harmonized regulatory framework for 5G in the existing mobile frequency bands in Europe (700 MHz, 800 MHz, 900 MHz, 1500 MHz, 1800 MHz, 2.1 GHz, 2.3 GHz, 2.6 GHz).

7. Electromagnetic compatibility evaluation methods

Congestion of the radio spectrum is growing with an ongoing rise in the demand for more wireless services. National communications regulators are faced with the challenge of identifying new frequencies for new uses while preventing interference to existing users of the spectrum.

7.1. Radio frequency interference

Interference occurs when a transmission from one system disrupts the reception of signals at the receiver of another nearby system. It can occur between systems operating on the same frequency known as co-channel interference or between systems in frequencies that are close known as adjacent channel or adjacent band interference. It is worth noting that there are also other types of interference such as intermodulation [10].

Co-channel interference is a result of the stronger interfering signal, which affects the victim signal. In adjacent channel interference, there are two main causes of interference: *unwanted emissions* and *blocking* or *receiver selectivity* as presented in **Figure 5**.

Unwanted emissions are any off-channel noise of the interfering equipment falling within the receive band of the victim receiver and thus acting as co-channel interference to the wanted signal. This sort of interference can only be removed at the source.

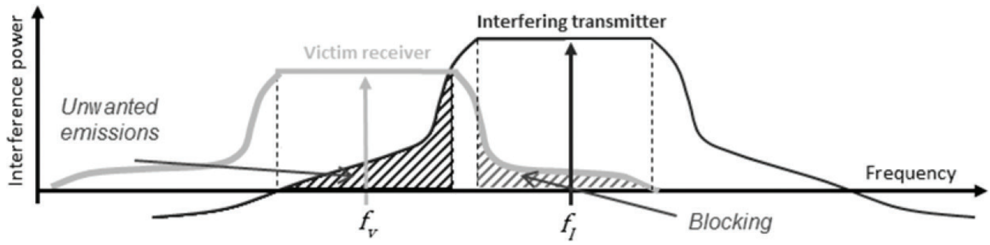

Figure 5. Causes of interference: unwanted emissions and blocking.

Blocking, i.e., a strong signal off the receive band of a victim receiver, desensitizes its reception. This sort of interference can only be removed at the victim. In most cases, adoption of power control for the interferer and efficient site engineering can improve the situation.

In practice, both of these can occur simultaneously. Sometimes, it is necessary to improve the design of both the transmitter and receiver to prevent interference, which is becoming increasingly important as the spectrum becomes more congested [10].

7.2. Interference prediction methods

Interference prediction typically is done through theoretical calculations known as sharing studies, which usually refer to in-band studies, and compatibility studies, which refer to adjacent band studies. Theoretical studies are necessary because it is not always possible to perform measurements on real systems, particularly in cases where the systems are still under development. Two types of studies are commonly used:

Deterministic studies based on fixed parameters, using the *minimum coupling loss* (MCL) method. This is a worst-case assessment of interference. The results usually determine the minimum required separation distance (in space or in frequency) between two systems to avoid interference. The MCL approach is relatively straightforward, modeling only a single interferer-victim pair. It provides a result that is spectrally inefficient.

Statistical studies based on variable parameters, using the *Monte Carlo* method. This is a more realistic assessment, which takes into account the real-world variation and randomization of certain parameters such as the relative positioning of systems. The result of a Monte Carlo simulation is a measure of system performance—it is commonly a probability of interference for the scenario under investigation, which can be compared against a relevant threshold to determine if the level of interference is considered to be a problem or not. Care must be taken when interpreting a probability of interference. A mobile system operator specifies that a system can provide a system availability of 95%. It is capable of modeling highly complex systems including LTE networks. The result is spectrally efficient but requires careful interpretation.

A mobile system operator specifies that a system can provide a system availability of 95%.

These studies can be performed using a range of software tools, for example, SEAMCAT for Monte Carlo analysis, which is an open-source software tool. In order to compare both methods, the same radiowave propagation prediction model should be adopted for all three methods.

In some cases, the assumptions used in the studies can be validated through laboratory measurements of real systems or through field measurements [10].

If the results of studies show that interference may occur, it may be necessary to investigate different mitigation techniques to minimize the risk of interference. This could include specification of additional filtering to be applied to the transmitter or receiver, additional frequency separation between both systems, and restrictions on the usage of the new system such as limits on maximum transmit power or geographical restrictions on where the new system can be used. In addition, with the emergence of new technologies, new and innovative sharing solutions are being explored, for example, techniques such as geolocation and licensed shared access (LSA).

This overall process, including the prevention of interference by quantifying the risk through studies and the cure through identifying suitable mitigation, is known as spectrum engineering [10].

Sharing studies need to have accurate input assumptions in order to produce meaningful and reliable results. Spectrum engineers are working with future technologies where not all the parameters can be defined in advance of the deployment of the new technology. Spectrum engineering results can be used to optimize frequency planning.

7.3. Protection criteria for mobile service

Different interference criteria can be used for interference assessment to the mobile service stations or other services, e.g., C/I, C/(N + I), (N + I)/N, or I/N.

The protection criterion for use in sharing and compatibility studies between IMT-Advanced and IMT-2020 and other systems and services irrespective of the number of cells and independent of the number of interferers is I/N value of −6 dB. This criterion applies to interference from a single source or to the aggregate interference from multiple sources of interference. The same protection criterion should be used for both co-channel and adjacent band studies [11, 12].

For the assessment of the interference of LTE and other services in 700 MHz band [13, 14], authors used both of these methods, namely, MCL and Monte Carlo method, and the criterion of $I/N = -6$ dB was used for interference assessment to the mobile service. In this assessment the predetermined trigger field strength values also was used. Additionally, some field measurements were also performed.

8. Conclusion

Global harmonization of IMT spectrum will be essential for developing 5G. The benefits of spectrum harmonization include facilitating economies of scale, enabling global roaming, reducing equipment design complexity, improving spectrum efficiency, and potentially reducing cross border interference. 5G mobile communication systems will require frequencies for their development and usage. Frequencies below 6 GHz are very valuable because of its optimum radio wave propagation, especially frequencies below 1 GHz. The results of the present study have shown that implementation of frequency bands even above 24 GHz remains needed to ensure all the performance targets of 5G, e.g., multigigabit per second data rates. 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.

It is important to note that the properties of higher-frequency bands, such as shorter wavelength, would better enable the use of advanced antenna systems including MIMO and beamforming techniques in supporting enhanced broadband.

The electromagnetic compatibility between LTE and different existent technologies in 700 MHz band authors was evaluated with different methods: MCL method, Monte Carlo method, and predetermined trigger field strength values; some field measurements were also done. According to results of electromagnetic evaluation, additional mitigation techniques were proposed in order to assure the compatibility between considered radio systems. Similar electromagnetic compatibility evaluation methods and approach can be also applied for IMT-2020 studies in frequencies above 24 GHz.

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

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