Mobile and wireless communications Enablers for the Twenty-twenty Information Society-II

Deliverable D3.1
5G spectrum scenarios, requirements and technical aspects for bands above 6 GHz

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Abstract

This deliverable provides a view on 5G spectrum usage scenarios, combining information from the wireless industry as well as vertical industries. Technical aspects like coexistence, performance and coverage are considered as well. The next step is to undertake detailed evaluations with regard to spectrum bandwidth demand for dedicated usage scenarios.

Executive summary

5G networks will be operated in a spectrum landscape comprising of heterogeneous spectrum usage scenarios, in order to cope with the demand for higher performance and capacity, but also higher reliability and lower latency.

Radio spectrum usage can generally be authorized in two ways: Individual Authorization (Licensed) and General Authorization (Licence Exempt / Unlicensed). Authorization modes recognized as relevant for wireless communications are *Primary user mode*, *LSA (Licensed Shared Access) mode* and *Unlicensed mode* [MET14-D53]. Furthermore, five basic spectrum usage scenarios can be identified for these authorization modes: dedicated licensed spectrum, limited spectrum pool, mutual renting, vertical sharing and unlicensed horizontal sharing [MET16-D11].

In [MET15-R31] it is demonstrated that the three basic means to increase wireless network capacity, namely access point density, spectrum efficiency and spectrum bandwidth, are exchangeable to some extent in conventional macro-cell environments. However, densification of access points becomes progressively inefficient in super-dense environments so that additional spectrum becomes the most effective solution for providing high capacity in such cases. In [MET15-R31] it is also shown that contiguous spectrum offers advantages over multiple fragmented frequency bands with regard to device complexity, signaling overhead, guard bands and interference. Therefore, additional wide contiguous frequency bands are needed to fulfill 5G capacity requirements.

WRC-15 has agreed that ITU-R will conduct sharing and compatibility studies for a number of frequency bands between 24.25 GHz and 86 GHz in time for WRC-19. Some of these frequency bands enable wide contiguous bandwidths, which would allow coping with the requirements of high bandwidth demanding applications. Although the band 27.5 – 29.5 GHz was not selected for ITU-R studies, the US and Korea have continued to progress with it for 5G which could, when combined with the band 24.25 – 27.5 GHz (which was selected at WRC-15 for ITU-R studies), provide a good solution for a global implementation of 5G systems.

5G will enable new usage scenarios for mobile networks in various vertical markets, ranging from wearable electronics to autonomous driving. However, the approach for spectrum usage for vertical markets seems to be still open to different solutions and the most important drivers seem to be market demand, time to market, and efficient spectrum use. According to a rough analysis of the vertical market's usage scenarios these are covered by METIS-I or METIS-II use cases. Thus vertical market requirements are expected to be met by the 5G system design developed in METIS-II.

Some spectrum related technical aspects are also covered in this deliverable. Concerning the opportunities for coexistence of fixed service links with 5G macro systems with beamforming capabilities, assessment results indicate that fixed service links can operate in the adjacent channels with very low impact from the 5G macro-cellular system.

Based on a simple link budget calculation, the 5G system performance is investigated for frequencies up to 100 GHz for different deployment options and environments. The assessment results indicate that the higher propagation losses with increasing carrier frequencies might be compensated to some extent provided that larger channel bandwidths are available than for lower carrier frequencies, or by implementation of advanced antenna systems. Nevertheless, for the outdoor to indoor (O2I) scenario, the more challenging radio propagation conditions impose more restrictions for the cell size. Depending on propagation conditions and equipment deployed, frequencies up to around 30 GHz are in particular suitable since all three considered stationary scenarios, i.e., O2I, non-line of sight outdoor to outdoor (O2O), and indoor to indoor (I2I), are feasible. With carrier frequencies in the range 30-60 GHz, the O2O and I2I scenarios appear to be feasible with the considered distance assumptions if advanced beamforming technologies with high antenna gain are applied. With carrier frequencies above 60 GHz, dedicated indoor services could still be still feasible, noting that at those frequencies there is also the advantage possibility of obtaining of very large contiguous channel bandwidths.

Contents

List of Abbreviations and Acronyms

3GPP	Third Generation Partnership Project
5G	Fifth Generation
5G PPP	5G Private Public Partnership
ACLR	Adjacent Channel Leakage Ratio
AGA	Air-Ground-Air
ARN	Aeronautical Radio Navigation
BB-PPDR	Broad-Band PPDR
BF	Beamforming
BPL	Building Penetration Loss
BS	Base Station
BW	Bandwidth
CDL	Clustered Delay Line
CEPT	European Conference of Postal and Telecommunications Administrations
CI-FSPL	Close-in FSPL
CMOS	Complementary Metal-Oxide-Semiconductor
CoMP	Coordinated Multi-Point
dB	Decibel
dBi	antenna gain compared to the hypothetical isotropic antenna
dBm	dB referenced to one milliwatt
DL	Down-Link
DTT	Digital Terrestrial Television
ECC	Electronic Communications Committee
EIRP	Equivalent Isotropically Radiated Power
ETRI	Electronics and Telecommunications Research Institute (of Korea)
EUTC	European Utility Telecom Council
FCC	Federal Communications Commission (in the US)
FSPL	Free-Space Propagation Loss
Gbps	Gigabit per second

GHz	Giga Hertz
GSM-R	Global System for Mobile Communications – Railway
I/N	Interference-over-Noise
I2I	Indoor to indoor
IMT	International Mobile Telecommunications
IMT-2020	IMT for year 2020 and beyond
ISD	Inter-Site Distance
ISM	Industrial, Scientific & Medical
ITS	Intelligent Transport Systems
ITU-R	International Telecommunication Union – Radiocommunication Sector
km/h	kilometer per hour
KPI	Key Performance Indicator
LoS	Line-of-Sight
LAA	Licensed-Assisted Access
LSA	Licensed Shared Access
LTE	Long-Term Evolution
M&E	Media & Entertainment
MBB	Mobile Broadband
Mbps	Megabit per second
MFCN	Mobile / Fixed Communications Networks
MHz	Mega Hertz
MIMO	Multiple Input Multiple Output
mMTC	Massive Machine-Type Communications
MNO	Mobile Network operator
MS	Mobile Station
MWC	Mobile World Congress
NF	Noise Figure
NGMN	Next Generation Mobile Networks (Alliance)
NLoS	Non-Line-of-Sight
nm	Nanometer

NPRM	Notice of Proposed Rulemaking
NR	New Radio (used in 3GPP)
O2I	Outdoor to indoor
O2O	Outdoor to outdoor
PMR / PAMR	Private/ Professional Land Mobile Radio
PMSE	Programme Making and Special Events
PPDR	Public Protection and Disaster Relief
RSPG	Radio Spectrum Policy Group
Rx	Receiver
SDL	Supplemental DL
SI	Study Item (used in 3GPP)
SINR	Signal to Interference plus Noise Ratio
SMT	Surface Mount Technology
SNR	Signal-to-Noise-Ratio
SRD	Short Range Devices
TBD	To Be Defined
TETRA	Terrestrial Trunked Radio
TRP	Transmission Reception Point
Tx	Transmitter
UC	Use Case
UE	User Equipment
UL	Up-Link
UMa	Urban Macro
UMi	Urban Micro
uMTC	Ultra-reliable Machine-Type Communications
US	United States (of America)
V2I	Vehicle-to-Infrastructure
V2N	Vehicle-to-Network
V2P	Vehicle-to-Pedestrian
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-Anything
WAN	Wide Area Network
WRC-15	World Radiocommunication Conference in 2015
WRC-19	World Radiocommuniction Conference in 2019
xMBB	Extreme Mobile Broadband

1 Introduction

The three basic properties that influence a wireless networks capacity are access point density, spectrum usage efficiency and spectrum bandwidth availability. These three proprieties are exchangeable to some extent in regular macro-cell environments. However, spectrum usage efficiency has physical constraints (e.g. Shannon law and physical availability of de-correlated antennas). Furthermore, densification of access points becomes progressively inefficient in super-dense environments so that additional spectrum becomes the most effective solution for providing high capacity in such cases. Contiguous spectrum bands offer advantages over multiple fragmented frequency bands reducing device complexity, signaling overhead, guard bands and interference [MET15-R31].

Due to the wide bandwidth required in some of the 5G scenarios, frequency bands above 6 GHz are needed to fulfill those requirements. Some channel and propagation measurements for frequencies above 6 GHz have been carried out in this Deliverable. Due to the fact that building penetration depth strongly decreases with increasing frequency, the lower part of the spectrum between 6-30 GHz is more suitable for outdoor to indoor coverage than the spectrum above 30 GHz. However, outdoor to outdoor and indoor to indoor mobile coverage are also worth investigating in bands above 30 GHz [MET15-R31].

WRC-15 has agreed an agenda item for the WRC-19 (agenda item 1.13) to consider the identification of frequency bands for the future development of IMT for 2020 and beyond in accordance with Resolution 238 (WRC-15). Therefore, ITU-R will conduct and complete in time for WRC-19 the appropriate sharing and compatibility studies for the frequency bands:

- 24.25-27.5 GHz, 37-40.5 GHz, 42.5-43.5 GHz, 45.5-47 GHz, 47.2-50.2 GHz, 50.4-52.6 GHz, 66-76 GHz and 81-86 GHz, which have allocations to the mobile service on a primary basis; and
- 31.8-33.4 GHz, 40.5-42.5 GHz and 47-47.2 GHz, which may require additional allocations to the mobile service on a primary basis.

Some of these frequency bands, or combinations thereof, enable wide contiguous bandwidths, which would allow coping with the spectrum requirements of xMBB applications with high bandwidth demands.

1.1 Objective of the document

The objective of this deliverable is to provide 5G spectrum scenarios, requirements and technical aspects for bands above 6 GHz.. This is done by describing spectrum related impacts of innovative 5G concepts by collecting inputs and information to create a common spectrum rationale and justification, focused on technical topics. The aim is to facilitate preparations towards WRC-19.

Note: The title of this Deliverable was changed as the technical justification and rationale why more spectrum is needed for 5G, in particular above 6 GHz, were already provided in [MET16-R31] publicly available.

1.2 Structure of the document

This deliverable is further structured as follows:

In section 2, frequency bands under consideration for 5G are considered. At first, the bands discussed at WRC-15 and the bands agreed for study in ITU-R prior to WRC-19 are covered, secondly, the bands with ongoing activities or potential for 5G are noted, and thirdly, spectrum ranges and scenarios considered for technology and performance evaluation purposes within 3GPP standardization are mentioned.

In section 3, 5G use cases and spectrum requirements of potential user groups, focusing on vertical industry sectors and other specific communities like Public Protection and Disaster Relief (PPDR), are discussed.

A number of technical aspects of spectrum are analyzed in section 4, covering coexistence between 5G and fixed links, outdoor-to-indoor performance and coverage feasibility of different deployment options.

An outlook on the next steps on spectrum related work is given in section 5.

2 Frequency bands for 5G

2.1 5G bands discussed at WRC-15 and agreed to be studied for WRC-19

WRC-15 agreed on a WRC-19 Agenda Item (1.13) to consider the identification of frequency bands for the future development of International Mobile Telecommunications (IMT), including possible additional allocations to the mobile service on a primary basis, in accordance with Resolution 238 (WRC-15). This involves conducting and completing the appropriate sharing and compatibility studies for a number of bands between 24-86 GHz in time for WRC-19, see Figure 2-1.

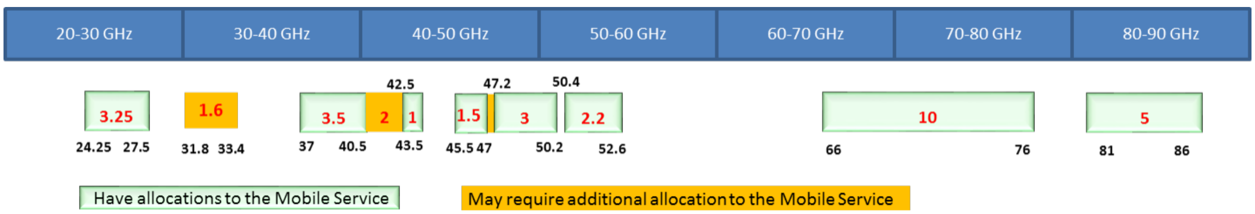


Figure 2-1: Frequency bands to be studied in ITU-R for IMT-2020 until WRC-19.

The compatibility and sharing studies for these bands will be carried out in ITU-R Task Group 5/1. For this to happen, spectrum needs, deployment scenarios, sharing parameters and propagation models are required to be available by 31 March 2017 [ITU-R CA/226].

Prior to WRC-15, there were several proposals from regional organizations for bands to be studied for 5G, which were not agreed at WRC-15, see Figure 2-2. Some significant regional markets intend to continue to develop 5G in some of those proposed bands.

Regional Organizations	
APT	Asia-Pacific Telecommunity
ASMG	Arab Spectrum Management Group
CEPT	European Conference of Postal and Telecommunications Administrations
CITEL	Inter-American Telecommunication Commission
RCC	Regional Commonwealth in the field of Communications (Russia, …)
✓	Specific bands supported
☑	General support for bands above 31 GHz
WRC-15	Results of WRC-15
	Band proposed by three or more Regional Org.
	Band proposed by less than three Regional Org.

Lower limit [GHz]	Upper limit [GHz]	APT	ASMG	CEPT	CITEL	RCC	WRC-15
10.000	10.450				✓		
23.150	23.600				✓		
24.250	24.500				✓		✓
24.500	25.250			✓	✓		✓
25.250	25.500	✓		✓	✓		✓
25.500	27.500	✓		✓	✓	✓	✓
27.500	27.700				✓		
27.700	29.500				✓		
31.800	33.000	✓	☑	✓	✓	✓	✓
33.000	33.400	✓	☑	✓		✓	✓
37.000	39.000		☑		✓		✓
39.000	39.500	✓	☑		✓		✓
39.500	40.500	✓	☑		✓	✓	✓
40.500	41.500	✓	☑	✓		✓	✓
41.500	42.500	✓	☑	✓			✓
42.500	43.500	✓	☑	✓			✓
43.500	45.500	✓	☑				
45.500	47.000	✓	☑	✓	✓	✓	✓
47.000	47.200		☑	✓		✓	✓
47.200	47.500	✓	☑	✓	✓	✓	✓
47.500	48.500	✓	☑	✓	✓		✓
48.500	48.900	✓	☑	✓	✓	✓	✓
48.900	50.200	✓	☑		✓	✓	✓
50.400	52.600	✓	☑		✓	✓	✓
59.300	66.000		☑		✓		
66.000	71.000	✓	☑	✓	✓	✓	✓
71.000	76.000	✓	☑	✓	✓	✓	✓
81.000	86.000	✓	☑	✓		✓	✓

Figure 2-2: Frequency bands proposed at WRC-15 by regional organizations to be studied for 5G.

Additionally, there were numerous proposals from individual countries for further bands (also in the range 6-24 GHz) which were not agreed for study in ITU-R.

2.2 Frequency bands with ongoing activities for 5G

In this section, frequency bands with ongoing activities and / or potential for 5G are listed, noting that not all of these bands are included (in part or totally) in the studies to carried out within ITU-R for WRC-19.

2.2.1 Bands below 6 GHz

Spectrum requirements for the year 2020 have been calculated for pre-IMT systems, IMT-2000, and its enhancements, and IMT-Advanced [ITU-R M.2290]. Due to differences in markets, deployments, and timings of the mobile data growth in different countries, two settings have been evaluated to characterize lower and higher user density settings. The results are presented in Table 2-1.

Table 2-1: Total spectrum requirement for the year 2020.

Total spectrum requirements for "Pre-IMT systems, IMT-2000 and its enhancements, and IMT-advanced" in the year 2020	
Lower user density settings	1340 MHz
Higher user density settings	1960 MHz

Spectrum bands currently identified for IMT in the ITU-R Radio Regulations will have to cope with the mobile traffic demand until the year 2020.

At the Mobile World Congress Shanghai 2015, a 5G testbed working on frequency bands below 6 GHz was demonstrated [HW15]. With a channel bandwidth of 200 MHz, a data rate of 10.31 Gbps was reached on the air interface.

In Europe, the potential of all harmonized IMT bands below 6 GHz that may respond to some IMT-2020 needs (before WRC-19/year 2020), are being discussed initially, for example the band 3.4 - 3.8 GHz. [ECC16-PT1083].

In USA, bands like 600 MHz and 3.5 GHz have been discussed for 5G [FCC15].

2.2.2 28 GHz band

Even though only the range 24.25 – 27.5 GHz band adjacent to the 28 GHz band was selected for ITU studies prior to WRC-19, large markets like the US and Korea have continued to progress with developing the 28 GHz band for 5G which therefore continues to be a focus for industrial research and development activity. When combined with the range 24.25-27.5 GHz, the entire range up to 29.5 GHz could provide a solution for flexible global device implementation (see Figure 2-3).

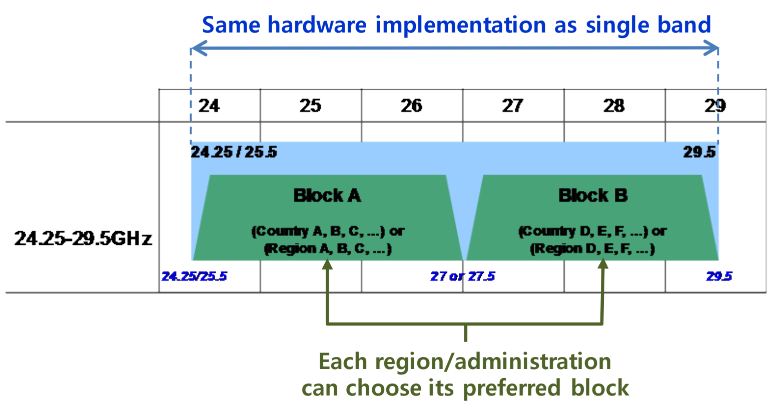


Figure 2-3: Implementation example for the frequency range 24.25 – 29.5 GHz.

This idea illustrates the opportunity due to the expectation that device tuning ranges are likely to extend outside the limits of a single block of spectrum into adjacent bands. The extent to which this is possible will depend on the ability for the signal processing to be able to maintain system performance and to efficiently calibrate out the less than optimal characteristics of the frequency dependent implementation aspects as operation moves away from the design center frequency. Ultimately, the physical characteristics of frequency sensitive components such as e.g. antenna elements will limit the lower and upper frequency bounds. This approach is most suited to immediately adjacent frequency ranges such as those illustrated in Figure 2-3 and provides flexibility to accommodate regional variations in band availability.

In the US, the 28 GHz band (27.5-28.35 GHz) is listed in the FCC's Notice of Proposed Rulemaking (NPRM), together with other bands (37.0-38.6 GHz, 38.6-40 GHz, 64-71 GHz). The FCC kicked off its NPRM in 2015 and received comments on the NPRM early 2016. During a speech at MWC-16 (Mobile World Congress, Feb 2016), a FCC commissioner indicated the FCC's intention to have a framework in place for the 28 GHz band by the end of the year 2016. In addition, the FCC announced a "Spectrum Frontiers and Technological Developments in the Millimeter Wave Bands" workshop held in March 2016. It's was set to explore 5G from all perspectives: technologies to be used, spectrum requirements, opportunities for new and incumbent providers, benefits to consumers, etc.

Researchers in the US (including New York University and University of Texas) are undertaking work in a range of bands. Ultra-wideband propagation measurements were conducted in the 28 GHz frequency band in a typical indoor office environment on the campus of New York University. The measurements provide large-scale path loss and temporal statistics that will be useful for ultra-dense indoor wireless networks. In Irving, Texas, USA, a pre-standards 5G test network for lab and field trials will be established in the second half of 2016. Pre-selected spectrum in the 28 GHz band will be used to trial and test 5G components and accompanying use cases that support massive bandwidth capacity and virtual zero latency [NOK16]. There are also plans to conduct 5G tests at 28 GHz in Euless, Texas, a suburb of Dallas, where major operators, venders and silicon companies cooperate to conduct experimental operations using prototype equipment [Fie16, The16, Wir16].

Korea is also considering a 5G trial in the 28 GHz band (26.5-29.5 GHz). The Korean government is aiming to present the world's first 5G services at the 2018 Winter Olympics in PyeongChang. The Korean Electronics and Telecommunications Research Institute (ETRI) has developed a 500 MHz channel sounder for the 28 GHz band for propagation investigations. More specifically, a beamforming antenna prototype for the 28 GHz band has recently been developed (details are provided in [KLK+15]).

In October 2015, in a mobile environment, an uninterrupted and stable connection of 1.2 Gbps was recorded from a vehicle travelling at over 100 km/h to successfully demonstrate 28 GHz beam forming implementations in prototype 5G base stations and user devices [SAM15].

2.2.3 71 – 76 / 81 – 86 GHz band

The availability of implementations for the E-band (71-76/81-86 GHz) is also to be mentioned. These implementations include the 40 nm CMOS direct transmitter [ZR14] and the E-band Doherty power amplifier [KZR14], the 90 nm CMOS transceiver at 77 GHz [MOH+10], and the SMT-ready E-band radio frontends [INF14, INF15].

Moreover, several demonstrations have proven the applicability of the E-band for enhancing mobile backhaul performance focusing on link availability, adaptive performance and link throughput versus rain rate [HW13]. Additionally, an over the air transmission speed of 115 Gbps was achieved with a 5G wireless technology prototype, which utilized a novel transceiver architecture operating in the spectrum range 70-90 GHz [HW14].

Also, there has been an experimental 5G system designed to operate at 73.5 GHz with a bandwidth of 1 GHz. The system communicates using a 28 dB gain antenna having a narrow 3 degree half-power beamwidth serving fully mobile user devices moving at pedestrian speeds. Further details of this experimental system can be found at [NTT14].

2.3 Spectrum ranges and scenarios considered in 3GPP for evaluation purposes

3GPP has started Study Items (SI) related to the so-called New Radio (NR, acronym not officially agreed but used internally in 3GPP), aiming to match the ITU-R 5G requirements. The first SI on NR aims to identify the typical deployment scenarios. Those include spectrum related parameters as number of carriers, carrier center frequency and available bandwidth in each of them. Technical Report [3GPP-TR38.913] is currently in preparation in 3GPP.

In this SI, there are 10 scenarios under development in for the evaluation of innovative 3GPP NR proposals. :

1. Indoor hotspot
2. Dense urban
3. Rural
4. Urban macro
5. High speed
6. Extreme rural for the Provision of Minimal Services over long distances
7. Extreme rural with extreme Long Range
8. Urban coverage for massive connection
9. Highway Scenario
10. Urban Grid for Connected Car

Some of these scenarios comply with the requirements of the available frequency scenarios that have already been used for LTE/LTE-Advanced performance evaluations, i.e. involving already available frequency carriers and bandwidths. This is the case for the scenarios “Rural”, “Extreme Rural ...” and “Urban coverage for massive connection”, as could be foreseeable from previous bandwidth requirement analyses as done in [MET14-D53].

Other scenarios such as “Highway Scenario” and “Urban Grid for Connected Car” are not yet finalized, but the carrier frequencies under consideration are below 6 GHz.

However, there is a common view in the industry [MET14-D53] that some scenarios are foreseen to require broader bandwidths, and therefore new frequency bands need to be used, including frequencies above 6 GHz.

The carrier center frequencies above 6 GHz considered in different 3GPP scenarios have been selected as representative for the evaluation purpose, not precluding further studies of different spectrum bands since the final standardization process will need to match the requirements from ITU-R studies.

In this sense, two different frequency bands above 6 GHz have been selected for the simulation purposes, representing different band ranges:

- Carrier frequencies around 30 GHz, as representative of the characteristics of the range of bands from 24 GHz to 40 GHz, under study for WRC-19
- Carrier frequencies around 70 GHz, as representative of the characteristics of the range of bands from 66 GHz to 86 GHz, under study for WRC-19

In 3GPP, those 30 GHz and 70 GHz frequencies are used for the physical layer technology evaluations but 3GPP have not yet agreed the simulation scenarios for coexistence evaluations. The carrier bandwidth of 1 GHz is initially considered as representative for frequency bands above 6 GHz as presented in Table 2-2,showing all the considered carrier frequency possibilities below and above 30 GHz (in the case of dense urban with two layers jointly used in the scenario), as well as the bandwidth associated with each of them.

Table 2-2: Frequency considerations in 3GPP NR simulation scenarios

Scenario	Simulation	Carrier Frequencies	Bandwidths
1. Indoor hotspot	1.1	4 GHz	200 MHz
	1.2	30 GHz	1 GHz
	1.3	70 GHz	1 GHz
2. Dense urban	2.1	4 GHz + 30 GHz	200 MHz + 1 GHz
3. Urban Macro	4.1	2 GHz	TBD
	4.2	4 GHz	200 MHz
	4.3	30 GHz	1 GHz
4. High speed	5.1	4 GHz	200 MHz
	5.2	4 GHz + 30 GHz	200 MHz + 1 GHz
	5.3	4 GHz + 70 GHz	200 MHz + 1 GHz
	5.4	30 GHz + 30 GHz	1 GHz + 1 GHz
	5.5	30 GHz + 70 GHz	1 GHz + 1 GHz

The aim is that the NR system should be able to use any spectrum band ranging at least up to 100 GHz, in order to be able to operate in any foreseeable frequency band even in the long term. In this SI it is also stated that: “There is huge on-going effort in industry as well as academia to investigate the feasibility of using around 1 GHz bandwidth in the frequency range above the current cellular spectrum.”

In order to incorporate the frequency bands above 6 GHz into the 3GPP specification process, the radio propagation at these high frequencies is currently being modeled in a new Study Item

RP-160210 “Study on channel model for frequency spectrum above 6 GHz“. This is making channel models valid for frequency bands above 6 GHz and is planned to be finalized in June 2016.

The current agreement how to progress these channel models (that will be included in the new Technical Report TR 38.900) include:

- Taking care of propagation aspects such as blocking and atmospheric attenuation
- The model should be consistent in space, time and frequency
- It should support large channel bandwidths

In this sense, some of the studies presented for these models (R1-161715) include attenuation measurements of materials for carrier frequencies at 28 GHz, 39 GHz and 73 GHz, in accordance with the values around 30 GHz and around 70 GHz mentioned earlier. Furthermore, the clustered delay line (CDL) approach models are defined for the full frequency range from 0.5 GHz to 100 GHz with a maximum bandwidth of 2 GHz.

Additionally, ITU-R (RP-160508) is asking for “Characteristics of terrestrial IMT systems for frequency sharing/interference analysis in the frequency range 24.25-86 GHz”, as this topic is currently under study in 3GPP RAN working groups dealing with the required base station and mobile station RF characterization, both for transmitters and for receivers.

Related to the bandwidth under consideration for NR, some studies (as e.g. R1-161717) are looking into the possibility of using bandwidths of 2 GHz that could be available in the bands 66-71, 71-76 and 81-86 GHz.

3 Spectrum scenarios, use cases and spectrum requirements of potential 5G user groups

3.1 Authorization modes and usage scenarios

In general the use of radio spectrum can be authorized in two ways: Individual Authorization (Licensed) and General Authorization (Licence Exempt / Unlicensed). Authorization modes recognized as relevant for wireless communications are *Primary user mode*, *LSA (Licensed Shared Access) mode* and *Unlicensed mode*.

Five basic spectrum usage scenarios can be identified for these authorization modes: dedicated licensed spectrum, limited spectrum pool, mutual renting, vertical sharing and unlicensed horizontal sharing (see Figure 3.1, depicting the relations between parts of the domains which are either necessary (mandatory: continuous lines) or supplementary (optional: dotted lines)).

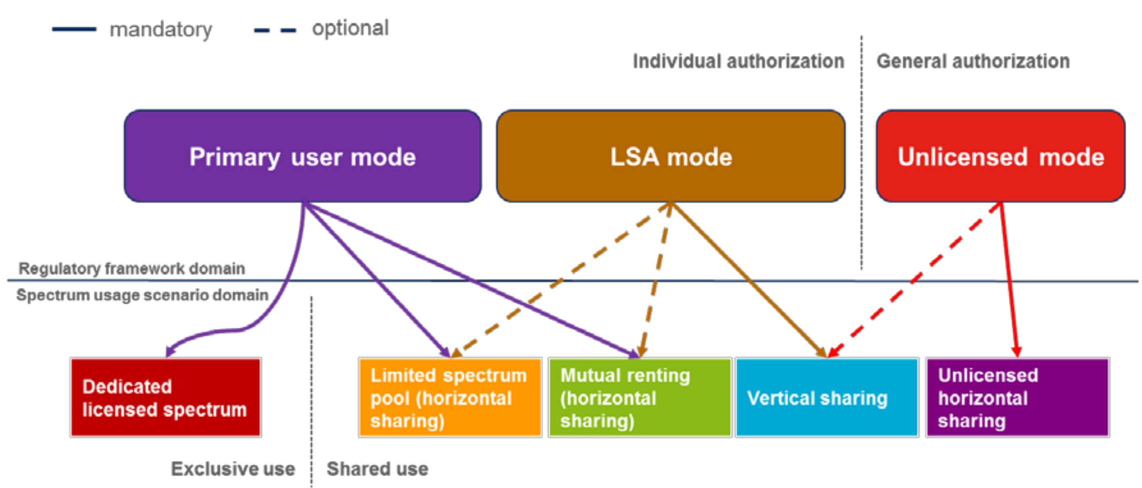


Figure 3.1: Spectrum usage/sharing scenarios [MET14-D53].

The general conclusion with regard to spectrum authorization for 5G is that

- exclusive licensed spectrum is essential for the success of 5G to provide the expected QoS and to secure investments,
- shared spectrum can be considered in addition, provided that predictable QoS conditions are maintained, e.g. by LSA regime,

- license-exempt spectrum might be suitable as a supplementary option for certain applications, for instance using the LAA (License-Assisted Access) scheme explained below.

3.2 Spectrum aspects of METIS-II 5G use cases

In METIS-II, three use case families and five use cases are considered, whereas each use case addresses at least one use case family. The three use case families are:

- **Extreme Mobile BroadBand (xMBB):** Provides both extreme high throughputs, and low-latency communications, and extreme coverage improving the Quality of Experience by providing reliable moderate rates over the coverage area.
- **Massive Machine-Type Communications (mMTC):** wireless connectivity for tens of billions of network-enabled devices with prioritization on wide area coverage and deep indoor penetration.
- **Ultra-reliable Machine-Type Communications (uMTC):** ultra-reliable low-latency and/or resilient communication links.

An overview of the five METIS-II 5G use cases, including the use case family or families these use cases belong to, is given in Figure 3-2. Furthermore, the scopes in terms of requirements and services are stated as well as the use case origin. The METIS-II 5G use cases, their main requirements as well as the selection methodology, are described in detail in [MET16-D11].

	Use Case (UC)	Scope of requirements (network/user perspective)	Scope of services (service perspective)	Source
xMBB, mMTC	Dense urban information society	Experienced user data rate / Traffic vol. per subscriber / Nb. of users and devices / Energy efficiency	Broad range of communication services covering needs related to both indoor and outdoor urban daily life (excl. office and factory)	METIS-I test case enriched by NGMN UC Mobile video surveillance
xMBB	Virtual reality office	Experienced user data rate / Traffic volume per subscriber / Latency	Broad range of communication services in the (indoor) office context	METIS-I test case
xMBB	Broadband access everywhere	Experienced user data rate / Availability / Mobility / Energy efficiency	Full coverage topic addressing outdoor/indoor communication needs especially in rural areas	NGMN use case 50+ Mbps everywhere incl. METIS-I test case Blind spot
mMTC	Massive distribution of sensors and actuators	Availability / Number of devices / Energy efficiency	Broadest range of IoT services covered	METIS-I test case Massive deployment of sensors and actuators
xMBB, uMTC	Connected cars	Latency/ Reliability / Mobility	Strong expectation from the (automotive) industry Belong to the first uMTC services expected to be commercialized	METIS-I test case Traffic efficiency and safety complemented by MBB aspects

Figure 3-2: METIS-II 5G use cases.

3.2.1 Spectrum bands for 5G use case families

The following general conclusions on the suitability of spectrum bands for the three 5G use case families can be drawn:

- For xMBB, a mixture of frequency spectrum comprising lower bands for both coverage purposes and data traffic, and higher bands with large contiguous bandwidth to cope with the ever-increasing traffic demand, including wireless backhaul solutions, is required. Exclusive licensed spectrum is essential to guarantee the coverage obligation and QoS, supplemented by spectrum authorized by other licensing regimes, e.g. LSA or unlicensed access (e.g. Wi-Fi offload) or new enhanced unlicensed access schemes (e.g. LAA) to increase overall spectrum availability.
- For some mMTC applications, frequency spectrum below 6 GHz is more suitable and spectrum below 1 GHz is needed in particular when large coverage areas and good outdoor to indoor penetration are needed. Exclusive licensed spectrum is the preferred option. However, other licensing regimes might be considered depending on specific application requirements.
- Licensed spectrum is considered the most appropriate for uMTC. For safety V2V and V2X communication the frequency band 5875-5925 MHz harmonized for Intelligent Transport Systems (ITS) [ECC08-DEC01] is an option. Another option is the sub-1GHz spectrum, particularly well-suited for high-speed applications and rural environments.

3.2.2 Categorization of spectrum related use case requirements

The requirements of the METIS-II 5G use cases concerning spectrum can be broadly categorized into three main groups:

- **Capacity** to cope with high traffic per cell / area, including large contiguous spectrum → high bandwidth.
- **Coverage** to ensure the availability of 5G everywhere → lower frequencies.
- **Reliability** to fulfil the demands of critical services, requiring stable and predictable operation conditions → dedicated spectrum.

The relationship between the METIS-II 5G use cases and the three categories defined above is illustrated in Figure 3-3, based on the evaluation shown in Table 3-1. It is obvious that a combination of different suitable frequency bands is necessary to cope with the use case requirements.

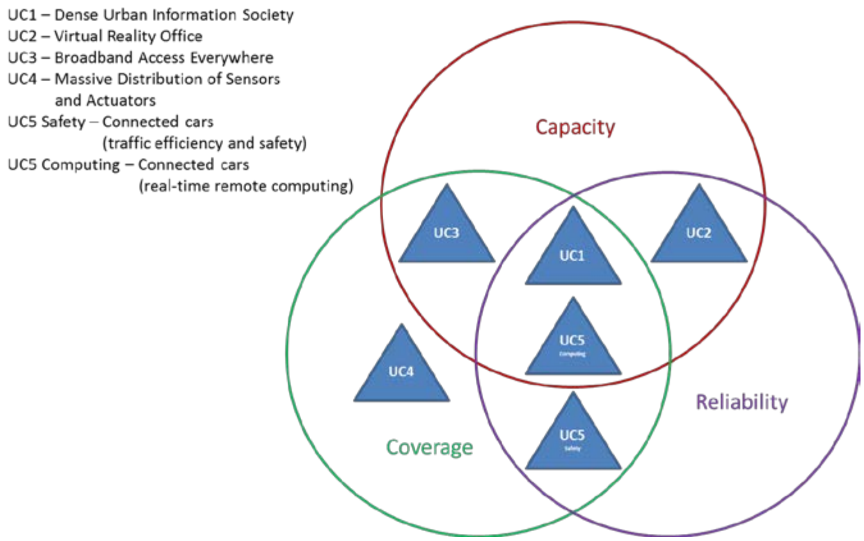


Figure 3-3: Relation between METIS-II 5G use cases and the three categories.

Table 3-1: Evaluation of use case KPI's in [MET16-D11], Annex B1.

	High	Medium	Low
Availability	> 99 % (UC4, UC5-S)	95 - 99 % (UC1, UC2, UC3, UC5-C)	< 95 %
Capacity	> 100 Mbps (UC1, UC2)	50 - 100 Mbps (UC3, UC5-C)	< 50 Mbps (UC4, UC5-S)
Coverage	Derived from requirements for Availability and Mobility		
Mobility	> 50 km/h (UC3, UC5-S/C)	3 - 50 km/h (UC1)	< 3 km/h (UC2)
Reliability	> 99 % (UC5-S)	95 - 99 % (UC1, UC2, UC5-C)	< 95 %

3.3 Categories of 5G user group requirements

5G which will offer better performance for applications that require it, and in particular, improved mobile broadband speed and capacity, but also better reliability and lower latency, enabling new usage scenarios for mobile networks in various vertical markets, ranging from wearable electronics to autonomous driving.

Opportunities associated with 5G and its vertical markets need to be carefully analysed and understood in order to address the specific requirements of each vertical sector, identifying the most challenging and urgent use cases and taking into account the technical, commercial, and regulatory challenges that 5G faces in such new markets.

Also, spectrum plays an important role in realising the 5G potential. Spectrum is essential for mobile broadband services, but 5G applications in the next-generation connected society will be also targeting devices other than typical mobile (smartphone) devices, for which possibly specific spectrum requirements need to be identified.

The spectrum policy thinking around 5G is about identifying the right bands for achieving the optimal use of spectrum based on technological readiness, attractiveness to investors and the economic and societal drivers for new applications and services . This is likely to mean allocating new bands to 5G, although re-farming of existing mobile bands may not be excluded.

Final decisions about the right spectrum bands for 5G require consideration of the potential for harmonisation of spectrum bands, to the largest global extent possible, as it provides for economies of scale and network and device interoperability with a clear and stable basis for standardisation. Interoperability is a fundamental element on which 5G should be built, even more so for some vertical markets.

However, for some market segments, time to market as well as long device life cycles have to be taken into account, which could lead to different approaches, especially with respect to spectrum harmonisation. The global spectrum harmonization processes can have long lead times while there can be the case that new vertical markets applications are brought more quickly to a market. Consequently, if there are large enough economies of scale, and the service requirements are fulfilled anyway, then there may be some rationale for addressing spectrum that can be made available either more quickly. This would then happen at the cost of lack of global harmonization.

For example, the RSPG has recently remarked that harmonisation is supported “where it leads to more efficient spectrum use and where it is driven by clear demand”, i.e., “where it supports economies of scale, where it responds to cross-border necessity, and where it is required for mobility of services or EU-wide provision”, giving “manufacturers the certainty they need, while ensuring that spectrum is not going to be sterilised and that Member States can continue to meet the needs of consumers” [RSPG 16-001].

Currently, the approach for new spectrum for vertical markets in Europe and globally, seems still open to different solutions and relevant drivers seem to be market demand, time to market and efficient spectrum use.

Furthermore, new legislative, regulation, and technical standardization frameworks need to be established to facilitate vertical applications’ inclusion and adoption. Taking into account that the standardization process should be inclusive of vertical industries (though each vertical industry typically has its own standard body and association) and address new issues, for example, legal issues and level of standardization (for example, there are already more than 600 closely related standards in the area of the internet of things). Domains such as e-health or smart cities, innovations can easily be connected up and re-used from one user group site (e.g. one hospital to another hospital), or different cities, possibly in different countries.

In Annex A spectrum aspects of different 5G user groups are summarized. The following vertical industry sectors are considered

- Automotive
- E-Health
- Energy
- Factories
- Media & Entertainment

as well as other potential user groups, namely

- Public Protection and Disaster Relief
- Programme Making and Special Events
- Private/ Professional Land Mobile Radio

For the vertical industries considered in Annex A.1, the information is based on white papers published by 5G PPP. For the other potential user groups touched in Annex A.2, respective CEPT ECC Reports have been used.

The examination of the information in Annex A shows that some industry sectors already have access to specific spectrum resources in dedicated bands or licence exempt bands. However, within each user group, several different usage scenarios or use cases can be identified that are mapped onto the METIS-I [MET15-D1.5] and METIS-II use cases in Table 3-2 and Table 3-3.

Table 3-2: Mapping of vertical industry sector use cases onto METIS-I and METIS-II use cases.

User Group	Usage Scenario / Use Case (Family)	5G Service	METIS-I Use Case	METIS-II Use Case	Category
Automotive	Wide-area infrastructure-based communications (V2N)	xMBB	Real time remote computing for mobile terminals	Connected cars (real-time remote computing)	Capacity Coverage
	Short-range communications (V2V, V2I, V2P, etc.)	uMTC	Traffic efficiency and safety	Connected cars (traffic efficiency and safety)	Coverage Reliability
E-Health	Assets and interventions	uMTC	eHealth	x	Reliability
	Robotics	uMTC	eHealth	x	Capacity Reliability
	Remote monitoring of health or wellness data	uMTC	eHealth	x	Coverage Reliability
	Smarter medication	uMTC	eHealth	x	Coverage Reliability
Energy	Smart Grids	uMTC	Teleprotection in smart grid network	x	Coverage Reliability
	Smart Assets	mMTC	Massive deployment of sensors and actuators	Massive distribution of sensors and actuators	Coverage
Factories	Time-critical process optimization inside factory	uMTC	Remote tactile interaction	x	Reliability
	Non time-critical optimizations inside factory	mMTC	Massive deployment of sensors and actuators	Massive distribution of sensors and actuators	Coverage Reliability
	Remote maintenance and control	xMBB	x	Broadband access everywhere	Coverage Reliability
	Seamless intra-/inter-enterprise communication	xMBB	x	Broadband access everywhere	Coverage Reliability
	Connected goods	mMTC	Massive deployment of sensors and actuators	Massive distribution of sensors and actuators	Coverage
Media & Entertainment	Ultra-High Fidelity Media	xMBB	Media on demand	x	Capacity Coverage
	On-site Live Event Experience	xMBB	Stadium	x	Capacity
	User Generated Content & Machine Generated Content	xMBB	x	Broadband access everywhere	Capacity Coverage
	Immersive and Integrated Media	xMBB	x	Broadband access everywhere	Capacity Coverage
	Cooperative Media Production	xMBB	x	Broadband access everywhere	Capacity Coverage
	Collaborative Gaming	xMBB	Gaming	x	Capacity Coverage

Table 3-3: Mapping of other potential user group use cases onto METIS-I and METIS-II use cases.

User Group	Usage Scenario / Use Case (Family)	5G Service	METIS-I Use Case	METIS-II Use Case	Category
Public Protection and Disaster Relief	Wide area network (WAN) communication		x	Broadband access everywhere	Coverage Reliability
	Airborne communications, Air-Ground-Air (AGA)		x	x	
	Direct terminal to terminal communications	uMTC	Emergency communications	x	Reliability
	Ad-hoc network communication	uMTC	Emergency communications	x	Reliability
Programme Making and Special Events	Audio Links	mMTC	Massive deployment of sensors and actuators	Massive distribution of sensors and actuators	Reliability
	Video Links	xMBB	x	Broadband access everywhere	Capacity Reliability
	Service Links	xMBB	x	Broadband access everywhere	Capacity Reliability
Private/ Professional Land Mobile Radio	Direct peer-to-peer communications		x	x	
	Communications between a base station and mobile user equipment	xMBB		Broadband access everywhere	Coverage
	Implementations with a common control channel (trunking systems)		x	x	

As almost all of the usage scenarios / use cases of the vertical user groups are covered by METIS-I or METIS-II use cases, it can be concluded that the requirements of these user groups can be generally met by the 5G system design developed in METIS-II. In addition, these use cases can be readily associated with the spectrum categorization identified in Section 3.1 above.

4 Analysis of spectrum related technical aspects of 5G

In the following subsections a number of spectrum related technical aspects of 5G are analyzed.

4.1 Coexistence between 5G macro systems and fixed service links

This section focusses on the quantitative assessment of opportunities for rooftop 5G macro systems to coexist with fixed service links operating in the 15 GHz frequency range. Beamforming capabilities are to be available in the 5G network [MSM+16]. The assessment results indicate that fixed service links can operate in the adjacent channels with very low impact from the 5G macro-cellular system.

The scenario for this assessment consists of a generic high-rise building scenario similar to a typical Asian city where different types of buildings with various materials randomly modeled and users placed both indoor and outdoor as shown in Figure 4-1 (a). The building heights vary from 16 m to 148 m. Macro base stations (BSs) and fixed service link nodes are placed on the rooftop. All macro BSs in this scenario have the same parameters (like Tx power, noise figure, number of Tx/Rx etc.), the only difference is the inter-site distance (ISD). The macro BSs in the city center are densely deployed with an ISD of 200 m, and the other BSs are deployed with an ISD of 400 m. In order to avoid cell edge effects, the entire area of 2x2 km^2 is simulated but only 1x1 km^2 area is studied, which includes the red and pink base stations in Figure 4-1 (a). A 3D ray tracing based propagation model is used which explicitly models both, diffraction and reflection, as well as frequency dependent building penetration and wall loss [SHF+14]. The antennas used in the study include the implementation of UE specific beamforming with high antenna gains such that the base station selects the beam with higher gain towards a specific UE in order to serve it.

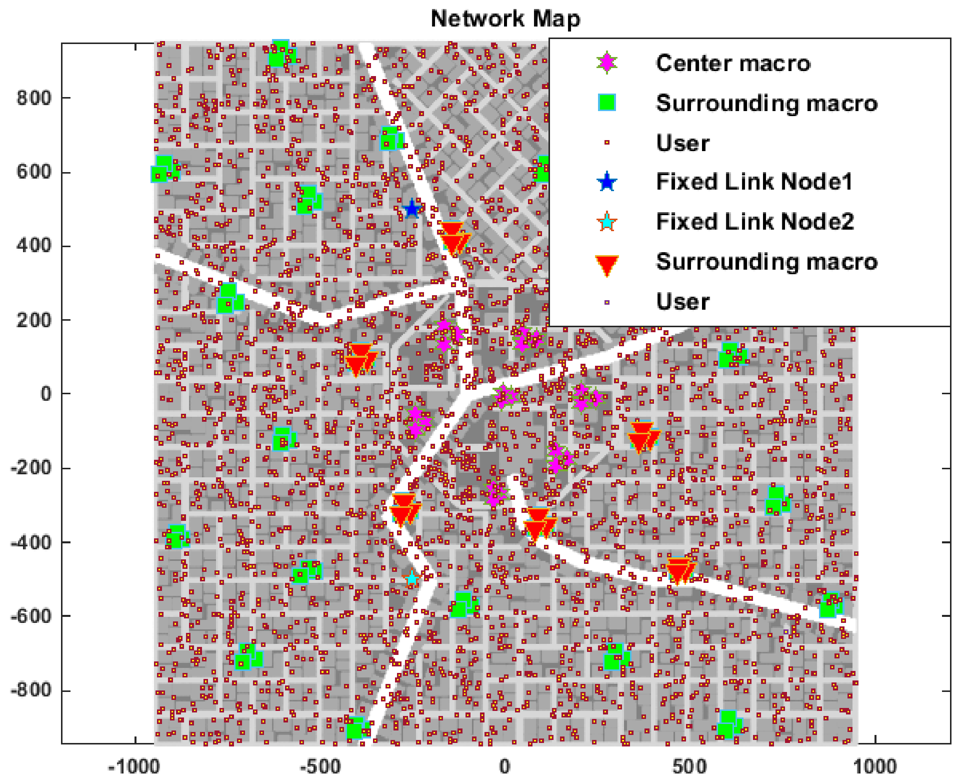


Figure 4-1: Assessment scenario for coexistence between a 5G macro system and a fixed service link at 15 GHz

A system bandwidth of 40 MHz for both, the 5G system and the fixed service link, was used in this evaluation. Table 4-1 shows the fixed service link parameters considered. The ACLR value in Table 4-1 is chosen for a typical LTE terminal [3GPP-TS36.101].

Table 4-1 Fixed service link parameters and requirements

Parameters	FS link
Tx power density (dBm/MHz)	17
Antenna type	3.5m/0.3m Dish
Antenna main beam gain (dBi)	47.6 dBi/31.1dBi according to [ITU-R F.699] [ITU-R F.1245]
Antenna height (m)	80
Noise Figure (dBm)	6
I/N (dB)	-10
ACLR (dB)	30

Table 4-2 Interference towards fixed link

Fixed Link Dish Size (m)	Offered 5G Traffic Load	Median of Adjacent channel interference (dBm/MHz)	99% of Adjacent channel interference (dBm/MHz)
0.3	Low	-161.7	-133.7
0.3	High	-122.46	-119.83
3.5	Low	-169.4	-140.9
3.5	High	-130.3	-127.74

Table 4-2 shows the median and the 99 percentile of the aggregate adjacent channel interference in dBm/MHz received at the fixed service receiver depending on traffic load level within the 5G system. It can be observed that irrespective of the traffic load in the 5G system, the adjacent channel interference level into the fixed service link is reasonably low if, for example, an acceptable interference level of -118 dBm/MHz is assumed [MSM+16]. It can also be seen that an increase in the fixed service link dish size lowers the interference level due to the higher directivity of the antenna, allowing for a better discrimination of the wanted signal.

These results are based on the 15 GHz frequency range. At higher frequencies, with the implementation of more directive beams and more spatial separation in the 5G system, the potential for interference would be reduced, hence improving the opportunity for coexistence. In addition, advanced cross-system coordination techniques (e.g. dynamic beam selection) could be a further area to be studied.

4.2 Performance and feasibility of 5G outdoor-to-indoor deployment

This section provides a performance and feasibility analysis of 5G outdoor-to-indoor deployment, enabling the evaluation of challenges and limitations with respect to cell range and carrier frequency for the 5G outdoor-to-indoor communication case. The key radio communication components for this analysis, i.e. channel bandwidth, radio propagation, antenna gain and transmit power have frequency dependent behaviors or limitations with substantial impact on the overall performance of the 5G system. Therefore, suitable assumptions and models for each of these components are considered in the analysis.

Preliminary studies on limitations of 5G outdoor-to-indoor deployment were discussed in [MET15-R31], where received signal level and throughput performance across the whole 5G frequency range were presented for some scenarios. In this section, in addition to refinements on radio propagation models, the numerical analysis was done, which considers radio link and coverage minimum requirements for the evaluation of the 5G deployment feasibility in different spectrum ranges.

It is observed that the average throughput in more challenging radio propagation conditions at higher frequencies can be improved or maintained with increasing antenna gains and channel bandwidths to some extent. However, regarding the fulfilment of radio link and coverage requirements, the network operation is more restricted, requiring shorter cell ranges or lower carrier frequencies, which depend on the building materials involved in the outdoor-to-indoor communication link and how demanding the radio link and coverage requirements are.

4.2.1 Assumptions for the 5G network deployment

All technical aspects, deployment scenarios (urban micro (UMi), urban macro (UMa)) and main elements considered in the numerical analysis presented in this section for outdoor-to-indoor communications are summarized in Table 4-3.

Table 4-3: Deployment scenarios and main elements

Element	**Value or description**
Scenario	UMa and UMi (outdoor-to-indoor communication)
Carrier frequency	from 1 to 100 GHz
Cell size	UMa: d = 50, 100 or 150 m UMi: d = 25, 50 or 100 m
Channel bandwidth	2% of carrier the frequency (i.e. 20 MHz at 1 GHz)
Path loss, shadow fading	CI-FSPL for LOS/NLOS [SIG15]
LOS probability	3GPP/ITU-R model [3GPP-TR36.873]
Building penetration loss	Concrete wall, modern window [SHF+14]
Antenna gain	<u>Increase with the square of the frequency:</u> Macro BS: 12 dBi (1 GHz), 30 dBi (f >= 8 GHz) Micro BS: 7.5 dBi (1 GHz), 30 dBi (f >= 14 GHz) UE: -5 dBi (1 GHz), 20 dBi (f >= 18 GHz)
Transmit power (at the antenna input)	<u>Decrease with the square of the frequency:</u> Macro BS: 48 dBm (1 GHz), 30 dBm (f GHz), 30 Micro BS: (constant) 30 dBm
Radio link requirement	SNR_{min} = -8 dB
Coverage requirement	95% cell edge users
UE noise figure	10 dB

Path Loss and Shadow Fading

As captured in Table 4-3, close-in free space reference distance path loss (CI-FSPL) model [SIG15] has been used for calculation of propagation loss and shadow fading. This model is based on FSPL at 1 m, as described by following formula:

$$PL(f,d) = FSPL(f,1m) + 10n\log_{10}(d) + X\,[dB]$$

where *f* and *d* are frequency in Hertz and cell edge distance in meters, *n* is the path loss exponent, *X* is the shadow fading component in dB, and $FSPL(f,1m) = 20\log_{10}(4\pi f / c)$ is FSPL at 1 m, where *c* is the speed of light. Values of *n* exponent for UMa and UMi (street canyon) scenarios from [SIG15] have been used for LOS and NLOS situations, as shown in Table 4-4.

Table 4-4: Path loss and shadow fading parameters for UMa and UMi scenarios

Scenario	Path loss exponent, *n*	Shadow standard deviation, σ_X
UMa-LOS	2.0	4.1
UMa-NLOS	3.0	6.8
UMi-LOS	1.98	3.1
UMi-NLOS	3.19	8.2

LOS probability

To determine LOS probability current 3GPP/ITU-R model [3GPP-TR36.873] has been adopted. It is the following d_1/d_2 model:

$$P_{LOS}(d) = \min\left(\frac{d_1}{d},1\right)\cdot\left(1 - e^{\frac{-d}{d_2}}\right) + e^{\frac{-d}{d_2}}$$

where *d* is the 2D Tx to Rx distance in meters, and d_1 and d_2 can be optimized to fit a measurement data set or to reflect a scenario. The pair (d_1, d_2) is (18, 63) for UMa and (18, 36) for UMi scenario [3GPP-TR36.873].

Building penetration losses

Two distinct building penetration losses have been used in this analysis, one for concrete wall and the other for what can be called a modern window, composed of infrared rejection glass. Both models are proposed in [SHF+14] as linear fitting of the data obtained in measurement campaigns, i.e.:

$$BPL(f) = af + b$$

where *BPL*(*f*) is the building penetration loss (BPL), and the parameters (*a*, *b*) are (4, 5) for concrete wall and (0.3, 23) for modern window. It should be noted that this is an average loss, for perpendicular incidence angle. To take into account the angular wall loss, the same approach as in [SHF+14] has been adopted, by considering an average angular loss for NLOS propagation as 5 dB, due to average incidence angle of 60°.

EIRP

As indicated in Table 4-3, this analysis assumes typical Fourth Generation (4G) antenna gains at 1 GHz, i.e. 12 dBi and 7.5 dBi for the base station (BS) in UMa and UMi deployment, respectively, and −5 dBi for the user equipment (UE). The antenna gains increase with the square of the frequency, but have upper bounds set by technology limitations at 30 dBi for BS and 20 dBi for UE [MET15-R31].

Similarly, typical (high) 4G BS transmit powers at 1 GHz have been assumed, i.e. 48 dBm and 30 dBm for UMa and UMi deployment, respectively. Then, while keeping the same transmit power across the whole 5G frequency spectrum range for the micro BS, the transmit power of the macro BS is modeled as decreasing with the square of the frequency, with 30 dBm as lower bound.

These assumptions aim to take into consideration the frequency dependent behaviors and technical limitations of antennas and power amplifiers. Therefore, the Equivalent Isotropical Radiated Power (EIRP) is fixed at 60 dBm for the UMa deployment, as a consequence of the complementary UMa transmit power and antenna gain models. For the UMi deployment, EIRP starts with 37.5 dBm at 1 GHz and increases with antenna gain (and carrier frequency) up to 60 dBm, for frequencies greater than or equal to 14 GHz.

4.2.2 Performance and feasibility analysis

A common link budget calculation is used in this analysis, where frequency dependent models for channel bandwidth, radio propagation, antenna gain and transmit power discussed in section 4.2.1 are taken into account. The link budget is calculated for the whole 5G spectrum range in different Tx to Rx distances assumed as cell edge. It thus provides a distribution of long term SNR at each (distance, frequency) pair, since propagation models include distance dependent LOS probability and shadow fading. The outdoor-to-indoor link budget can be considered optimistic, since all metrics are evaluated just behind the concrete wall or glass window, i.e. no indoor propagation is modeled, as well as no body loss or other additional signal statistical variation is considered. Separate results for propagation through concrete wall and modern window show how different the outdoor-to-indoor 5G performance can be according to building materials.

Throughput gains

The throughput performance of a single link is a function of the quality of the received signal and the bandwidth of the communication channel. Then, to compensate throughput degradation due to more challenging signal propagation in higher frequencies:

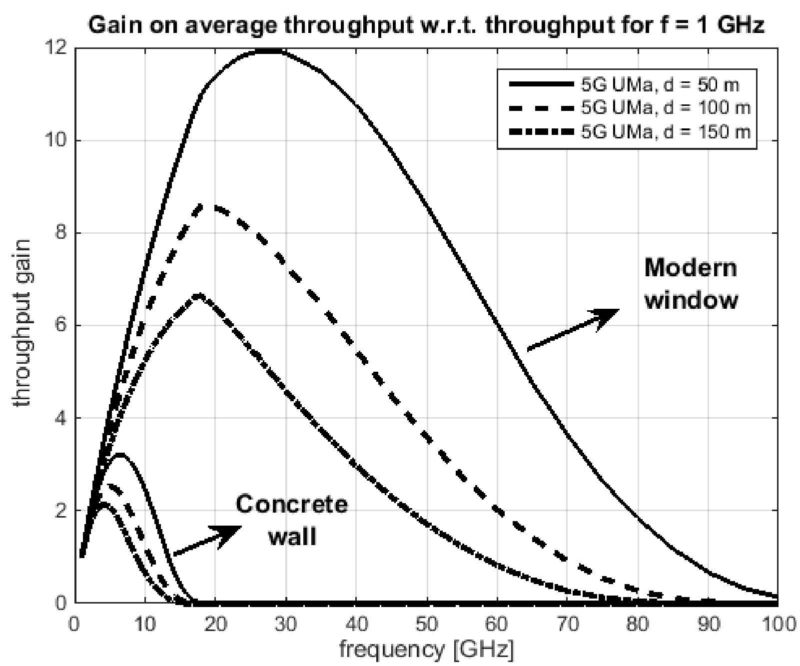
- The increase of antenna gain with carrier frequency is able to improve the quality of the received signal, and consequently the throughput performance;
- The adoption of wider channel bandwidths is also able to boost the throughput performance, under the condition of acceptable received signal quality.

In the following analysis, throughput is estimated from the long term SNR samples by applying the Shannon's channel capacity formula:

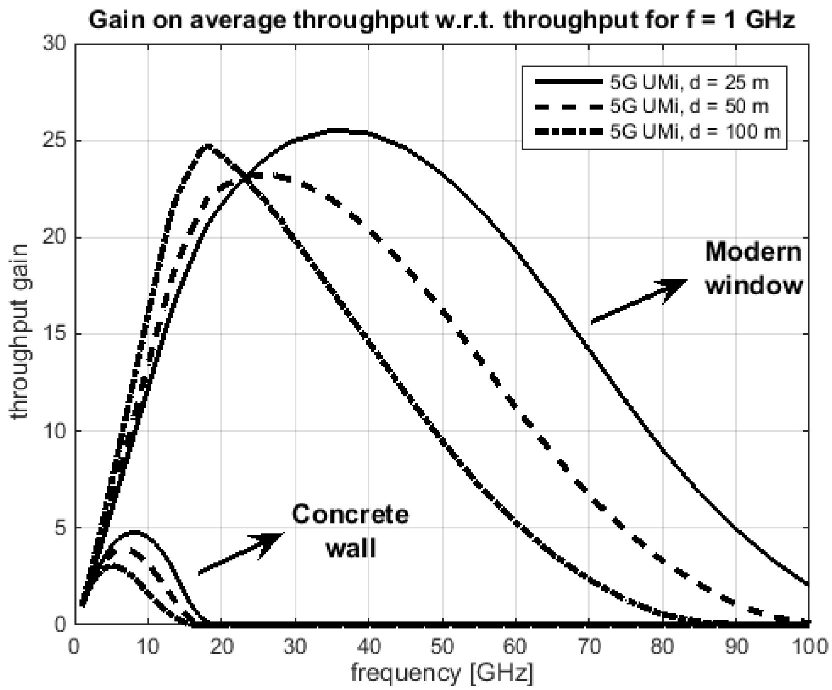
$$C = B \cdot \log_2(1 + SNR)$$

where C is the channel capacity in bits per second and B is the channel bandwidth in Hertz. No multiplexing gains are assumed, since for the considered scenarios, i.e. cell edge outdoor-to-indoor links, channel conditions are not favorable to multiple data streams, but more likely to require high beamforming gain from the multiple antennas installed in Tx and Rx.

Figure 4-2 shows estimates of average throughput gains across the whole 5G frequency range for different cell edge distances. As the reference performance in these curves is the throughput obtained at 1 GHz with a typical 4G network setting in terms of EIRP, Rx antenna and channel bandwidth, the average throughput gains in Figure 4-2 can be understood as an estimate of cell edge throughput gains of 5G deployment over 4G.



(a) UMa scenario.



(b) UMi scenario.

Figure 4-2: Gain on cell edge average throughput as a function of carrier frequency with increasing bandwidth, which is assumed to be 2% of the carrier frequency. The throughput at 1 GHz is used as a reference.

The challenging propagation through concrete wall is clearly reflected in the average throughput gain curves for UMa (Figure 4-2 (a)) and UMi (Figure 4-2 (b)) scenarios, which are shown very restricted in magnitude and in carrier frequency range. On the other hand, consistent cell edge average throughput gains are observed in the case of propagation through modern windows in both UMa (Figure 4-2 (a)) and UMi (Figure 4-2 (b)) scenarios. For this building material, it can be observed that there is a frequency region, up to 18 GHz, of prominent throughput increase due to combined EIRP (in UMi scenario only), Rx antenna and channel bandwidth increase with carrier frequency. For frequencies above 18 GHz no antenna gain is improved, and the continuing linear increase of channel bandwidth with carrier frequency is still able to compensate increasing propagation losses and provide some further throughput gains only for shorter cell edge distances, as 50 m or less.

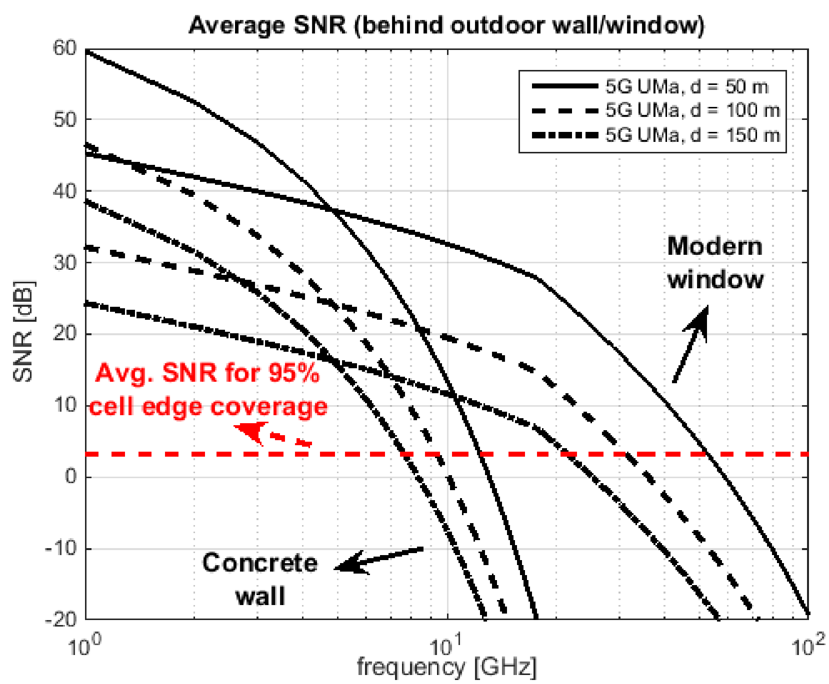
Coverage limitations

In order to determine the feasibility of a specific 5G deployment, i.e. (cell range, carrier frequency) pair, fthe minimum required average (long term) SNR, to fulfill both radio link and coverage requirements, $\overline{SNR}_{req}$, is calculated,. Then, $\overline{SNR}_{req}$ serves as cut off value for the average SNR obtained from the link budget calculation, determining the feasible range of carrier frequency for a certain cell size.

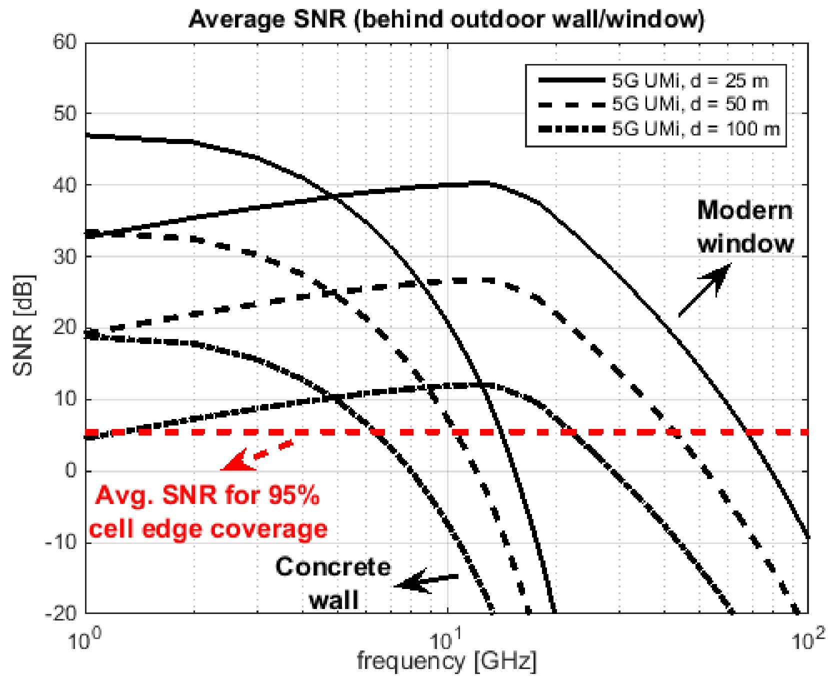
$\overline{SNR}_{req}$ is easily obtained by considering the fading margin over the minimum required SNR, $SNR_{\min}$, with which the requirement of *Y* % cell edge coverage is satisfied:

$$P\{SNR > SNR_{\min}\} = Y/100 \Rightarrow \overline{SNR}_{req} = SNR_{\min} - \sigma_X \cdot Q^{-1}(Y/100)$$

where $Q(\cdot)$ is the *Q*-function, i.e. the right-tail probability for Gaussian random variable. For this analysis, $SNR_{\min}$ = −8 dB and *Y* = 95% minimum cell edge coverage are considered. Also, it is assumed NLOS at the cell edge, with the corresponding standard deviation σ_X given in Table 4-4. Therefore, from above formula, the minimum average SNR, for feasible 5G deployment in UMa and UMi scenarios are, respectively, **3.2 dB** and **5.5 dB**. Figure 4-3 shows the average SNR curves obtained from the link budget calculation for the whole 5G frequency range, as well as the minimum required average SNR curves. From Figure 4-3 (a) and Figure 4-3 (b), one can assess the limiting carrier frequency for the different cell ranges in scenarios UMa and UMi, respectively.



(a) UMa scenario.



(b) UMi scenario.

Figure 4-3: Cell edge average SNR as a function of carrier frequency.

Under the assumptions made throughout this section, UMa deployments with cell ranges as short as 50 m could be able to use carrier frequencies as high as 50 GHz in favorable (modern window) and 12 GHz in unfavorable (concrete wall) outdoor-to-indoor scenarios to fulfill the radio link and coverage requirements. In case of UMi deployments, cell ranges as short as 25 m could be able to operate in frequencies as high as 70 GHz and 15 GHz in favorable and unfavorable conditions, respectively.

4.2.3 Conclusions

Increasing antenna gains and channel bandwidths are able to compensate for the more challenging radio propagation conditions at higher frequencies and improve or maintain the average throughput to some extent. However, for the fulfillment of radio link and coverage requirements the network operation is more restricted, requiring shorter cell ranges or lower carrier frequencies according to the building materials involved in the outdoor-to-indoor communication link and the radio link and coverage requirements.

To illustrate this, consider the favorable scenarios (modern window). The 5G network meets the feasibility limits in terms of cell range and carrier frequency at points where the average throughput gains over 4G are still high, relatively close to maximum. For the UMa scenario, the feasibility limits are met at (150 m, 20 GHz), (100 m, 30 GHz) and (50 m, 50 GHz), where the average throughput gains over 4G vary between 6 to 8 times. For the UMi scenario, the feasibility limits are met at (100 m, 20 GHz), (50 m, 40 GHz) and (25 m, 70 GHz), where the average throughput gains over 4G vary between 15 to 20 times.

Further restrictions on the 5G outdoor-to-indoor network deployment can result from the consideration of the reverse communication link. The UE transmission may be subject to technical and regulatory limitations, which avoid UE EIRP levels as high as the 60 dBm assumed for the BS in the presented analysis. Therefore, even with a superior quality of the BS receiver when compared to the UE receiver, which is translated in a lower noise figure, a similar link budget analysis could lead to more reduced cell and carrier frequency ranges for 5G outdoor-to-indoor network deployments.

4.3 Coverage feasibility of different 5G deployment options

In this section, a rough 5G system coverage analysis with different deployment options is provided, taking into account the transmit power and beamforming (BF) uncertainty in high frequency ranges. It should be noted that the propagation models for high frequency ranges are still under discussions so that the interpretations of this analysis are considered as initial research results. Further investigations are needed depending on the progress in propagation model development. In this analysis, the frequency range up to 100 GHz is considered together with the impact of macro-cell densification. Three different deployment options for downlink coverage are examined with node types and user locations leading to different propagation characteristics: outdoor to indoor (O2I), outdoor to outdoor (O2O), and indoor to indoor (I2I).

4.3.1 Models and Approaches

Coverage metric

It is one of challenging tasks to analyze the 5G coverage in high frequency ranges since there is uncertainty in 5G hardware capability. Especially, the beamforming gain and average output power amplifier efficiency in high frequency ranges might not be so well predictable. Therefore, the approach taken here is estimating the required average transmit power and the TRx beamforming (BF) gain in order to reach a certain performance target. The focus is on the cell edge user by assuming a downlink performance target of 50 Mbps. In this example analysis, a fixed bandwidth of 100 MHz and 2x2 MIMO stream in a polarization domain is assumed. According to the Shannon's law this is equivalent to a SINR of -7.2 dB. The required power and BF gain is calculated as follows:

Required Tx power + TRx BF gain (dBm) = S(I)NR target (dB) - Path gain (dB) + Noise power (dBm)

The noise power is computed from:

-174 + 10 log10 (BW) + NF (with bandwidth BW in Hertz and a noise figure NF of 5 dB)

Although this metric may not provide the coverage feasibility directly because the realizable transmit power and TRx beamforming gain are still needed, it gives good guidance on the overall sensitivity in high frequency ranges and also an indication on how much average output power and TRx beamforming gain together are required to achieve a specific target data rate. In principle one can conclude: the higher the value of Tx power plus TRx BF gain, the more difficult it is to achieve the intended coverage.

Deployment scenarios and propagation models

Table 4-5 provides the sketch of three deployment scenarios and main propagation loss components.

The O2I scenario represents the case of indoor services provided by an outdoor rooftop macro-cell. In this scenario, there are several different propagation components jointly affecting the overall coverage feasibility. The base line propagation loss comes from the frequency dependent free space loss. Both building penetration loss and indoor wall loss are included, and they are based on the simple frequency dependent model. For the analysis, two different building types are considered which reflect the different mixture of building materials. Building type I consists of 70% of infrared rejection glass windows and 30% of concrete, which is similar to a modern building with coated windows. Building type II is made up of 30% of standard windows and 70% of concrete which represents classical buildings in Western Europe. Indoor internal wall loss and body loss are added on top of the penetration loss. The indoor wall loss is also dependent on the distance between a transmitter and a receiver, which is 10 meter in this example analysis. Beside of the wall loss, angular loss due to the incident angle of the main ray to building entry is included, and the angle of incidence is assumed to be 60 degree. More details on these models can be found in [SHF+14]. Besides the indoor NLoS condition, there is the additional loss caused by outdoor Macro NLoS before the building entry due to installation of rooftop of the building. This is captured by a diffraction loss. We assume that it is given by

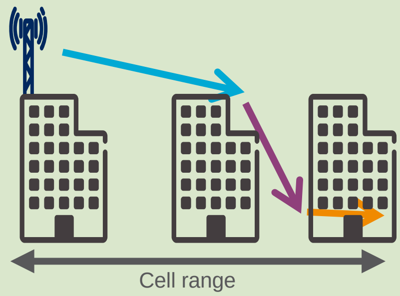
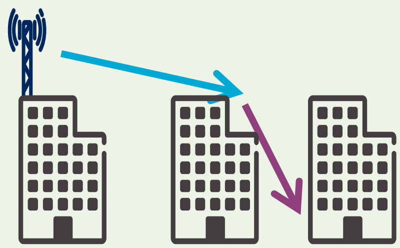
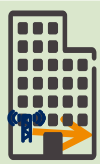
30 + 10log10 (f) where f is the center frequency in GHz.

This model is based on a measurement campaign and simple fitting [ITU-R P.526-13, Nys15]. It is still under development and further refinement based on more measurement results is needed.

In the O2O scenario it is assumed that the user is located outdoor on the street, but there still exists outdoor Macro NLoS with the diffraction loss and the body loss. In this example, no outdoor mobility effect is taken into account so that the baseline O2O scenario corresponds to NLoS stationary users.

In the I2I scenario free space loss, internal wall loss, and body loss are to be considered. An indoor distance of 10 meter is assumed.

Table 4-5: Deployment scenarios and key propagation loss components.

Scenarios		Key propagation loss component
O2I		Free-space loss, diffraction loss, building loss, angular loss, indoor wall loss, body loss
Macro NLoS O2O		Free-space loss, diffraction loss, body loss
I2I		Free-space loss, indoor wall loss, body loss

4.3.2 Analysis results

In Figure 4-4 , the required value of Tx power plus TRx BF gain for frequencies up to 100 GHz for a fixed cell range of 100 m to the edge user is illustrated for different deployment scenarios. It can be seen that O2I is the most challenging scenario, and most sensitive with regard to frequency ranges. This indicates clearly that the spectrum below 30 GHz appears to be essential for ensuring O2I coverage. In addition, there is a very large variance on the O2I coverage feasibility according to the variety of building types and materials. For example, by assuming a macro-cell with 40 dBm average output power and a maximum of 50 dBi TRx beamforming gain, the feasible coverage range would be varying from around 15 GHz to around 32 GHz.

Compared to O2I, the O2O and I2I scenarios have more relaxed requirements on the transmit power and BF capability so that the frequency above 30 GHz could be still useful for these scenarios. However, the beamforming capability is essential to compensate the propagation loss in the high frequency ranges.

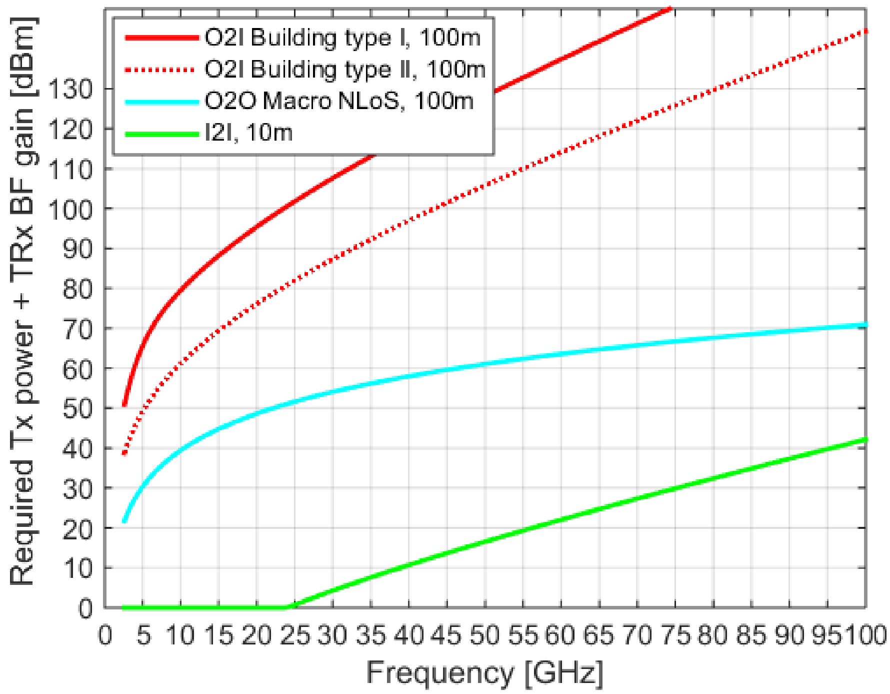
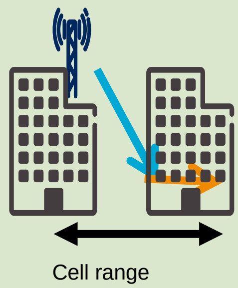


Figure 4-4: Required transmit power + TRx beamforming gain over frequency ranges for different deployment scenarios.

Macro-cell densification for O2I coverage improvement

One solution to resolve the O2I coverage is densifying the macro-cell sites if dedicated indoor deployment is difficult due to the lack of indoor site acquisition. In principle, the densification lowers the free space loss due to a reduced distance and increases the LoS probability. To investigate the extreme dense scenario, the Macro LoS scenario is also investigated as described in Table 4-6. Building penetration loss and indoor wall loss effects are still to be taken into account since the LoS represents only path between the Macro BS and the building entry. Figure 4-5 shows the effect of the macro-cell densification. It can be seen that with a reduced cell range alone the O2I coverage improvement is minimal, unless the Macro LoS scenario is achieved.

Table 4-6: Dense Macro LoS for O2I scenario.

Scenarios		Key propagation loss component
O2I with Macro LoS		Free-space loss, building loss, angular loss, indoor wall loss, body loss

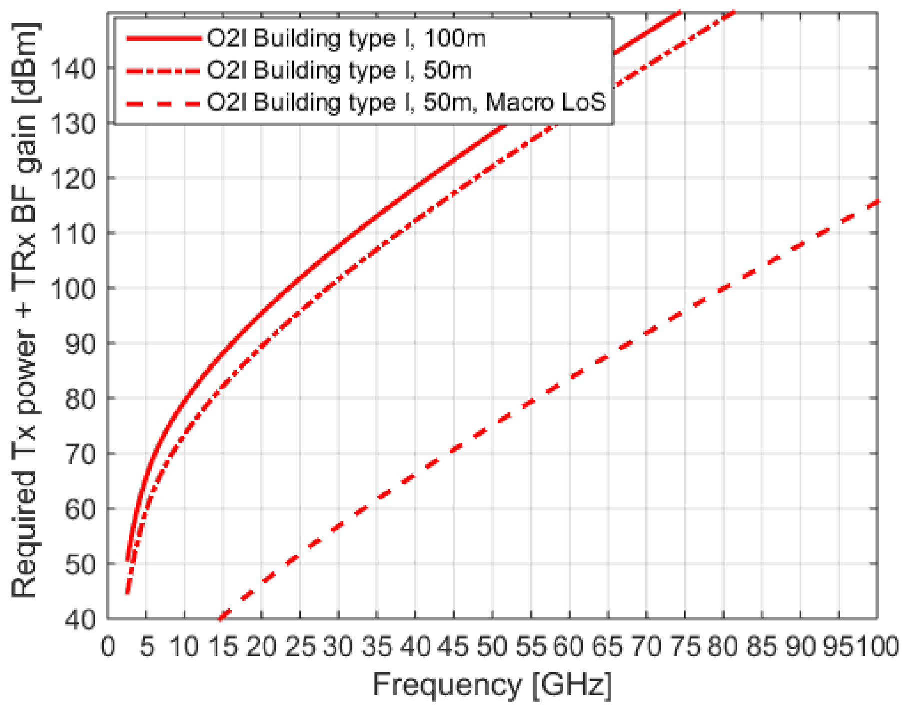


Figure 4-5: Macro densification for O2I coverage improvement.

4.3.3 Discussion on frequency ranges and deployment options

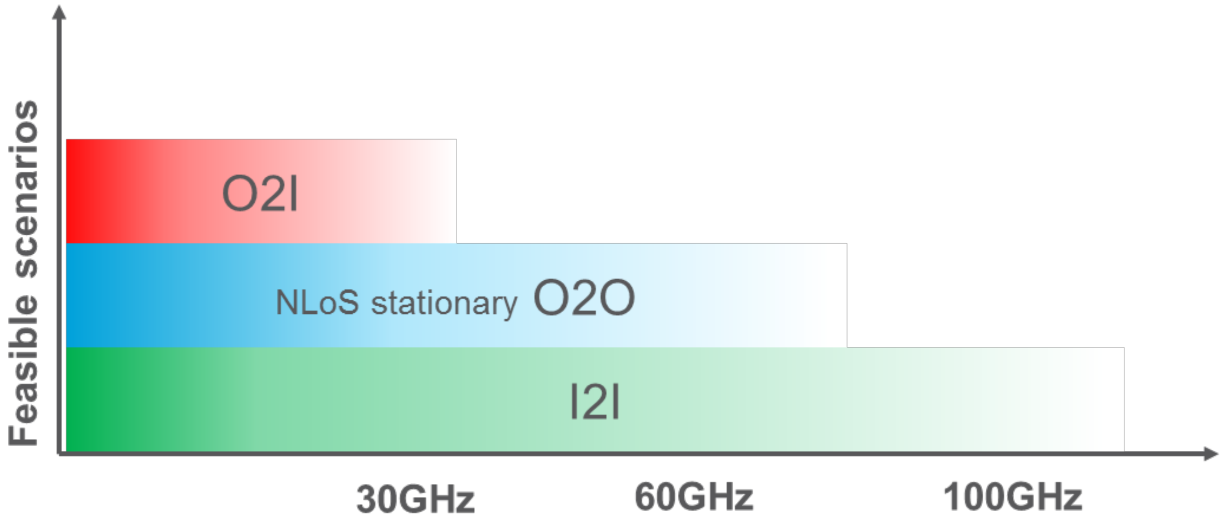


Figure 4-6: Indicative coverage feasibility of different deployment scenarios in different frequency ranges.

With a simple link budget based analysis, the sensitivity of frequency ranges with regard to achievable coverage for different deployment options and environments can be demonstrated. Although scenarios such as O2I coverage would be affected significantly by building types, the rough estimated results show that the lower the frequency, the more diverse deployment scenarios in terms of coverage can be supported, as illustrated in Figure 4-6. For instance, frequencies below 30 GHz are in particular useful since all three considered deployment scenarios are feasible. Especially, frequencies below 30 GHz are beneficial for O2I coverage since early 5G services may still rely on outdoor systems until dedicated indoor deployment is realized. In addition, outdoor macro-cell densification provides limited indoor coverage enhancement unless LoS between the macro-cell and the building entry is ensured. Although the frequencies above 30 GHz might not be the best option for O2I coverage, they are suitable for other deployment scenarios if advanced beamforming technologies with high antenna gain are applied. In the range between 30 GHz and 60 GHz, stationary outdoor services and dedicated indoor services appear to be feasible for the considered distance assumptions. Outdoor mobile services require further studies by considering real-time beam tracking and CSI acquisitions so that the O2I coverage feasibility in this study is only limited to the stationary user case. At frequencies above 60 GHz, dedicated indoor services could be still feasible, thus this range might be advantageous due to the availability of bands with large contiguous bandwidth.

5 Conclusions and next steps on 5G spectrum work in METIS-II

In this deliverable a view on future spectrum usage scenarios has been given, taking into account information from the wireless industry as well as vertical industries. The general conclusion with regard to spectrum authorization for 5G is that

- exclusive licensed spectrum is essential for the success of 5G to provide the expected QoS and to secure investments,
- shared spectrum can be considered in addition, provided that predictable QoS conditions are maintained, e.g. by LSA regime,
- license-exempt spectrum might be suitable as a supplementary option for certain applications, for instance using the LAA (License-Assisted Access) scheme.

Technical aspects like coexistence, performance, and coverage have been considered as well. The main conclusion is that the higher propagation losses with increasing carrier frequencies might be compensated to some extent provided that larger channel bandwidths are available than for lower carrier frequencies, or by implementation of advanced antenna systems. But the more challenging radio propagation conditions impose more restrictions for the cell size for outdoor to indoor (O2I) deployment scenarios.

The roadmap to enable and secure sufficient access to adequate spectrum for 5G has to include a quantity (such as spectrum bandwidth demand) and quality (such as radio propagation conditions) assessment of the spectrum aspects for 5G usage scenarios. Currently, different estimation approaches are under consideration in other organizations like e.g. in ITU-R: a traffic forecast-based approach, an application-based approach, a survey-based approach and finally a technical performance-based approach. These approaches differ basically with regard to the input parameters used for the estimation: e.g. for the traffic forecast-based approach, the user demand forecasts to predict future usage is utilized, while for the technical performance-based approach, certain key performance indicators and capabilities are used to estimate the bandwidth demand.

In 5G systems, diverse applications will be deployed and multiple performance requirements may need to be met at the same time, e.g., traffic volume density and user experienced data rate. Therefore, the spectrum demand analysis should take into account the multiple requirements for multiple deployment scenarios.

The bandwidth (BW) requirement analysis developed in the METIS project [MET14-D53] was based on the assumption of different achievable values of SINR Gaussian distributions, whose availability will finally depend on the Technology Components (TeC) deployed. In fact, the performance of any TeC was evaluated in terms of SINR enhancement compared with the previous state of the art. Several other parameters, as the radio link spectral efficiency, traffic patterns, etc. were also estimated in order to obtain the first analysis of BW requirements for the scenarios under study. One of these parameters used for the estimation was the reuse factor of the BW, which could be estimated for a number of Transmission Reception Points (TRPs). In order to obtain more accurate BW requirement estimations, and to link this value to the actual two dimensions deployment of TRPs and User Equipment (UE), an enhanced approach with randomization of both elements over the scenario area is going to be developed in METIS-II.

Furthermore, novel dynamic spectrum access concepts (including spectrum sharing, necessary technical enablers and 5G spectrum management architecture), are going to be studied. The availability of different air interfaces, addressing the challenges of diverse spectrum scenarios with additional spectrum ranges above 6 GHz, new ways of spectrum authorization, more dynamic and local use of spectrum, will be taken into account.

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A Annex: Spectrum options for different 5G user groups

In the following sections the spectrum aspects of different 5G user groups are summarized. For the vertical industries considered in A.1, the information is based on white papers: [5GPPP15-A], [5GPPP15-H], [5GPPP15-E], [5GPPP15-F], [5GPPP16-M&E]. For the other potential user groups touched in A.2, respective ECC Reports have been used.

A.1 Vertical industries

A.1.1 Automotive sector

Usage scenarios

There are two broad categories of potential automotive applications; those based on wide-area infrastructure-based communications (V2N), and those based on short-range communications (V2V, V2I, V2P, etc.).

Spectrum options

Many infrastructure-based applications are likely to require reliable contiguous coverage, and therefore need mobile bands preferably below a few GHz.

Additional spectrum is likely to be required for shorter range and extreme traffic density. This is likely to be identified above 6 GHz.

In the framework of automotive connectivity, ITS applications are intended to be operated in the 5.9 GHz band.

Dedicated spectrum has the advantage that there is no sharing with other applications, and therefore a tighter security control and integrity can be applied. A designated band can also simplify roaming as end users drive between different countries or regions.

Use of an unlicensed band could simplify access, without any license fee burden. In this sense, the unlicensed bands may be suitable for V2V communication. As integrity is still important in this scenario, it may be provided by higher layers of the protocol stack.

A.1.2 E-Health sector

E-health is the transfer of health resources and health care by electronic means. It encompasses three main areas:

- The delivery of health information, for health professionals and health consumers, through the Internet and telecommunications,

- Using the power of IT and e-commerce to improve public health services, e.g. through the education and training of health workers,
- The use of e-commerce and e-business practices in health systems management.

Usage case families and their requirements

- Assets and interventions management in hospitals
  - scalability of connectivity in terms of number of connected devices,
  - precise positioning accuracy of around 1 meter in indoor conditions,
  - support for multi-Radio Access Technologies with seamless handover,
  - mobility > 300 km/h.
- Robotics
  - reliability of transmit/received data, the connectivity should be available even in case of natural disaster,
  - low latency in the order of 30 ms.
- Remote monitoring of health or wellness data
  - Coverage, including very good indoor coverage,
  - energy consumption and battery life at device level to avoid any charge/battery replacement for at least 10 years,
  - mobility at high speeds (> 300 km/h).
- Smarter medication
  - coverage and mobility,
  - energy efficiency for connected artefacts, in the same order of magnitude as for remote monitoring. High number of connected objects per covered area.

Current Technology options

Today there exist a wide variety of wireless network technologies, ranging from short-range point-to-point communication, over wireless sensor networks, cellular networks, wireless networks of the IEEE 802-family of networks, etc. In many cases each of the technologies specifies a number of profiles that are aimed to meet certain requirements. This situation makes it extremely difficult for developers to make the best choice of technologies to implement in a wireless medical device. The result is that ensuring and certifying proper functioning of the devices (e.g. interoperability among each other) is an extremely costly undertaking and is a roadblock for massive deployment of properly functioning and certified devices for medical applications.

Current spectrum options and aspects

- ISM bands are reserved for medical devices,
- Specific licensing of spectrum for medical use might be an innovation killer,
- Manage interference, i.e. certifying correct functioning and fair spectrum use.

A.1.3 Energy sector

Usage scenarios

Communication networks for Smart Grids, Smart Meters and other use cases such as Electric Vehicles need to be able to serve the needs of various applications. Since these assets in a smart grid network currently have no communications or measurement equipment in the medium, 5G can provide economically viable wireless solutions.

Spectrum options

The European Utilities Telecom Council (EUTC), for example, recommends the use of dedicated spectrum in its position paper [EUTC13-PP] and lists a certain number of spectrum parts to be considered:

- Dedicated spectrum of 2 x 3 MHz in the frequency range 450-470 MHz to satisfy conditions for the roll-out of smart meters as well as for grid management,
- Additional 10 MHz of spectrum in the L-band (1500 MHz range) for more data intensive applications, including security and point-to-multipoint applications,
- Complementary spectrum, including deregulated shared spectrum in the band 870-876 MHz.

A.1.4 Factories sector

Fundamental to the industrial revolution is the implementation of a reliable communication layer capable of dealing with an increase in several orders of magnitude the number of assets, volume, and variety of information and reaction times in future manufacturing systems. 5G promises to be a key enabler for Factories of the Future as it will provide the unified communication platform needed to disrupt with new business models.

Usage scenarios

Five use case families have been identified:

- Time-critical process optimization inside factory: This use case family is characterized by communication latencies that may go below 1ms.
- Non time-critical optimizations inside factory: Given the harsh and metalized industrial environments, indoor coverage and high availability are key requirements.
- Remote maintenance and control: This use case family will require increased capacity to facilitate video-supported remote maintenance, from any place in the world.

- Seamless intra-/inter-enterprise communication: To support these use case, there is a specific need for flexible, reliable and seamless connectivity across different access technologies, as well as the support for mobility.
- Connected goods: For this use case family there is the need for ultra-low-power (high autonomy), and ultra-low-cost communication platforms.

Technology aspects

Current networking technologies don't offer the capabilities to easily manage and optimize the network performance for a diverse set of wireless technologies, protocols and data formats. In manufacturing, commonly used technologies are 2G/3G, WirelessHart, ISA100.11a, Wi-Fi and ZigBee. As the majority of machine interactions are still executed using wired technologies, there is still a lack of technology to monitor and optimize wireless networking.

The total cost of ownership of factory automation systems will be largely determined by its capability to manage heterogeneity of device types, wireless technologies and vendors in a cost effective way. Regarding wireless technologies, there won't be a single technology that can meet the different, varying requirements of the 5 use case families.

Spectrum related issues

To cope with the increasing diversity of wireless IoT systems in manufacturing, there is the need for novel capabilities to ensure the same level of reliability as offered in wired architectures. To manage the co-existence of wireless technologies, new protocols are needed to manage the cooperation of technologies working in the same frequency band, or to spread the usage over multiple frequency bands in a coordinated and adaptive way.

A.1.5 Media & Entertainment sector

The biggest change driving all others in Media & Entertainment is associated with the fact that the individuals themselves do not only passively consume, but interact, share, chat, talk, tweet, while walking, running, driving, commuting by subway or train etc., during their media and entertainment enjoyment.

Usage scenarios and requirements

5G shall enable at least six main families of use cases with an overall user experience that well exceeds that of 4G and other legacy networks:

- Ultra-High Fidelity Media,
- On-site Live Event Experience,
- User Generated Content & Machine Generated Content,
- Immersive and Integrated Media,
- Cooperative Media Production,
- Collaborative Gaming.

Requirements

In order to achieve the Media & Entertainment experience that consumers and businesses are starting to expect "anywhere, anytime", a number of critical requirements need to be met in terms of improved capabilities. As shown in Figure 6-1, these requirements are a function of the use case.

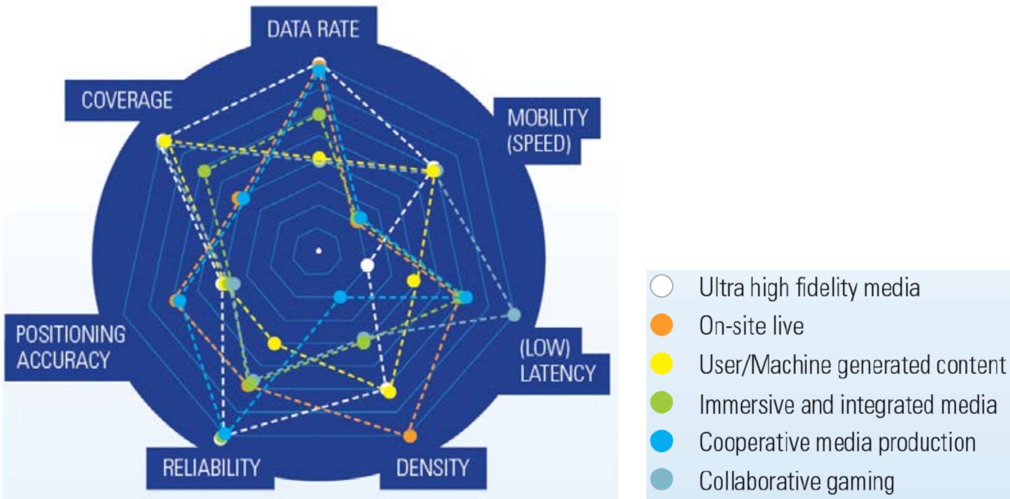

Figure 6-1: Capability spider diagram for Media & Entertainment (Source: [5GPPP-M&E]).

A.2 Other potential user groups

In addition to the vertical industries, other potential 5G user groups could be envisaged. Three of them are considered in the following subsections.

A.2.1 Public Protection and Disaster Relief

The Public Protection and Disaster Relief (PPDR) sector is typically regarded as vital and of the utmost importance to maintain law and order and to protect the life and values of citizens. For most nations PPDR is intimately connected to the public sector of society, both directly as part of the governmental structure or as a function which is outsourced under strict rules and intensively monitored by governments contracting ministry or department.

The main use cases for Broadband-PPDR (BB-PPDR) are:

- Wide area network (WAN) communication,
- Airborne communications, Air-Ground-Air (AGA),
- Direct terminal to terminal communications,
- Ad-hoc network communication.

Technology and network implementation aspects

The PPDR user community wants BB-PPDR to be part of the global LTE ecosystem due to benefits derived from economies of scale achieved in commercial networks and the commitment to develop mission critical capabilities into the standard.

BB-PPDR services could generally be provided via three infrastructure implementation models:

- Dedicated network infrastructure for BB-PPDR (either owned by the government or a contracted operator),
- Commercial network(s) infrastructure (provided by one or several commercial mobile network operators over networks carrying both PPDR and commercial traffic),
- Hybrid solutions with partly dedicated and partly commercial network infrastructure.

Candidate frequency ranges for harmonization

Spectrum has been identified for the optional implementation of BB-PPDR services in CEPT countries [ECC15-R218] within the 400 MHz band (Figure 6-2) and the 700 MHz band (Figure 6-3).

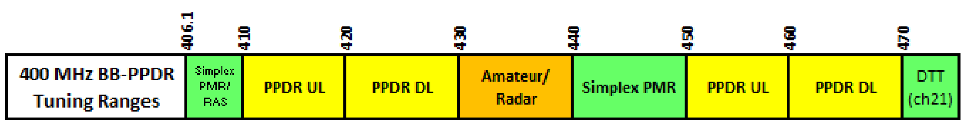

Figure 6-2: BB-PPDR tuning range and other primary usages in the 400 MHz band.

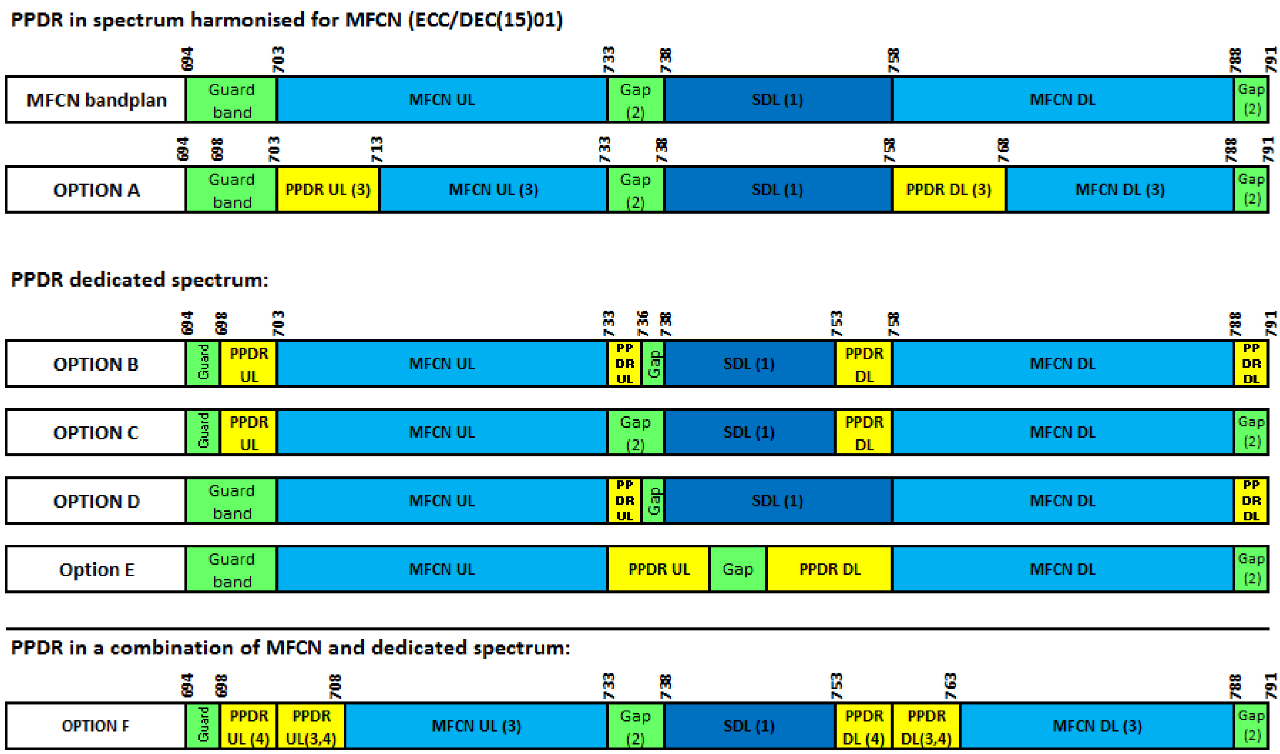

Figure 6-3: Principal options for BB-PPDR in the 700 MHz band.

Spectrum requirements

The main conclusion in the CEPT Report is that a minimum amount of spectrum in the range of 2x10 MHz is needed for broadband data communications in the future European BB-PPDR WAN [ECC13-R199]. However, there could be additional spectrum requirements on a national basis to cater for direct terminal to terminal communications (off-network working), AGA, ad-hoc networks and critical voice communications over the WAN.

While the same frequencies as for the WAN could be used for direct terminal to terminal communications and ad-hoc networks, [ECC13-R199] does neither provide an indication on alternative options nor a solution for future BB-PPDR AGA systems.

The assumption is that mission critical voice will continue to be carried in most CEPT countries by the existing dedicated mission critical voice (and narrowband data) TETRA and Tetrapol networks until years 2025-2030. The duplex bands 380-385/390-395 MHz have been designated for such narrow-band PPDR networks. However, some PPDR agencies could migrate all of their mission critical voice and data services on to network(s) using broadband technology such as LTE in a shorter timescale.

A.2.2 Programme Making and Special Events

Service and technology aspects

The range of applications covered by PMSE spans from theatrical productions and corporate events to various levels of broadcasting contribution activities. Terrestrial audio and video links are used for a number of Programme Making and Special Events applications (PMSE). In addition, a variety of different service links are required in order to facilitate and organise the production of programmes and special events.

A range of new technologies has been or is currently being developed that may increase spectrum efficiency. However, they will not have a deep penetration to PMSE equipment for a number of years.

Spectrum considerations

Spectrum identified for the use by PMSE is considered on a tuning range basis. PMSE has always shared spectrum with a wide range of services. Generally, individual licenses are issued for a specific use on a specific date and at a specific location.

PMSE usage has been built around current spectrum allocations which have been in place for decades. In recent years, available spectrum for PMSE has been reduced since parts of these spectrum allocations have been targeted for other usages as a consequence of the digital dividend, and of the increase of bands designated for mobile broadband.

Due to the range of activities that PMSE covers, from single camera news-gathering to multi-camera international sporting or cultural events, and the temporal and location specific nature of use it is difficult to quantify spectrum requirements. However, it is clear that the use of cordless cameras has seen an increase over the last few years as production values and coverage requirements have increased. This has correspondingly led to an increase in demand for spectrum, especially to support major events. More details can be found in [ECC14-R204].

A.2.3 Private/ Professional Land Mobile Radio

Private / professional land mobile radio systems – often shortly called PMR or PAMR – typically can support the industrial sector, transportation sector (including airports and railways) and governmental sector (blue light forces, but also e.g. embassies), lifesaving services, cross border links, the energy/utilities sector (smart metering/smart grids), hotels/tourism sector, financial sector, the agricultural and forestry sector, the retail sector, or electronic communications for the public.

Technical implementations can be differentiated into three tiers:

- Direct peer-to-peer communications,
- Communications between a base station and mobile user equipment,
- Implementations with a common control channel (trunking systems).

Current systems and evolution

At this stage PMR systems could be digital, but also numbers of them are still using analogue transmissions. Some equipment is staying in operation more than 15 years and there are little benefits for the users to migrate to more efficient technology. In order to promote migration from analogue to digital PMR, administrations may consider a minimum required spectral efficiency.

The evolution of technologies is expected to follow the general evolution in the radio communication sector. LTE seems to be a technology that can evolve to meet PMR needs with channel bandwidths of less or equal to 1.4 MHz, 3 MHz, 5 MHz or 10 MHz.

Spectrum considerations

Whenever practicable, the same frequency bands should be assigned in different CEPT countries for land mobile systems for PMR as identified in [ECC08-TR2508] that also provides guidance on international cross-border co-ordination issues. The band planning in three PMR bands is shown in Figure 6-4.

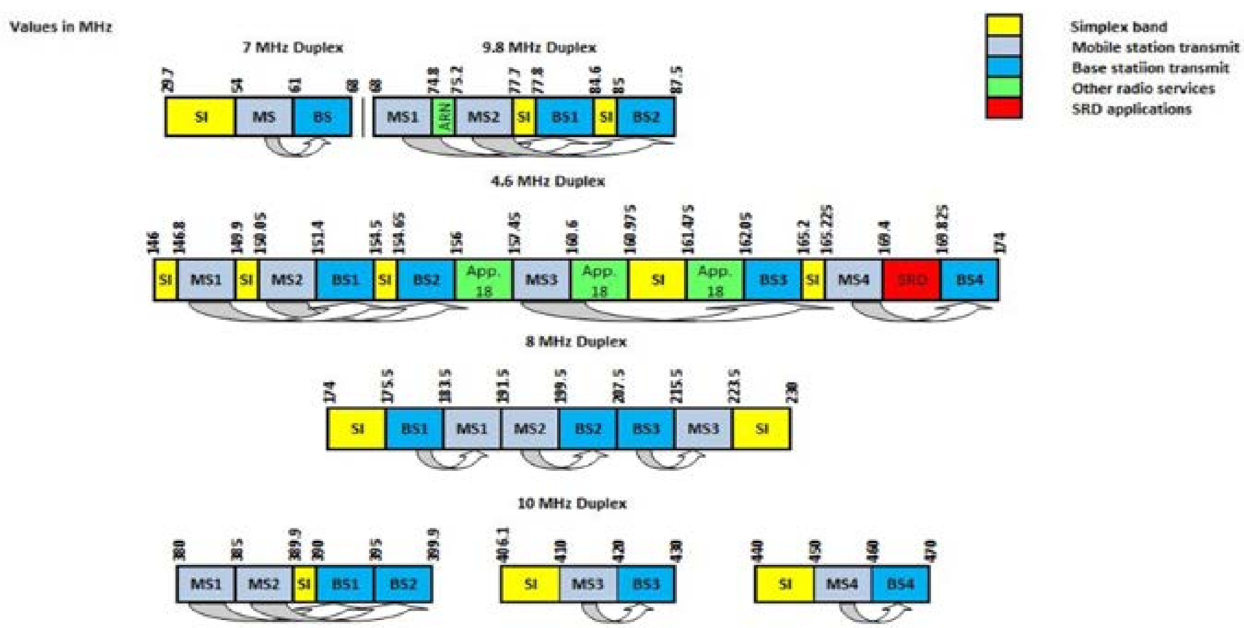

Figure 6-4: Band planning in PMR bands.

The regulatory framework for PMR in the 450-470 MHz band is currently under review in ECC Project Team FM54. Also the band 870-876 MHz paired with 915-921 MHz, which is adjacent to the GSM-R band 876-880 MHz paired with 921-925 MHz, is designated to PMR.

The RSPG [RSPG13-540] has not identified any indications that the bandwidth requirements of the narrowband PMR sector will increase within the medium or long term future.