European Commission

Study on using millimetre waves bands for the deployment of the 5G ecosystem in the Union

FINAL REPORT

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IDATE DIGIWORLD

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List of abbreviations

3D	3 Dimensions
3GPP	3rd Generation Partnership Project
AI	Agenda Item
AR/VR	Augmented Reality / Virtual Reality
BBU	BaseBand Unit
BS	Base Station
CBRS	Citizen's Broadband Radio Service
CEPT	European Conference of Postal and Telecommunications Administrations
CPE	Customer Premises Equipment
DL	Downlink
eMBB	Enhanced Mobile Broadband
EESS	Earth Exploration Satellite Services
FCC	Federal Communication Commission
FDD/TDD	Frequency Division Duplex/Time Division Duplex
FNRM	Further Notice Proposed Rules Making
FS	Fixed Services
FSS	Fixed Satellite Services
FWA	Fixed Wireless Access
GEO	Geostationary Earth Orbit
GPS	Global Positioning System
IMT	International Mobile Telecommunications
IoT	Internet of Things
ISD	Inter-Site Distance
ITS	Intelligent Transport Systems
ITU	International Telecommunication Union
LEO	Low Earth Orbit
LOS / NLOS	Line-Of-Sight and Non Line of Sight
LTE	Long Term Evolution
MEO	Medium Earth Orbit
MFCN SDL	Mobile/Fixed Communications Network Supplemental Downlink
MNO	Mobile Network Operator
mMTC	Massive Machine Type Communications
MIMO / MU-MIMO	Multiple Input Multiple Output / Multiple User MIMO
NATO	North Atlantic Treaty Organization
NRA	National Regulation Authority
NYU	New York University
PFD	Power Flux Density
PPDR	Public Protection Disaster Relief
QoS	Quality Of Service
R&O	Report & Order
Rx	Receive x
RRH	Remote Radio Head
RSPG	Radio Spectrum Policy Group
SRS	Space Research Services
TRxP	Transmit Receive xP

TTT	Transport and Traffic Telematics
Tx	Transmit x
UAV	Unmanned Aerial Vehicle
UL	Uplink
UE	User Equipment
UHD	Ultra High Definition
URLLC	Ultra-Reliable and Low Latency Communications
V2X	Vehicle-to-X (infrastructure, vehicle…)
WBB ECS	Wireless Broadband Electronic Communications Service
WRC	World Radiocommunications Conference

0. Executive summary

0.1. Context and methodology of the study

The study on using millimetre wave bands for the deployment of the 5G ecosystem in the Union (SMART 2017/0015) was carried out by a team led by IDATE DigiWorld with Plum Consulting and Scott Marcus.

The objectives of the study were the following:

- Identify the state of play and the prospects for the use of the mm-waves frequency bands[1], for the 5G ecosystem;
- Clarify the role of the '26 GHz' band and the use of the adjacent '28 GHz' band for fixed and/or satellite;
- Contribute to the assessment of opportunities for electronic communications as well as other relevant services, in line with the 5G Action Plan (5GAP);
- Assess the potential health effects due to exposure to the electromagnetic fields (EMF).

The methodology of the study combined desk research, interviews with 30 experts/stakeholders and a stakeholder's workshop organised on 30 May 2018 prior to finalising the second Interim Study report. The main objectives of this workshop were to gather necessary evidence and information from relevant stakeholders and experts to improve the findings from the various tasks of the study.

This Final Report is the result of the research carried out and the feedback received from stakeholders during interviews and the workshop. It comprises the following chapters:

Chapter 1 is the introduction of the report.

Chapter 2 (Identification of potential 5G services in mm-wave bands and analysis of the potential demand) describes the potential mm-wave services that are expected to use mm-wave bands, presents 5G market forecasts and the expected demand for 5G services in the mm-wave bands. It also provides an evaluation of spectrum capacity in mm-wave bands and presents trials and plans for 5G services in Europe and in advanced countries in other regions of the world. Finally, it covers the impact of 5G on growth, employment and competitiveness.

Chapter 3 of the study (Analysis of potential co-existence scenarios and assessment of the prospects for the evolution of the business environment) provides a detailed, but selective, review of the work undertaken within ECC PT1 and ITU-R TG5/1 concerning potential spectrum allocations for 5G millimetre-wave services. The aim of this review was to give an indication of the likely constraints, both spectral & geographical, that will be imposed on occupants of these bands in the future. This information, combined with knowledge of the telecommunications market across Europe and our awareness of technical network options, has allowed us to study options for the evolution of the business environment in the bands affected.

Chapter 4 (Allocation and authorisation of mm-wave spectrum for 5G) covers allocation and authorisation of mm-wave spectrum for 5G. The current position on allocation and authorisation is reviewed based on the literature, research interviews undertaken as part of the study, the outcome of the workshop held on 30th May 2018 and consultation and other documents published by Spectrum Management Authorities (SMAs) in recent months. It should be noted that this area continues to develop with further outputs expected from SMAs.

In chapter 5 (Assessment of the prospects for the development of hybrid scenarios or systems) the prospects for the development of hybrid scenarios or systems in the European 5G context are considered, together and their impact on efficient spectrum use.

[1] Framed by ITU Resolution 238

Chapter 6 presents implications of exposure to electromagnetic fields in the mm-wave bands.

Chapter 7 summarises the findings of the study and presents the recommendations.

0.2. Key findings

Key findings of this Study can be summarised as follows:

0.2.1. Identification of potential 5G services in mm-waves bands and analysis of the potential demand

- Services expected to use mm-wave bands are the following:
  - Enhanced Mobile Broadband (eMBB) services for high capacity (Fixed Wireless Access (FWA), high-definition video communications, virtual, augmented and mixed realities),
  - Services for vertical sectors including automotive (V2X: Vehicle-to-everything, autonomous cars), other transportation (trains and buses), manufacturing / industrial automation, energy grid communications, smart cities, and medical applications;
  - Public safety and
  - Fronthauling / backhauling.
- The first services that are likely to be deployed in mm-wave bands will be eMBB and new use cases of backhauling (different from incumbent fixed links), but no killer application has been identified so far.
- Use of the mm-wave bands will be progressive in Europe with expected initial adoption by 5G operators in congested hot-spots, roads and major transport paths. Deployment of small cells using the 26 GHz band is expected to start in 2022-2023, but with limited initial volumes.
- Based on our evaluation, a maximum of 10% of the 5G cell sites would support mm-waves in 2025.
- The framework for using existing spectrum for 5G is considering 2020 for availability in EU-28 countries. For EU-28, the expected availability of at least 1 GHz in the 26 GHz band in 2020 will provide sufficient initial capacity for the progressive 5G deployment.

0.2.2. Analysis of potential co-existence scenarios and assessment of the prospects for the evolution of the business environment

- Of the potential coexistence issues, only that with 26 GHz fixed links appears to require significant study.
- The decision to protect the EESS (passive) service below 24 GHz with a stringent out-of-band emission limit at 26 GHz has enforced a 'maximum compliance' approach, with implications for the practical availability of the lower part of the 26 GHz band. This may have an impact more in terms of the administrative process for spectrum assignment (i.e. block sizes available for operators) than on constraining capacity, given the relatively long period foreseen to build demand at mm-wave.
- Co-ordination with receiving (EESS, SRS) and transmitting (FSS) Earth stations is not expected to be a significant constraint on 5G deployment, due to the small number[2] of sites involved and their rural location. CEPT Report 68 also notes the "*need to maintain the possibility for additional earth stations to be deployed in the EU Members States…*". The necessary technical tools for coordination with these services already exist.

[2] There are five major Ka-band receive Earth stations operating in the EESS and SRS within Europe (see Section 3.6.2)

- Studies in PT1 and elsewhere indicate that no significant co-existence issues are envisaged with respect to the 40.5 – 43.5 GHz band identified in the RSPG 'second opinion' as a priority band for second-stage deployment.
- The 66-71 GHz band, identified as the other 'second-stage' 5G band, is attractive partly by virtue of its adjacency to the existing 57 – 66 GHz licence exempt band. The potential for adjacent band interference between the two allocations is under study, but is unlikely to be more problematic than that between different users within the same band.

0.2.3. Allocation and authorisation

Below is a summary of the findings on allocation and authorisation.

- There is recognition among SMAs that the 26 GHz band is a priority band for 5G and that it should be made available when demand occurs.
- Member States indicated that they will make at least 1 GHz of the 26 GHz band available before the end of 2020 in line with the Code and this is likely to be the frequency range 26.5-27.5 GHz as recommended by RSPG.
- The sub-band below 26.5 GHz is more problematic to make available in the near term in Member States due to both the presence of incumbent services and the requirement to protect space sensors of the EESS.
- In line with good practice, the least onerous and most flexible access mechanism should be adopted as a default for authorisation of mm-wave spectrum. However, most SMAs have yet to publish proposals on this.
- For the 26 GHz band, there are authorisation challenges resulting from protection of incumbent and out of band services, including the EESS. This tends to point toward use of an IA or light licensing approach for this band.
- Subject to study of local circumstances, different authorisation approaches may be possible for indoor vs outdoor services. Consideration should be given to GA for indoor if protection requirements can be met (subject to retaining a common band plan).
- Consideration should be given to authorisation mechanisms to enable regional and local operators as well as industry vertical to access mm-wave spectrum on a location basis. Use of a GA or light licensing approach could enable access for these players.
- While there may be legitimate reasons for differences in authorisation approaches between Member States based on local conditions, there is a need for consistency and coordination between Member States to avoid fragmentation and reducing investment incentives, in particular for services with a pan-European dimension (for example services that are used either side of a country border such as for railways).
- Authorisation in the 26 GHz band could be based on the use of a mechanism based on advanced database techniques (e.g. LSA) to provide the required flexibility and adaptability over time as demand for both 5G and incumbent services develop.
- The position on authorisation of other mm-wave bands is less clear but there appears to be a consensus emerging on use of GA for the 66-71 GHz band.

0.2.4. Hybrid services

- Developments on satellite hybrid solutions are taking place (with a global emphasis as well as Europe)[3]. However, there seems to be a lack of awareness among many of what is happening (albeit at an early stage) and these developments are lagging behind terrestrial ecosystem developments.

[3] For example, the Sat5G project, which is addressing 6 pillars of work including SDN/NFV for satellites, network management and network orchestration, multilink and heterogeneous transport, harmonisation of satcom and the 5G user plane. Also, Satis5 – a demonstrator for satellite – terrestrial integration in the 5G context

- Further analysis is required of the potential satellite use cases that hybrid solutions potentially enable in the European context, given the high penetration of terrestrial solutions.
- No interest was expressed by any of the stakeholders approached in broadcast / terrestrial 5G convergence.

0.2.5.EMF

- As regards wireless services in general and mobile services in particular, there have been long-standing public concerns over possible health effects due to exposure to the electromagnetic fields (EMF).
- Various global and regional bodies have studied EMF effects, including the World Health Organisation.
  - A quite huge literature exists on the analysis of overall health effects of EMF associated with mobile services. A number of rigorous studies have been conducted, including epidemiological cohort and incidence time trend studies and animal studies. In this chapter, we review a number of the most recent and most highly respected results (see especially Section 6.5.1).
  - There are diverging views on the interpretation of the results of this research.
  - Existing literature seems to indicate that current scientific evidence has not conclusively demonstrated that wireless and mobile communications cause harmful health effects in humans when operated within established limits; however, risks cannot be excluded.
  - Health effects associated with mm-waves are distinct from those in the traditional mobile bands because mm-waves have little ability to penetrate the skin. Even though mm-waves have not been used for mobile services, there is a body of research on potential health effects due to the use of mm-waves in Eastern Europe for medical purposes; however, very little reliable and reproducible data is available. Among these, the most reliable research results are associated with pain relief (analgesia). (Le Dréan et al. (2013))
  - Other than heating effects (which are not significant at the power levels to be expected for 5G), no harmful mm-wave health effects have been demonstrated in humans to date. (Le Dréan et al. (2013)) Many assume that health effects would be limited to the skin and eyes, due to the limited penetration; however, the use in Eastern Europe of mm-waves for pain relief raises the possibility that there might also be effects that are transmitted in other ways. (Le Dréan et al. (2013))
- In Europe, EMF guidelines for non-ionising[4] EMF are primarily based on the guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The current ICNIRP guidelines are reflected in a 1999 Council Recommendation[5] on the permissible level of emissions for equipment to be deployed. Article 58 of the newly enacted European Electronic Communications Code (EECC) effectively requires Member States to notify the Commission of draft measures where the Member State intends to deviate from the Council Recommendation, and empowers the Commission or other Member States to propose amendments to the draft measure in order to remove or reduce barriers this might create to the free movement of goods.
- Some Member States, and some regions or municipalities within Member States, impose EMF limits one or even two orders of magnitude more restrictive than the Council Recommendation of 1999. At these levels, 5G deployment would likely be seriously impeded.

[4] Non-ionizing radiation is the term given to radiation in the part of the electromagnetic spectrum where there is insufficient energy to cause ionization. It includes electric and magnetic fields, radio waves, microwaves, infrared, ultraviolet, and visible radiation (see https://www.who.int/topics/radiation_non_ionizing/en/).

[5] European Council (1999), Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz), (1999/519/EC).

- The move to 5G will be accompanied by a move to large numbers of small cells, some of them operating in the mm-wave bands. Exposure of the population to EMF is less than linear in the number of base stations; nonetheless, the shift is sure to change exposure. Transmit power in the mm-wave bands will be much lower than is typical in the macro cellular network today, but the presence of large numbers of base stations in conjunction with beam-forming means that exposure at any given instant in time could vary greatly depending on where an individual is relative to the base stations, and which locations they are sending to at that moment.
- Our modelling results suggest that any increase in exposure of the population to EMF caused by the shift to 5G and small cells is likely to cause only a very modest increase in exposure of the population to EMF. This is broadly in line with measurements conducted in a measurement study relating to the deployment of small cells in the town of Annecy by the French ANFR,[6] which found an increase in EMF associated with the move to small cells of only 0.1 V/m (to a maximum of 0.5% of the ICNIRP limit). The ANFR study represents only a single small city under a 4G small cell deployment scenario that may or may not prove to be fully representative of 5G deployments, but it nonetheless represents an important datum to the extent that it embodies experience in a real world setting.
- The characteristics of 5G raise new issues for the measurement of EMF. Simply measuring the power delivered to the antenna is of limited value in a setting where beam-forming plays a key role; moreover, 3GPP specifications for base stations operating above 24 GHz assume that no antenna connectors will be available and that power must therefore be defined in terms of Over-the-Air (OTA) performance (see Section 6.8). Measurement is therefore possible only where a user terminal is present. Standards bodies including 3GPP are currently studying these issues. The recommendations that we make in this report reflect the contingency that the standards bodies might not settle on a solution to this problem as quickly as Europe needs or desires it.
- In order to ensure that EMF limits are respected it is likely that national authorities will find it necessary to place greater reliance on field tests than in the past. Exchange of best practice among national authorities will probably be needed (as suggested by COCOM),[7] possibly accompanied by action on the part of the Commission.

[6] See https://www.anfr.fr/fileadmin/mediatheque/documents/Actualites/2017-04-26 - Rapport résultats Annecy.pdf.

[7] COCOM Working Group on 5G (2018), "Report on the exchange of Best Practices concerning national broadband strategies and 5G "path-to-deployment", COCOM18-06REV-2.

0.3. Recommendations

Our recommendations are the following:

1. In light of the low risk of harmful interference, the primary focus of the European Commission in monitoring Member State developments as regards allocation and authorisation of mm-wave bands for 5G should be on ensuring that the objectives set in the European Electronic Communications Code as regards the timely availability for use of the 5G pioneer bands are achieved.

2. The European Commission should monitor the implementation of vertical services within the European Union using mm-wave spectrum and work with relevant Spectrum Management Authorities and/or NRAs to ensure that there are no barriers or authorisation conditions which could slow down the implementation of vertical services using mm-wave bands.

3. Authorisation of mm-wave spectrum for 5G at Member State level should take into account (1) spectrum availability in the band in question, (2) specific competitive circumstances, and (3) the risk of harmful interference, which is likely to be far less for mm-wave than for frequencies below 6 GHz. An overall goal is that licensing regimes be no more onerous or restrictive than is strictly necessary, and that they promote opportunities for the sharing of spectrum. This implies that Member States should consider light licensing regimes in the 26 GHz band if scarcity is present; otherwise, General Authorisation should be preferred. Furthermore, any progressive authorisation of the 26 GHz band should facilitate contiguity of spectrum holdings upon market demand. The Commission should monitor the development by ETSI of ENs for 5G mm-wave bands[8], which will improve the coexistence and authorisation environment for 5G and future incumbent service deployment in these bands.

4. The 26 GHz band should be harmonised for 5G ensuring that sharing with incumbent services and services requiring protection in adjacent bands is possible. The European Commission should monitor availability and authorisation of services in the 26 GHz band (both the minimum of 1 GHz required by the EECC to be made available by end 2020 subject to market demand and the expansion up to full band use for 5G) in Member States to assess progress with implementation.

5. The Commission should exercise its coordinating powers as regards the next ITU WRC in 2019 to seek to ensure that the bands recommended by the RSPG for 5G deployment, including mm-wave bands, become or remain available for 5G.

6. The European Commission and the European Space Agency should continue to cooperate on R&D pilots and test beds related to 5G satellite hybrid networks.

7. The European Commission should monitor standards developments in 3GPP and elsewhere that seek to provide a means of measuring EMF in laboratory conditions, and in field conditions (see Section 6.8). If these efforts fail to deliver practical solutions in a reasonable period of time, the Commission may need to initiate corrective actions.

8. Once standards for measurement of EMF are stable (see again Section 6.8), Member State authorities should establish procedures for verifying that EMF limits for 5G (including mm-wave 5G deployments) fulfil European requirements as specified in the Council Recommendation of 1999 (or any successor). Some degree of field testing might well be necessary in the future.

[8] See https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=54728 and https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=54786

9. Once standards for measurement of EMF are stable (see again Section 6.8), it may be appropriate for the Commission (in consultation with suitable bodies such as the RSPG) to provide default procedures for verifying the EMF limits for 5G (including mm-wave 5G deployments. We assume for now that use of these default procedures on the part of the Member States would be voluntary, but would spare participating Member State authorities the need to each develop their own methodologies.

10. In line with ITU recommendations,[9] the ICNIRP limits, and taking into account the technical views of Associations such as the Small Cell Forum,[10] the Commission may consider issuing guidance so as to ensure that deployments of small cells operating in the mm-wave bands maintain an appropriate distance from human beings, taking into account the EIRP or PFD at which the equipment operates. This could, if needed, be mandated in the Implementing Decisions that the Commission will be making. Determining the exact parameters to be specified is beyond the scope of this report, but Section 6.6.3 identifies necessary framing conditions on distance from the base station to the human body. The Commission may wish to entrust the determination of detailed parameters and the formulation of suitable technical standards to a standards body, for which CEN / CENELEC seems to be a good candidate. CEN and CENELEC are European Standards Organisations (ESOs), which is to say that the Commission is empowered to issue mandates to them to study relevant standardisation issues.

11. In light of the sensitivity of these matters, and the need to ensure public confidence in the correctness, balance and objectivity of the decisions reached, the Commission may wish to put in place a process for the periodic review of relevant portions of standards with EMF implications, specifically beginning with and including those mentioned in these recommendations. An obvious candidate to conduct these reviews is the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) replacing the former Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) that has already demonstrated competence in dealing with EMF issues. The SCHEER is an advisory committee that was specifically created to provide the Commission with "opinions on questions concerning emerging or newly identified health and environmental risks and on broad, complex or multidisciplinary issues requiring a comprehensive assessment of risks to consumer safety or public health", including "physical hazards such as noise and electromagnetic fields". [11] Its procedures are designed to ensure "excellence, independence and impartiality, and transparency".[12] Alternatively, the Scientific Advice Mechanism (SAM) could be charged with this task.[13]

[9] ITU-T (2018), “The impact of RF-EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and 5G mobile network deployment”, Series K Supplement 14 (05/2018).

[10] Small Cell Forum (2018), ”Simplifying Small Cell Installation : Harmonized Principles For RF Compliance”, SCF012.

[11] C(2015) 5383 final. Commission Decision of 7 August 2015 on establishing Scientific Committees in the field of public health, consumer safety and the environment.

https://ec.europa.eu/health/sites/health/files/scientific_committees/docs/call_2015_5383_decision_with_annexes_en.pdf

[12] Ibid.

[13] Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) (2015), “Opinion on Potential health effects of exposure to electromagnetic fields (EMF)”.

1. Introduction

The study on using millimetre wave bands for the deployment of the 5G ecosystem in the Union was carried out by a team led by IDATE DigiWorld with Plum Consulting and Scott Marcus.

The objectives of the study were the following:

- Identify the state of play and the prospects for the use of the mm-waves frequency bands[14], for the 5G ecosystem;
- Clarify the role of the '26 GHz' band and the use of the adjacent '28 GHz' band for fixed and/or satellite;
- Contribute to the assessment of opportunities for electronic communications as well as other relevant services, in line with the 5G Action Plan (5GAP);
- Assess the potential health effects due to exposure to the electromagnetic fields (EMF).

The results of the study will contribute to the assessment of opportunities for electronic communications as well as other relevant services, in line with the 5G Action Plan (5GAP).

The assignment was broken down into five tasks. The first task comprises the identification of potential 5G services in the mm-waves bands & analysis of the potential demand. Task 2 covers the analysis of potential co-existence scenarios and assessment of the prospects for the evolution of the business environment. The third task is the analytical overview of applicable spectrum authorisation rules in each relevant band. Task 4 provides an assessment of the prospects for the development of hybrid scenarios or systems in the European 5G context, and their impact on efficient spectrum use. Task 5 focuses on the analysis of the potential health effects due to exposure to the electromagnetic fields (EMF).

The methodology of the study combined desk research, interviews with 30 experts/stakeholders and a stakeholder’s workshop organised on 30 May 2018 prior to finalising the second Interim Study report. The main objectives of this workshop were to gather necessary evidence and information from relevant stakeholders and experts to improve the findings from the various tasks of the study. This draft Final Report is the result of the research carried out and the feedback received from stakeholders during interviews and the workshop. The structure of this draft Final Report is the following:

- Chapter 0: Executive summary
- Chapter 1: Introduction
- Chapter 2: Identification of potential 5G services in mm-wave bands and analysis of the potential demand
- Chapter 3: Analysis of potential co-existence scenarios & assessment of the prospects for the evolution of the business environment
- Chapter 4: Allocation and authorisation of mm-wave spectrum for 5G
- Chapter 5: Assessment of the prospects for the development of hybrid scenarios or systems
- Chapter 6: Implications of exposure to electromagnetic fields (EMF)
- Chapter 7: Findings and recommendations
- Chapter 8: Annex

[14] Framed by ITU Resolution 238

2. Identification of potential 5G services in mm-wave bands and analysis of the potential demand

2.1. Introduction

In this chapter, we discuss:

- The potential 5G services in the mm-wave bands, with a focus on the 26 GHz, 42 GHz (40.5-43.5 GHz) and 57-71 GHz (including 66-71 GHz) frequency bands which have emerged as priority for Europe according to the RSPG Opinion and the CEPT's 5G roadmap;
- The available spectrum capacity in the mm-waves bands;
- The potential demand for 5G services in the mm-waves bands; and
- Estimates of the overall socioeconomic and environmental effects (both positive and negative) on growth, employment and competitiveness.

Section 0 describes the potential mm-wave services that are expected to use mm-wave bands. Section 2.4 presents 5G market forecasts and the expected demand for 5G services in the mm-wave bands. Section 2.5 provides an evaluation of spectrum capacity in mm-wave bands. Section 2.6 presents trials and plans for 5G services in Europe and in advanced countries in other regions of the world. Section 2.7 covers the impact of 5G on growth, employment and competitiveness.

2.2. Summary of findings

Below is a summary of the findings on 5G services in the mm-wave bands and potential demand.

- Services expected to use mm-wave bands are the following:
  - Enhanced Mobile Broadband (eMBB) services for high capacity (Fixed Wireless Access (FWA), high-definition video communications, virtual, augmented and mixed realities),
  - Services for vertical sectors including automotive (V2X: Vehicle-to-everything, autonomous cars), other transportation (trains and buses), manufacturing / industrial automation, energy grid communications, smart cities, and medical applications;
  - Public safety and
  - Fronthauling / backhauling.
- The first services that are likely to be deployed in mm-wave bands will be eMBB and new use cases of backhauling (different from incumbent fixed links), but no killer application has been identified so far.
- Use of the mm-wave bands will be progressive in Europe with expected initial adoption by 5G operators in congested hot-spots, roads and major transport paths. Deployment of small cells using the 26 GHz band is expected to start in 2022-2023, but with limited initial volumes.
- Based on our evaluation, a maximum of 10% of the 5G cell sites would support mm-waves in 2025.
- The framework for using existing spectrum for 5G is considering 2020 for availability in EU-28 countries. For EU-28, the expected availability of at least 1 GHz in the 26 GHz band in 2020 will provide sufficient initial capacity for the progressive 5G deployment.

2.3. The potential 5G services in mm-wave bands

In this section, we identify potential 5G services that are likely to use the mm-wave bands. Focus has been given to the 26 GHz band.

2.3.1. Expected 5G services in mm-wave bands

Traffic forecasts from Cisco VNI and from the Ericsson Mobility Report show that mobile traffic can be expected continue to grow at a rapid pace in the coming years. Ericsson anticipates that "total mobile data traffic is forecast to rise at a compound annual growth rate (CAGR) of 43 percent, reaching close to 107 exabytes (EB) per month by the end of 2023"[15]. This figure was 15 EB in 2017 according to the same source. CISCO's VNI[16] for Western Europe forecasts that "mobile data traffic will reach 4.0 exabytes per month in 2021, up from 724 petabytes per month in 2016".

With potential availability of very large bandwidths, the millimetre wavebands above 24 GHz should enable provision of very high data rates in specific areas where traffic demands are very high. Very high traffic demand is expected in places such as stadiums where concentration of devices using Ultra High Definition (4K & 8K) video and high-resolution video-sharing applications are likely to generate tremendous traffic. Services such as these will require data rates above 1 Gbps. They are likely to primarily use spectrum above 6 GHz as it will be easier to find large blocks of spectrum in these bands rather than below 6 GHz even if it is already possible to offer Gbit services with 4G using carrier aggregation over three or four frequency bands[17].

5G services likely to use mm-wave bands include the following:

- Enhanced Mobile Broadband (eMBB) based-services for high capacity such as
  - Fixed Wireless Access (FWA),
  - high-definition video communications,
  - virtual, augmented and mixed realities;
- Services dedicated to vertical sectors including:
  - automotive (V2X: Vehicle-to-everything) autonomous cars,
  - other transportation: 5G on trains and buses,
  - medical applications;
  - manufacturing / industrial automation,
  - energy grid communications,
  - smart cities.
- Public safety;
- Fronthauling / backhauling, e.g. backhauling aggregate traffic from vehicles;

Some services dedicated to vertical sectors will also rely upon Ultra-Reliable Low Latency Communications (URLLC).

eMBB services

Enhanced Mobile Broadband (eMBB) appears to be the main demonstrated use case for mm-wave bands during the period 2020-2025. It includes the following use cases:

- Scenarios/locations
  - Urban hotspots;
  - Stadiums/arenas and other indoor venues with ultra-high density of users;

[15] Ericsson Mobility Report – June 2018

[16] https://www.cisco.com/c/m/en_us/solutions/service-provider/vni-forecast-highlights.html. Globally, mobile data traffic will reach 48.3 Exabytes per month in 2021, up from 7.2 Exabytes per month in 2016.

[17] For instance three licensed bands (800 MHz, 1800 MHz, 2.6 GHz) and the 5 GHz unlicensed band. Telstra also used four licensed bands: 100 MHz of spectrum across the 700 MHz, 1800 MHz, 2100 MHz and 2600 MHz (2 x 20 MHz)

  - Airports, Railway stations and other transport hubs with very high user concentrations.
  - Rural areas for fixed wireless access;
  - Large data transfers for wireless connectivity in data centres (access) and between data centres (backhauling);
- Services/applications:
  - High data rate video (4K, 8K…) and media delivery. It is expected that 4K and 8K will be mainly available in urban areas;
  - Virtual Reality (VR) / Augmented Reality (AR) applications: AR / VR will lead to throughput requirements in the order of 50 Mbit/s to 1 Gbit/s and 10 ms latency (end-to-end);
  - Cloud gaming.

Fixed wireless access

Part of enhanced Mobile Broadband, Fixed Wireless Access is targeting to provide high data rates to fixed locations.

With decreasing cost per bit compared to 4G[18], 5G should be able to provide an alternative to fibre connections in areas where the density of population does not support fibre deployment.

In the United States, Verizon conducted trials in 11 markets in 2017 and announced commercial fixed wireless service this year in three to five markets including Sacramento (California). The operator estimates it could target 30 million households nationwide with this service and compete with cable operators with Internet access and 4K TV services. Verizon is planning to provide 1 Gbps speeds at ranges of up to 2,000 feet (approximately 600 meters) and looks confident in its ability to find a sustainable business model for 5G fixed wireless access. Verizon launched commercial service in Houston, Indianapolis, and Los Angeles and Sacramento, on October 1st 2018 with guaranteed speed of 300 Mbps and peak speeds of 1 Gbps.

There is interest in fixed wireless access in Europe as well, with Arqiva testing the technology in the 28 GHz band and also some interest in Italy.

Orange is undertaking tests in Romania during the second half of 2018 in the 26 GHz band with equipment manufacturers Samsung and Cisco and the operator indicates that investments in fixed wireless access would then be considered as investment in the fixed network. In October 2018, Telefonica also indicated that it was planning fixed wireless access tests in Germany using the 26 GHz band.

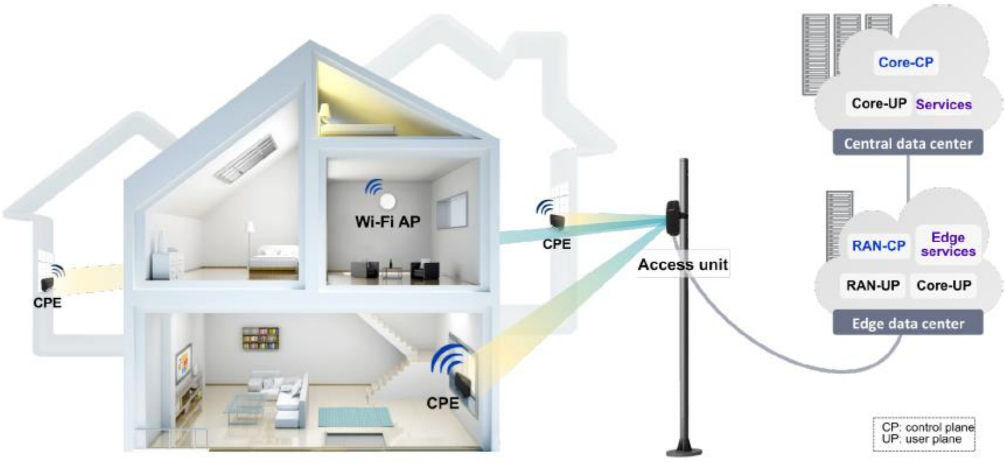
Initial trials presented in section 2.6 show that 5G could be used as a complement to fibre in specific areas but it is likely that there will not be wide scale deployment of 26 GHz spectrum for contiguous coverage across rural/suburban areas.

It should be noted that in the USA, only Verizon is providing this service to compete against cable operators[19]. The European and US markets have many differences: footprint of fixed networks (not national for Verizon and AT&T) and presence of cablecos are the main differences.

[18] Cost efficiency is one of the most important objectives set out in the 2015 NGMN (Next Generation Mobile Networks) 5G white paper

[19] In the USA, other mobile operators AT&T and T-Mobile are also considering the launch of fixed wireless services using mm-wave bands.

Figure 1: Samsung's end-to-end 5G FWA network



Source: Samsung

The fact that mobility does not have to be managed will certainly facilitate early deployments of 5G networks for fixed applications. It is easier to model multiple paths transmissions and antennas de-correlation in fixed configuration rather than in mobile configuration.

5G will bring much higher capacity than 4G networks. For a 5G service providing 4K television service, it is estimated by Ericsson that the average data rate will be around 15 Mbps per household. For a device density of 4000 Customer Premises Equipment per square km, the traffic density could reach 60 Gbps/km². Table 17 shows that with a 400 MHz channel in the 28 GHz band, the average throughput would be 12 Gbps.

High data rate video and media delivery

It is expected that delivery of UHD video will require throughput on the order of 30-40 Mbit/s (4K) and 80-100 Mbit/s (8K) with latency on the order of 20 ms (end-to-end). The key driving factors for this family of use cases are expanded use of HD TV, development of 4K and 8K video resolution, streaming audio and video services and interactive video on the go. Expected users for this use case are the end viewers, pay TV operators, broadcasters, new content owners, content aggregators, and over-the-top (OTT) providers. This type of service will be provided to mobile users (eMBB) as well as to Fixed Wireless Access users.

In the media on-demand use case from mmMagic H2020 project, the challenge is represented by the connection density, which is estimated to rise up to 4000 users/km².

Media delivery via multicast and broadcast

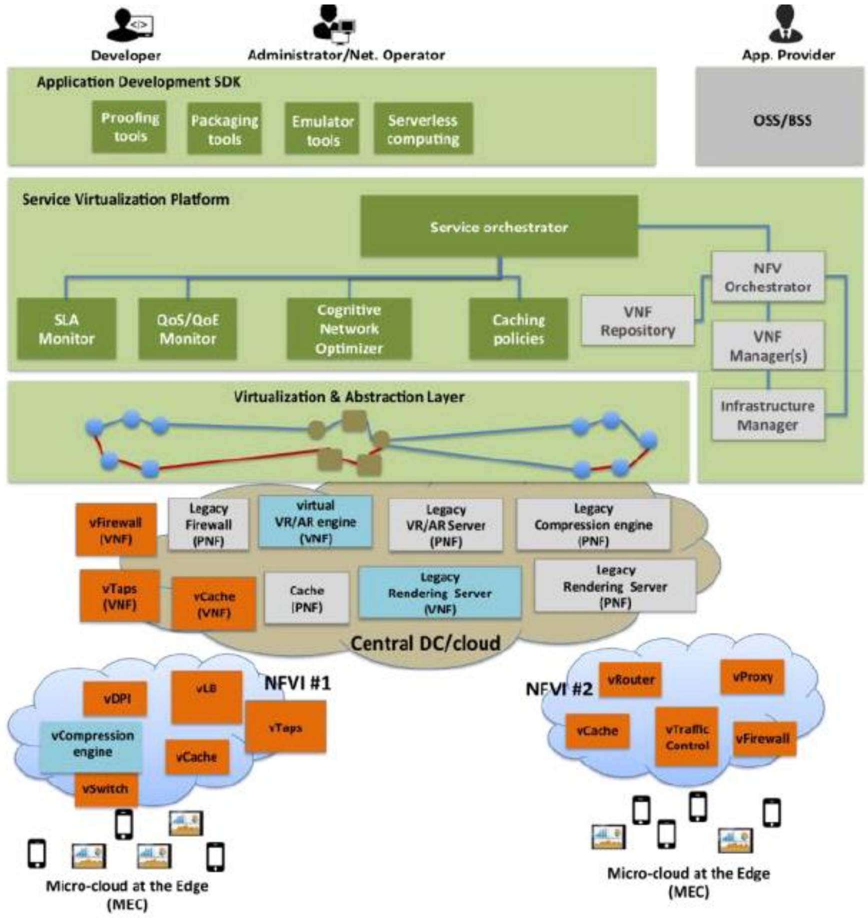
Along with unicast, the multicast and broadcast modes will also be used in 5G networks. The H2020 phase 2 project 5G Media[20] identifies the following use cases:

- Immersive applications and Virtual Reality
  - Scenario 1: Tele-immersive participatory media
  - Scenario 2: Immersive Interaction
- Remote and smart media production incorporating user-generated content
- Dynamic and Flexible UHD content distribution over 5G Content Delivery Network (CDNs)

These use cases are likely to require the use of mm-wave bands in order to support high data rate requirements. The architecture of the 5G-MEDIA platform is presented in the figure below:

[20] http://www.5gmedia.eu/use-cases/dynamic-and-flexible-uhd-content-distribution-over-5g-cdns/

Figure 2: High-level architecture of the 5G-MEDIA platform



Source: 5G-MEDIA

eMBB example: outdoor and indoor urban hotspots

The ONE5G[21] H2020 phase 2 project presented in the figure below studied a use case involving mm-wave bands called "outdoor hotspots and smart offices with AR/VR and media applications". This use case takes into account high throughput demand and the use of services like augmented reality (AR), virtual reality (VR), high-quality video streaming or file transmission among others.

In this use case, spectrum at around 30 and 70 GHz would be used and the estimated need in terms of bandwidth would be up to 1 GHz. User experienced data rate for the indoor configuration would be 1 Gbps in the downlink and 500 Mbps in the uplink.

Inter-site distance considered here is 200 m.

Frequency bands considered for this use case are the following:

- Around 4 GHz: Up to 200MHz (DL+UL)
- Around 30 GHz: Up to 1GHz (DL+UL)
- Around 70 GHz: Up to 1GHz (DL+UL) (Only indoor)

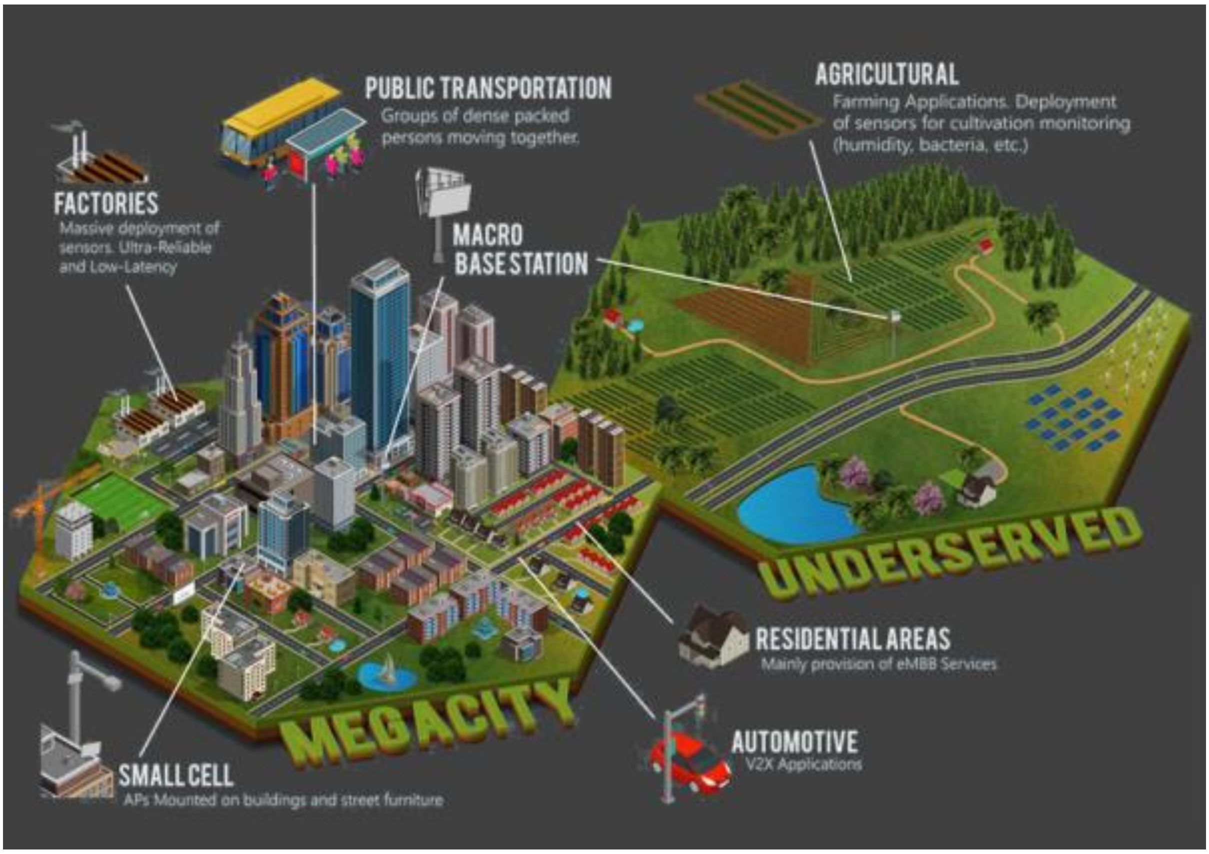
Other characteristics:

- Above 4 GHz: Up to 32 Tx and Rx antenna elements.
- Traffic density would be 750 Gbps/km2 for a downlink throughput of 300 Mbps.

Details are provided in section 8.2 of this report.

[21] E2E-aware Optimizations and advancements for Network Edge of 5G New Radio (ONE5G) - Deliverable D2.1 -Scenarios, KPIs, use cases and baseline system evaluation

Figure 3: ONE5G – overview of vertical use cases



Source: https://one5g.eu/

Automotive

Table 1 presents the key drivers and barriers of the mm-wave technology introduction for the typical use cases in the automotive vertical.

Table 1: 5G drivers and barriers – Automotive sector

Use case	Drivers	Barriers
Infotainment	• High resolution navigation maps DL when car is parked • More data hungry applications	• Rural areas
WiFi hotspot backhaul	• Multi-devices connections in the car (up to seven today) • Autonomous cars will let people enjoying more content	• Low service take-up so far
Software update downloads	• Shorter DL time • DL completed at anytime	• New business model (see Tesla case)
Autonomous cars	• Need for security (danger image upload for instance)	• This will take time

Source: IDATE

Infotainment use cases should mainly rely upon cellular connectivity in frequency bands below 6 GHz (this is regular eMBB service in direct mode) whereas WiFi hotspot should mainly use a backhauling link provide by the car and would use the 3.4-3.8 GHz band and in a limited number of cases mm-wave bands (when the car is parked or in very dense urban areas). The WiFi hotspot will be installed by the car manufacturer and will require a dedicated subscription in order to provide WiFi service to the passengers of the car. High resolution navigation maps download could make use of the mm-wave bands when the car is parked. Software update downloads should benefit from the high data rates provided by mm-wave bands when the car is parked, reducing dramatically time needed to perform the software update.

Infotainment

Infotainment refers to vehicle systems that combine entertainment and information delivery to drivers and passengers. It mixes video streaming, turn-by-turn navigation services, etc.

With less time attention focused on the road, passengers and the driver will be able to enjoy more entertainment in the car, like social network, video games and obviously video streams.

Some different use cases are already adopting this functionality today, mainly focusing on passengers (kids on backseats or business travellers, etc).

This could also be a feature/service provided by the taxi companies. In France, G7 Taxi Company has settled a deal with Bouygues Telecom to provide WiFi service (a 4G Wi-Fi router is installed in each taxi). 5G mm-wave backhauling could provide greater service in terms of data rate, especially in urban areas.

In this use case, the drivers for use of mm-wave 5G would be in situations where the car is parked or a very low speed in dense urban areas:

- Video streaming with increased definition
- High resolution navigation maps downloading

Video streaming with increasing definition

As for traditional video delivery system, vehicle systems will need to anticipate increasing demand for better image quality requiring better encoding bitrate and therefore higher bandwidth (even taking into account improved video compression techniques).

End consumers will not be willing to pay for services providing them lower quality video services (compared with their charge-free smartphone).

Original Equipment Manufacturer (OEM) and equipment vendors are already designing the 2025 cockpit. In 2025, Continental plans a cockpit with numerous data (including video movie) on the windshield (functionalities similar to heads-up display).

WiFi hotspot backhaul

This is the key use case for the automotive vertical. The main drivers for 5G mm-wave introduction are:

- multi-devices feature
- improved leisure time in autonomous cars (time previously spent with the hands on steering wheel)

Data plans are currently offered by subscription, with the price ranging from 10 USD to 40 per month with different data options. Customers can also purchase one-off data pass at 5 or 150 USD. For existing AT&T customers, a 4G LTE-equipped GM vehicle can be added to a mobile share plan for a monthly 10 USD.

Today, all premium cars manufacturers offer a built-in Wifi hotspot into and around the vehicle. In the medium term, all OEMs should provide such features.

Because of parallel streams (up to 10 devices today in the AT&T offering – depending the OEM and the related offering), hotspot features with higher capacity in terms of data rate will be required.

Software update downloads

With software based automotive functions such as Autopilot for Tesla cars, next-gen cars give a larger place to software which takes control of the hardware. Main functions could be controlled electronically through a digital interface. These software-based functions obviously require frequent updates as for traditional software building blocks. Example of applications in Autopilot are lane centering, adaptive cruise control, self-parking, ability to automatically change lanes with driver confirmation.

In some way, this is already the case of Tesla vehicles today. Tesla vehicles regularly receives over-the-air software updates that add new features and functionalities. When an update is available, the user is notified on the center display with an option to install immediately, or schedule the installation for a later time.

However, the user is asked to connect his vehicle to his home's Wi-Fi network for the fastest possible download time (and to avoid downloading time - through the slow 3G module embedded in the Tesla and related costs).

With 5G mm-wave, it will be more convenient to download very fast this update, even when on the go. In addition, autonomous vehicles should be on roads, in urban areas at first, where 5G mm-wave will be primarily deployed as well. Given the reduced coverage provided by mm-wave bands, downloads would probably take place at home or in urban hot-spots.

High resolution navigation maps downloading

Without a map update, the car system will be missing important data including new and modified roads, addresses, and points of interest. This information greatly improves the navigation system's routing accuracy and overall functionality.

In most cases, the vehicle owner can install map updates sold on specific websites like navigation.com. Most manufacturers release a new map update once a year. Map updates are unique to a specific vehicle's navigation system. Navigation systems vary from model to model and, in some instances, from year to year.

On the online mode, it seems that the navigation system HERE uses about 1.0 - 1.5 MB per hour when online mode. In the medium/long term, high resolution and the number of POIs in maps should increase dramatically, requiring higher bitrate.

Autonomous vehicle

Up-to-date technology - ITS-G5 / IEEE 802.11p.

ITS-G5 is a broadcast technology based on an evolution of the wireless standard 802.11p. It is a validated and available technology on the market and capable of delivering secure ad-hoc direct vehicle-to-vehicle and/or vehicle-to-infrastructure communication. ITS-G5 is running in the designated 5.9 GHz frequency band that is foreseen for road safety.

The IEEE 802.11p-2011 standard supports communication between vehicles and the roadside infrastructure and between vehicles in the unlicensed ITS band of 5.9 GHz (5.85-5.925 GHz), while operating at speeds up to 200 km/h for short-range communication (up to 1,000 m).

- In the United States, 75 MHz of spectrum was allocated in this 5.9 GHz band, for Dedicated Short-Range Communications (DSRC).
- In Europe, 802.11p is set as a basis for the ITS-G5 standard, supporting the GeoNetworking protocol for V2V and V2I communication. Both ITS G5 and GeoNetworking are being standardised and supported by the European Telecommunications Standards Institute (ETSI) group for Intelligent Transport Systems (ITS).

C-V2X is also standardised (ETSI EN and TS modified in October 2018[22]) and validated, and the very first chipsets are being made available. There is a competition between G5 and C-V2X. Car manufacturers supporting ITS-G5 are VW and Renault and C-V2X is supported by all the other ones, with Toyota supporting both of the two technologies.

[22] ETSI TS 122 186 V15.4.0 (2018-10) - 5G; Service requirements for enhanced V2X scenarios (3GPP TS 22.186 version 15.4.0 Release 15)

Recent developments

The goal of self-driving vehicle development is to allow the car to perform all driving operations without any human intervention. To reach this goal, numerous technologies are used in parallel, which we can divide in two main categories:

- **Surroundings detection**, which includes most functions of detecting and analysing the composition and possible movement of all objects surrounding the car, in addition to the road itself. These functions are arguably the most critical, since almost all automated driving tasks rely heavily on their input
- **Connectivity and communication**, which encompass all key technologies used in a car to receive and transfer information to the outside world, including Internet access, with the goal of further improving driving automation and/or prevent accidents (intelligent merging using V2V communication, for example). Always-on Internet connectivity is expected to be extremely important for the future of self-driving vehicles, it is not technically compulsory to achieve autonomous driving today.

In Audi's newer models, a V2I feature is available as part of the Audi Connection Prime package (200 USD for six months of service). It displays the time remaining before the traffic light changes on the vehicle’s dashboard. At launch, it was compatible with most of the 1,300 traffic signals managed by the Regional Transportation Commission of Southern Nevada. At the end of 2016, Audi stated it was in talks to roll out the feature to more than 10 other cities.

In Europe, a V2X trial was performed in 2018 by the Connected Vehicle to Everything of Tomorrow (ConVeX) consortium, which is made up of AUDI AG, Ducati, Ericsson, SWARCO, the Technical University of Kaiserslautern, and Qualcomm CDMA Technologies GmbH, a Qualcomm subsidiary. It was the first live demonstration of Cellular Vehicle-to-Everything (C-V2X) interoperability between a motorcycle, vehicles and roadside infrastructure.

Upcoming technologies would include dash cameras[23] to send videos (or even photos) of traffic incident, to the infrastructure, in order to be shared with other vehicles to alert them. The photo or video would be combined with GPS coordinates to accurately locate the danger.

This feature would also require greater bandwidth and capacity than current LTE, especially if performed on the go.

This would be essential in very dense areas to prevent multi collision accidents.

C-V2X (LTE and 5G)

5G has been from its onset developed with a willingness to address vertical industries, with the promise to bring not only bandwidth capacity but also support for a massive number of devices, ultra-low latencies, better coverage and support of mobility at high speeds. These promises are welcomed by the automotive industry as they can help to meet the requirements of the foreseen automotive digital services. 5G is especially anticipated as a solution for advanced infotainment (requiring improved bandwidth and latency) and for Vehicle to Everything (V2X communications).

V2X encompass vehicle communications with other vehicles (V2V), but also with its direct environment: pedestrians (V2P) and road infrastructure (V2I) as well as with the internet (V2N). It is seen as necessary building block of future intelligent transport systems (ITS).

[23] A dash camera is an on-board camera that continuously records the view through a vehicle's windscreen

Figure 4: V2X Vision

Source: Qualcomm

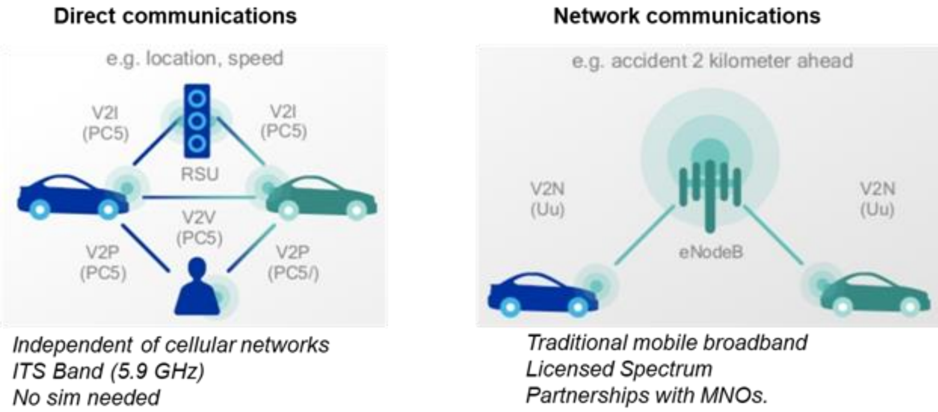
MNOs also view the development of ITS as an opportunity for reducing the costs of small cells deployments: they would gain access to the road infrastructures to deploy 5G cells in exchange of giving access to the network for V2X communications. In this example, CAPEX would be reduced for mobile operators as installation costs and installation time would be reduced. Partnerships with Smart Cities, as the one established by Verizon Wireless and the city of Sacramento in the USA illustrate this possible relationship and the associated benefits.

The mutual interest of both automotive industrials and 5G developers has been materialised by the set-up of the 5G Automotive Association (5GAA) that support the standardization process, promote the automotive industry requirements and run joint innovation and development projects.

The cellular Vehicle to Everything vision

One of the prominent result of the 5GAA activities is the promotion of the "cellular Vehicle to Everything" (cV2X) vision. This vision relies on two complementary transmission modes: direct communications in the ITS band (5.9 GHz) functioning fully independently of cellular networks and without the need for a SIM or mobile subscription and network communications relying on traditional mobile broadband (using licensed spectrum and with a need for MNO subscription or partnership).

Figure 5: Cellular Vehicle to Everything (cV2X) vision



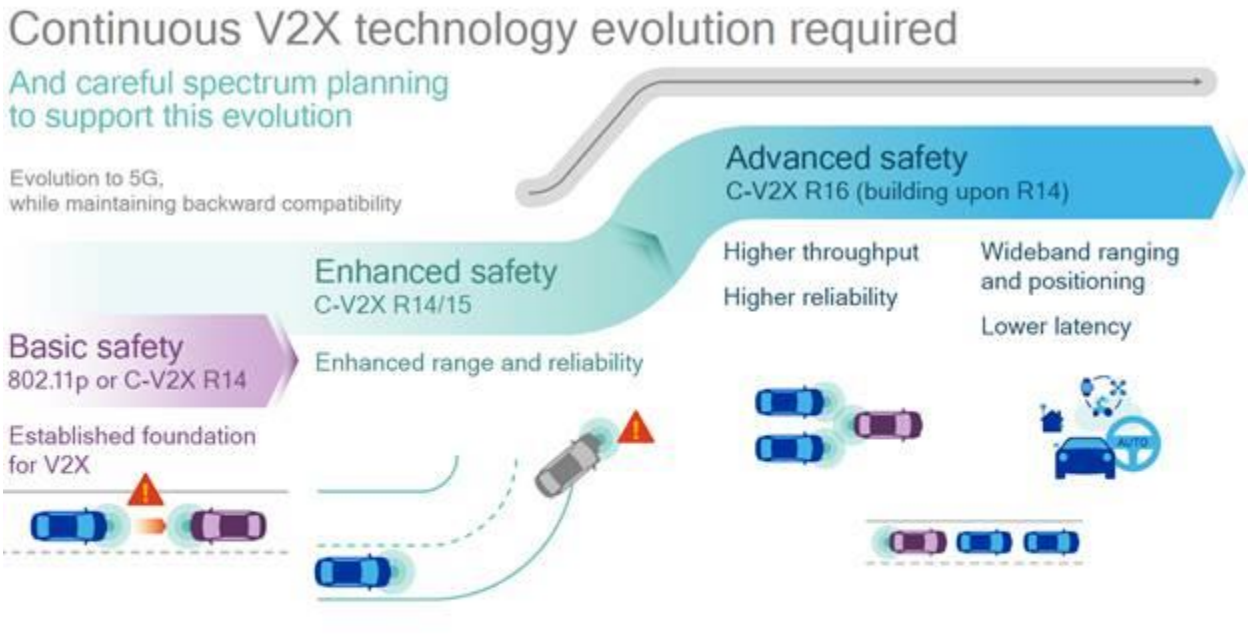
Source: IDATE

This vision benefit from a harmonized common spectrum for V2V communication and can coexist with 802.11p using different channels in the ITS band. The cV2X vision can be seen as a middle ground between the ideal MNO vision (network centric) and the automotive industry actual needs (ability to function without the mobile networks). It shows the willingness to take into account potential benefits from 5G network while enabling shorter term V2V communications.

5G Benefits that are still uncertain

The foreseen benefit of mixing network communications with traditional V2V and V2I communications reside mainly in extended range and reliability of the communication enabling more advanced autonomous car behaviours. The use case seen as a key application of cV2X is intersection management.

Figure 6: Cellular Vehicle to Everything benefits



Source: Qualcomm

However, this vision is clearly seen rather as a long term objective as the 5G coverage requirements of the automotive industry are unlikely to be met in short or mid-term.

Coverage is indeed seen as a key issue to improve the quality of service and potential interest of V2N in intelligent transport system scenarios. Additional issues such as security concerns, reliability of communications and differentiated SLA guarantee need to be addressed by the 5G standard before it can be used in ITS and autonomous cars scenarios.

This is illustrated by the current focus of the automotive 5G trials on infotainments rather than on ITS and autonomous cars solutions. The critical machine type communication (critical MTC) promises of 5G are taken as long term and low priority objectives by both MNOs and automotive players.

Technical requirements

Main technical requirements for automotive services are listed in the table below:

Table 2: Requirements for automotive services

Service	Quantity of data to transmit (per month)	Latency	Data rate	Traffic direction
Infotainment	Up to 20 GB per month	Low latency (< 10 ms)	> 100 Mbps	Downlink
WiFi hotspot	Tens of GB	Low latency for critical applications (video mainly or e-commerce)	> 100 Mbps	Downlink
Software updates	Tens of GB	Not really a real-time issue (on-demand)	> 100 Mbps	Downlink
Autonomous vehicles	-	A maximum network end-to-end delay (including device detection, connection setup and radio transmission) of 5 ms	> 100 Mbps	Downlink and uplink

Source: IDATE

URLLC (Ultra Reliable Low Latency Communications) capabilities of 5G should be enablers for automated driving and road safety.

Other transportation: 5G on trains and buses

This use case is about providing broadband access in public transport systems such as high-speed trains. The use case consists of providing robust communication link and high-quality Internet for information, entertainment, interaction or work with a high mobility component.

mm-wave bands could enable high bandwidth backhaul links between a base station on the trackside and an access unit on the carriage. Distribution within the train via WiFi and/or small cells then enables users to get very fast broadband access services.

The mmMAGIC-1 (H2020) project evaluated the backhauling need for trains to up to 10 Gbps.

The following table presents the key drivers and barriers of the mm-wave technology introduction for the typical use cases in the transportation vertical.

Table 3: Drivers and barriers for 5G on trains and buses

Use case	Drivers	Barriers
WiFi access in train/bus	• Poor coverage now (in 2018)	• Costs and interrogation regarding the revenues • business model • Short range • Limited to urban areas?
High resolution video applications in trains (on demand video services)	• New revenues streams for transport service companies	• Difficulty to sell • Need for replacing legacy equipment (displays, etc)

Source: IDATE

Direct 5G access would also be provided to the trains and buses. In the case of trains, it would use mm-wave spectrum for high data rate links.

WiFi access in public transportation

This use case is similar to in the one for passenger cars. What it is true for 1 or 2 passengers, is even more relevant for 100 passengers, as well as for the network requirement in terms of capacity and bandwidth.

This is already in use today for bus and train, for commute or for long trips. The long commute to the final destination is more productive and fun for end-consumers.

This is also the case within trains today, especially for the first class. In this category, the business model is easier to find. Related costs are mostly compensated through a ticket mark-up.

High resolution video and/or mobile TV based applications

This use case is based on scaled up delivery of high resolution content via live TV or on demand video using enhanced data capacity and data rates.

This refers to the delivery of video streaming and entertainment media to smart phones, tablets and other devices in high mobility environments such as trains, and buses.

Bus or train service companies could also provide what it is already provided for in-flight entertainment.

This configuration could be replicated for train or bus transportation but would require very high bitrate connection, provided by next-gen technology with performances similar to 5G mm-wave.

Technical requirements

Main requirements for services on trains and buses are listed in the table below. Basically, in terms of data rate, for a bus, 10 Mbps per stream for 100 seats represents a real requirement of 1 Gbps for the entire bus network requirement.

Table 4: Requirements for services on trains and buses

Service	Quantity of data to transmit (per month)	Latency	Data rate	Traffic direction
High resolution video	Up to 20 GB per month	Low latency (< 10 ms)	> 1Gbps	Downlink
Backhaul for a WiFi hotspot	Tens of GB	Low latency for critical applications (video mainly or ecommerce)	> 1Gbps	Downlink

Source: IDATE

As on the move communications are very challenging above 6 GHz, it is likely that provision of backhauling in the mm-wave bands will be offered only on a limited number of train tracks during the first years of 5G operation.

Medical applications/healthcare

With the vibrant growth of the Internet of Things (IoT) in the healthcare sector, the industry, along with healthcare providers, authorities and standardisation bodies, has put much emphasis on connected health, where promise is seen in addressing the challenges and services already developed without 5G. The most-often cited issues within connected health include: telemedicine and remote patient monitoring, mobile access to care services, connected medical or fitness devices, robotics, assisted living and prevention.

Beyond connected health, there are also some possible scenarios where 5G network offers new capabilities to improve the right execution of the use cases, such as asset management.

For urgent healthcare and remote surgery, the 5G network should be able to support the timely and reliable delivery of audio and video streaming. Very-low latency will enable the use of haptic feedback and will be brought by the URLLC capabilities of 5G.

Remote monitoring of health or wellness

The notion of remote monitoring includes wearable and portable devices for consultation, monitoring, diagnosis and therapy, and supporting treatment plans at a distance for people living with chronic disease. Active ageing, prevention care as well as follow-up of discharge from hospitalization will all be addressed. Patients are at the core of such services, and given more power in self-managing their own care. Consequently, as mentioned below, hospital resources will be optimised, by, for example, a reduction in the beds and structures required for hospitalization.

These services will inevitably require the collection of abundant individual data on a continuous basis via sensors and cyber-physical systems, fast consuming all available network capacities. The type and allocation of resources (IT services, data availability and monitoring activities) varies depending on the intensity of care needed. Identifying the correct needs is crucial. Meanwhile, to ensure that health and social care providers will be able to process information to coordinate their activities in a seamless way, the 5G network should facilitate integration with the service layer and enable an effective network resource negotiation, including bit rate, QoS and network availability in both rural and urban areas with a high density of users.

Asset management and intervention management in hospitals

Real-time tracking of hospital resources and assets is also critical. The assets include wheelchairs, ECG monitors, consumables and drugs. The main services that have a close relationship with care delivery efficiency and quality are listed below.

- Tagging and tracking of equipment and consumables, to prevent them from being removed from the operating theatre.
- Real-time tracking of value assets to avoid the unauthorised removal of the value items.
- End-to-end management of pharmaceuticals across the whole supply chain, for drug security.

Intervention management often refers to surgery planning, establishing right priorities in the items on the surgery list. Considerable information should be available for the correct scheduling of critical surgeries.

In this critical context, it is essential to have available data updated in real time. Continuous monitoring is more than necessary, which requires medical devices and other assets, monitored data and personnel of responsibility connected to a central infrastructure through a secure and reliable network.

Robotics

Robotics is being applied in healthcare, principally to remote surgery. Specialists can thus join local surgeons remotely to perform some procedures, or assist junior surgeons to fulfil a particular task. In the scenario of robotics-assisted surgery, the quality of image, a sensation closer to reality such as the resistance of organs, and synchronization of cooperative action pose a critical requirement for end-to-end latency. Another issue is that the reliable availability of information from back-end databases and real-time data streaming from a large variety of sources should be guaranteed in such immense coordination.

Smart medication

With city-wide monitoring devices and big-data analytics for public health, the decision for medication could be made not only based on monitoring of the patient's condition but also through the tracking of various high-risk factors such as air pollution and climate.

In addition, new pharmaceuticals with embedded connected devices could be applied to the treatment and management of chronic diseases in general. This process may require the connection of thousands of devices by geographical area, and data processing after transmission to secured clouds. 5G will provide the capabilities to guarantee real-time data gathering, sending and process with much higher level of security. Given the very high number of devices connected at the same time and the expected use in indoor environment, it is likely that mm-wave bands will be useful on the long term.

Expected use of mm-wave bands for eHealth

Generally, e-health applications require very low latency (especially for tele-surgery), high throughputs and especially much-improved uplink throughputs, traceability of data, QoS management and reliability of the network, and easy deployment in case of emergency. In addition, this must be delivered in a high-quality and secure way to ensure trustworthy e-health services.

Table 5: Communication performance requirements of particular 5G-enabled use cases

	High-level needs for the communication					
	Latency	**Reliability**	**Data rate**	**Coverage**	**Mobility (speed)**	**Density (No. of connected devices)**
Remote monitoring of health or wellness	Less critical	High	High	Ultra-high	High	Ultra-high
Assets management and intervention management in hospitals	High	Less critical	Low	High	Low	High
Robotics-assisted surgery	Ultra-high	Ultra-high	Ultra-high	Less critical	Low	Low
Smarter medication	Less critical	High	Low	High	High	Ultra-high
Emergency care management	High	High	High	Ultra-high	High	Low

Source: IDATE

Manufacturing / industrial automation

The evolution of the manufacturing industry is driven by long-term societal trends, the first and foremost being the globalisation of the economy. On top of this, other societal trends such as the focus on environmental sustainability or growing individualism are also impacting its development.

This is leading to a transformation of the manufacturing domain toward more integration with additive manufacturing, a stronger role of the customer in the production process, and a trend toward a circular economy.

Three main types of demand are emerging from the manufacturing industry regarding smart factory opportunities:

- **Demand for increased flexibility in manufacturing**: There are demands both for more flexibility in the manufacturing process itself and in supply chain integration. This includes needs to anticipate, forecast and adapt production rapidly and the tighter integration of the manufacturing process in the value chain. These new demands require that this forecasting, flexibility and adaptability will need to be overall on the value chain. In order to reach these goals, the smart factory is expected to integrate new technologies such as virtual reality, advanced robotics, and increased connection and integration of different ICT-enabled components in a single networked system (Production Monitoring, Data Analytics, Process Control and Cyber Physical Systems.
- **Demand for cost reduction and increased efficiency**: As a direct result of global competition, the demand for solution for reducing cost and increasing efficiency is important. This can take many forms in the manufacturing process, such as the reduction of start-up times, and the scale-up of production, fewer maintenance needs, less integration time for new equipment or workforces needs through automation. It also includes the need for production monitoring and decision-making tools that can improve overall efficiency.
- **Demand for better integration of human workers in the manufacturing process**: The manufacturing domain is looking for increased productivity by better integrating the workers with the manufacturing process. This can take different forms, from uncaged robots, to new user interfaces based on mobile devices and to contextualization of information displays and controls.

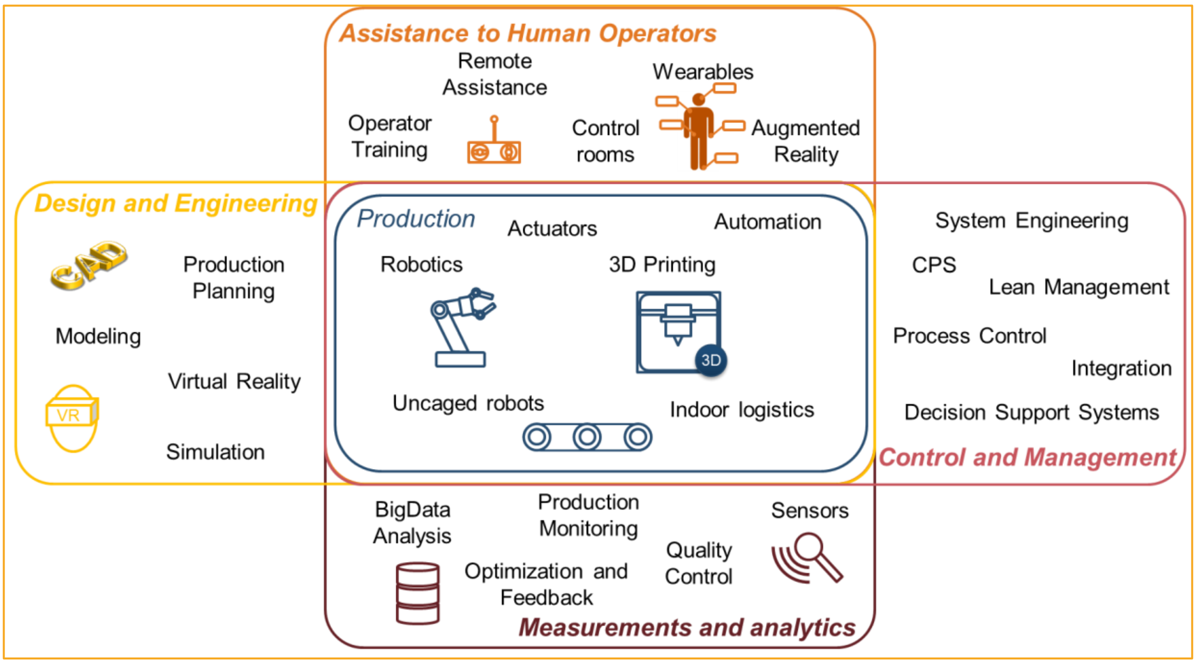
Table 6: Drivers and barriers for the manufacturing/industrial automation sector

Use case	Drivers	Barriers
WiFi hotspot	• Connected employees (with tablets, etc.) • Improved quality with adequate tools • Intranet access though this WiFi	• Coverage (not pure urban environment)
Security (video-surveillance)	• Higher camera resolution • Shape recognition for quality control, etc.	• Coverage (not pure urban environment)
Remote operation & smart manufacturing	• Massive cost savings (travel cost savings mainly but also maintenance cost optimization) • Higher camera resolution	• Coverage (remote areas mainly so far) • Limited use cases

Source: IDATE

The smart factory concept encompasses various technologies that reach all along the production value chain, from the early design phase to production and maintenance.

Figure 7: Smart factory use case



Source: IDATE DigiWorld

This various technologies can be grouped by the type of services:

- **Design and Engineering**: The use of ICT technologies in the design and engineering phase of manufacturing is already well developed. The smart factory concept however brings some additional innovations such as the use of 3D real-time technologies and virtual reality in the design and engineering phase. It also brings increased integration and interoperability, ensuring that data and models are used consistently all along the value chain from early design phase to engineering, production, and eventually to the full life cycle of the product. It also introduces a need for increased flexibility in the design and engineering to adapt to the needs of shorter manufacturing cycles, and increased product customisation.
- **Production:** The smart factory concept impacts the production process through the new possibilities offered by ICT technologies, such as more advanced automation in cyber-physical systems, mobile, uncaged robotics in the factory floor, or 3D printing

technologies. It also does so through the increased integration possibilities offered by ICT technologies that enable the integration of the entire shop floor in an ICT-controlled system and the possibility to integrate the production with the other phases of the manufacturing process.

- **Assistance to Human Operators:** The role of humans on the shop floor is also impacted by the smart factory vision. The use of new technologies such as mobile devices, wearables and the use of augmented reality will enhance operator abilities. They enable new use cases in operator assistance, training, or support for remote maintenance. They are also part of the global integration of the smart factory, with the integration of the human operators in the production process requiring increased mobility and access to data (including 'heavy' data such as 3D models and historical data sets).
- **Measurement and analytics:** The smart factory concept also relies on an increased overview over the production process. This is made possible by new technologies such as the ubiquitous deployment of sensors on the shop floor, the use of tracking technologies to follow goods along production cycles, 3D scanners for quality control, or the possibility to rely on big-data technologies to treat and analyse the collected data. It becomes part of the global integration process by providing early feedback mechanisms that can impact the design and production process with the goal of zero-defect production. It also enables increased integration and optimisation in the value chain with the ability to identify and track use of goods and resources all along the production process.
- **Production control and management:** The control of the production process is also strongly impacted by the smart factory concept. The introduction of advanced prediction technologies, decision-support systems and big-data analysis will strengthen control and management possibilities over the production process. Beyond that, the impacts of the smart factory concept in terms of integration go further with managing the production process. One aim is for control of production to be a single, fully efficient process, integrated all along the value chain, with concepts such as 'systems of systems' and 'lean manufacturing'. Another, related, aim is flexibility and adaptability of the production process through concepts of 'on-demand manufacturing'.

WiFi hotspot

The 'smart factory' refers to the introduction of various technologies such as a connected operation centre (overall supervision and predictive maintenance, chiefly) or connected devices (tablets and wearables) to optimise processes.

Today, many applications can improve working conditions and optimise *in fine* the productivity. Many applications rely on broadband connectivity, even though it could be based on private networks. In the near future, all employees will have a connected device. Implementations could concern:

- Connected eyewear to visualise information in augmented reality. It features a camera that facilitates remote technical assessments or adjustments.
- Tablet to consult and enter data anywhere on-site. This tool allows the user to communicate directly in real time with an expert.
- Highly detailed plans of installations can be rapidly drawn up in 3D.

All these upcoming technical configurations will require higher bitrate at the hotspot level which 5G mm-wave could meet.

Security through video surveillance

Factories and other manufacturing facilities can benefit from the security provided by video surveillance. Theft of raw materials like lumber, copper and steel is at an all-time high, and thieves are targeting factories and other storage facilities with higher frequencies.

Table 7: Pros and cons of video surveillance services

Pros	Cons
• Remote monitoring with an NVR (Network Video Recorder) added to a surveillance system • Prevent theft • Quality control with advanced digital camera technology => Reduce false liability claims • Workplace safety: protection of building and assets • More and more easy to install	• Privacy (employees could feel to be tracked) • Social threat

Source: IDATE

On the drawback side, the video-surveillance cameras could represent a threat for employee intimacy/privacy and for that reason, cameras have to be in public areas like manufacturing and administrative areas, and out of break rooms and restrooms.

The resolution (and therefore the encoding rate) of the camera is increasing and the need for controlling the camera remotely (HD zoom, etc.) clearly require higher internet connection data rate. The higher resolution is even more required for shape recognition and quality control features**.**

Using mm-wave for this high data rate application will certainly be necessary. It should be noted that traffic will mostly be uplink.

Remote operation & smart manufacturing

For the smart factory trend to unfold to the full relies for a good part on several technologies enabling reductions in production costs through automation and control.

The smart factory trend is pushing the evolution of design and engineering solutions further, because of both evolutions in the visualization technologies (virtual reality) and integration with other smart factory solutions.

Virtual reality is already gaining traction for remote operation. Indeed, it provides

- Accurate Decision-Making through better reactivity when a technical problem occurs
- Massive cost savings, by avoiding both transportation costs and maintenance costs optimization.

Some use cases already exist in the oil industry where remote operation with the help of video is far more efficient on both operation and costs aspects. Indeed, when a critical issue occurs in an offshore oil platform, virtual reality provides plenty of benefits to the oil company. However, this requires a specific connectivity architecture where latency and bandwidth are key.

5G mm-wave will meet those performance requirements, especially when video resolution demand will get higher very rapidly (detailed-focused maintenance will need higher video resolution). It is anticipated that applications for oil rigs will need this type of high resolution.

Technical requirements

Main requirements for manufacturing / industrial automation are listed in the table below.

Table 8: Technical requirements for manufacturing / Industrial automation

Service	Quantity of data to transmit (per month)	Latency	Data rate	Traffic direction
WiFi hotspot	In TB	Low latency for critical applications (video mainly or ecommerce)	The more the better (1 Gbps)	Downlink mainly
Video surveillance	Depending on the system	Low latency	> 50 Mbps	Uplink
Remote operation	Variable	Low latency	The more the better (1 Gbps)	Both downlink and uplink

Source: IDATE

URLLC (Ultra Reliable Low Latency Communications) is seen as one of the enabling technologies for the industry of the future. 5G Americas[24] identifies the following use cases: motion control, Industrial Ethernet, control-to-control communication, process automation and electric power generation and distribution.

Energy distribution

Smart grid (AMI: Automated Metering Infrastructure) concentrator connections

In the smart grid backhaul and backbone domain, networks provide the needed control monitors and fault protection.

Today, in electric smart metering deployments, utility players use concentrators to send aggregate data. Indeed, cellular communications provide a reliable connectivity option for smart metering infrastructure, including full IP infrastructure and low latency in 4G LTE today while first deployments rely on GPRS technology five years ago.

More performing technology in terms of data rate should reduce the number of this type of equipment or could even anticipate the volume increase of the data transmitted (increased frequency, additional KPIs, etc.). In Japan, some electric meters are now connected through cellular technology and no longer Power Line Communications. Indeed, KDDI's advanced metering infrastructure services are designed to support more than 10 million smart meters generating about 500 million meter reads each day, representing 50 reads a day per meter (2 reads per hour per meter).

Table 9: Drivers and barriers for smart grid use case

Drivers	Barriers
• Costs savings in hardware CAPEX (less concentrators due to higher capacity per unit)	• Latency • Urban areas only

Source: IDATE

Nevertheless, the communications are built to meet strict requirements on latency for automated fault detection, security, resilience and reliability.

The reliability and security of network systems are essential for mission critical applications that includes device authentication, data protection and identity of end devices.

Finally, the majority of concentrators are not located in urban areas, reducing the interest of 5G mm-wave technology in this market segment, even though the market opportunity is huge in volume (see the market forecasts section).

[24] http://www.5gamericas.org/files/5115/4169/8314/5G_Americas_URLLLC_White_Paper_Final_11.8.pdf

Technical requirements

Main requirements for the smart grid use case are listed in the table below.

Table 10: Main requirements for smart grid use case

Service	Quantity of data to transmit (per month)	Latency	Data rate	Traffic direction
Concentrator connections	Data from 50 meters through GPRS or other low data rate system	Low latency	Limited data rates (~1 to 10 Mbps)	Uplink

Source: IDATE

Smart cities

Smart cities 5G use cases likely to use mm-wave bands include backhaul/mesh for WiFi access points digital signage, and video surveillance. Cameras will require ability to zoom in (stadium…) and will require high throughput.

WiGig access points in the 60 GHz band could also be used to provide backhaul but 5G will be able to support higher QoS.

Table 11: Drivers and barriers for smart city use case

Use case	Drivers	Barriers
Backhaul/mesh for WiFi access points	• High adoption from cities (public policies) • Urban areas	• -
Digital signage	• Willingness to pay • Need for better resolution • Economies of scale • Better marketing RoI	• Costs • Energy consumption
Video surveillance	• High adoption from cities • Limited capacity of existing technologies • Improving resolution of the cameras (strong requirement for form recognition)	• Uplink mainly

Source: IDATE

WiFi access points

This use case relates to providing enhanced broadband access in densely populated areas such as building complexes, urban city centers, crowded areas, etc. Moderate mobility and high data rates will be required here.

This is usually done by providing municipal broadband via Wi-Fi to large parts or all of a municipal area by deploying a wireless mesh network. 5G mm-wave is positive sign for this use case as it provides many benefits in terms of broadband capacity and coverage (urban areas by definition). Mm-wave bands will probably be used for backhauling needs both in indoor and outdoor configurations.

Digital signage (Video based outdoor advertising)

Digital signage is defined as a remotely managed digital display typically tied in with sales, advertising and marketing or as a network of electronic displays that are centrally managed and individually addressable for the display of text, animated or video messages for advertising, information, entertainment and merchandising to targeted audiences.

More and more video is used for such displays (with enhanced resolution) and 5G mm-wave would meet the network requirements, especially in urban areas.

Video surveillance

As cities become more crowded, both the urban environment and its citizens become increasingly sensitive to the many events and circumstances that can affect public safety. There is a huge temptation to engage in full surveillance of the city, notably to reduce the financial and social impact of felonies, crime and other accidents, acts of vandalism or deterioration. The development of digital technologies, and now the IoT, the potential offered by data processing, the deployment of data collection and capture devices (starting with video), open up prospects for strengthening safety and security in urban spaces, on transport networks and other places that are open to the public, not to mention on private property.

There are several reasons for installing CCTV networks:

- Preventing technical incidents is the predominant reason for installing cameras, the images from which are both looked at directly and also, increasingly often, analysed using software;
- Preserving the integrity of these facilities; misuse and intentional damage require rapid interventions for certain equipment, the functioning of which might affect thousands of people;
- Compensating for the reduction in the human workforce responsible or operating the equipment;
- Increasing the crime/misdemeanour clearance rate by assisting police forces in their work.

The rise of open street CCTV, i.e. the 24/7 surveillance of public areas in cities for the purposes of crime control and public order management, has been increasing unabated.

After the different attacks worldwide (since 2001 in the US), homeland security became a priority on the global agenda, and one taken on by cities of course, given their concentrated population. Since then, the range of technologies available to meet the demand for public safety and security has continued to grow.

Today, video cameras are mainly low quality or are connected through wired connection. With higher resolution and features requirements (shape or even face recognition, zoom, etc), enhanced connection would be required. As in the case of video surveillance in the manufacturing sector, the resolution of the camera is increasing and the need for controlling the camera remotely (HD zoom, etc.) clearly require higher internet connection data rate. 5G mm-wave is thus a relevant option, especially in urban areas where it will bring a very high density of traffic.

Technical requirements

Main requirements for smart city services are listed in the table below.

Table 12: Technical requirements for smart city services

Service	Quantity of data to transmit (per month)	Latency	Data rate	Traffic direction
Digital signage	Up to 5 GB per month	n.a.	> 100 Mbps	Downlink
WiFi hotspot	In PB	Low latency for critical applications (video mainly or ecommerce)	The higher the better (1 Gbps)	Downlink mainly
Video surveillance	Depending on the system	Low latency	> 100 Mbps	Uplink

Source: IDATE

Other 5G services in the mm-wave bands

Drone control

According to Goldman Sachs, use cases for unmanned aerial vehicles (drones) are construction, agriculture, insurance claims, offshore refining, police, fire, coast guards, border control, journalism, news, utilities, filmography, logistics.

Drones equipped with LiDAR for intensive inspection is an emerging business in infrastructure, power line, and environment. Huge volumes of data is generated by the LiDAR scanning and >200 Mbps real-time payload transmission is required.

Requirements for aerial vehicles agreed in TSG RAN WG2 in May 2017 are the following:

- Heights up to 300 m above ground level
- Speeds: up to 160 km/h
- Latency: 50 ms
- Data rates: up to 50 Mbps uplink

The use of millimetre wave bands for drone control and very high data rate payload transmission looks promising even though the 26 GHz band will likely be excluded. [25]

Public safety

Public safety use cases include requirements like real time video and the ability to send high quality pictures. They cover day-to-day operation such as for police forces or fire brigades and emergency services in case of floods, earthquakes or hurricanes.

Even though public safety features have been recently added in LTE specifications, the following advantages are expected from 5G:

- Higher area capacity (1000x greater)
- Higher capacity density (~1000 bits/s/Hz/km2)
- Higher connection density (~10,000/km2)
- Lower latency (ms)
- Lower energy consumption
- Software-defined flexibility

Mission critical services, such as public protection and disaster relief (PPDR) services, require ultra-high reliability, ultra-low latency, high security and mobility. They will benefit from URLLC (Ultra Reliable Low Latency Communications) capabilities of 5G. PPDR services are likely to use mm-wave at massive events to complement already available frequency bands. In the event of a dire situation, emergency 5G hotspots could be deployed using mm-wave. 5G will enable the provision of capacity and reduced latency for image sending, video calling and video streaming. With 5G, video cameras could be used for shape or face recognition.

Main expected 5G use cases for public safety should be the following:

- Rapid disaster response: disaster recovery, rescue and relief operations, Public warning system
- Public event management: routine or "day-to-day" operation, large and/or planned event operation
- Critical assets protection

[25] CEPT Report 68 on technical conditions for 5G use of the 26 GHz band (in response to Mandate from the European Commission) states: "The use of these UAV and drones within WBB ECS networks could have an impact on the compatibility with existing services and hence connectivity from base stations to terminals on board UAV shall be prohibited in the 24.25-27.5 GHz band and only communications for connectivity from terminals on-board UAV to base stations are authorised."

The H2020 R&D project Coherent[26] identified a PPDR use case with the following description:

- Coordination of rapidly deployable mesh networks;
- Flexible resource sharing for broadband PMR (Private Mobile Radio) networks;
- Coverage extension and support of out-of-coverage communications (D2D communications).

NG (Next Generation) 112 eCall is expected to provide context-aware rich content service and will improve safety with advanced situational awareness. The 112 system is more likely to use sub-6 GHz spectrum due to coverage constraints. Moreover, 700 MHz or 800 MHz are already been identified for 4G/5G PPDR by WRC-15.

Satellite use cases

3GPP is examining the role satellites will play in delivering on 5G connectivity. The roles and benefits of satellites in 5G have been studied in 3GPP Release 14 and 15, leading to the specific requirement to support satellite access being captured in TS22.261 (Service requirements for next generation new services and markets; Stage 1) and TR 38.811V1.0.0 (Study on New Radio (NR) to support non terrestrial networks).

One of the main difference with 5G is that satellite direct access should involve the same hardware in order to remove the barrier observed in the past and a specific software which could be downloaded as an application by the user. This should enable devices' price to be reduced and could foster adoption if this integration of the satellite segment is successful at standardisation level (3GPP).

Today, it does not seem feasible to use mm-wave bands for on the move communications to end user devices. It is expected that use of satellite for 5G direct access will essentially use frequency bands below 6 GHz as mobility support is only possible with very large antennas in mm-wave bands. Direct satellite access is likely to be used for asset tracking of goods for instance for the maritime sector. Drone control is also under study.

Various use cases involving satellite for 5G are being studied in 3GPP:

- eMBB services
  - Multi connectivity for users in underserved areas
  - Fixed cell connectivity for users in isolated villages or industry premises
  - Mobile cell connectivity for passengers on board vessels or aircrafts
  - Network resilience for critical network links requiring high availability
  - Trunking for a network operator willing to deploy or restore 5G service in an isolated area
  - Edge network Delivery: media and entertainment content transmitted in multicast mode to a RAN equipment at the network edge
  - Mobile cell hybrid connectivity: passengers on board public transport vehicles (e.g. high speed/regular trains, buses, river boats) access reliable 5G services
  - Direct To Node broadcast: TV or multimedia service delivery to home premises or on board a moving platform
  - Direct to mobile broadcast: Public safety authorities wants to be able to instantaneously alert/warn the public
  - Wide area public safety
  - Local area public safety: set up of a tactical cell
- mMTC
  - Wide area IoT service
  - Local area IoT service

[26] http://www.ict-coherent.eu/

Hybrid satellite terrestrial use cases are described in chapter 55 of this document. In the hybrid scenarios, satellite would provide high capacity links to fixed terrestrial terminals as a complement to terrestrial infrastructures. In the Hybrid Multiplay use case, satellite would provide high bit-rate backhaul connectivity to individual homes in multicast mode for video, HD/UHD TV and other non-video data. It would also serve as a complement to existing terrestrial connectivity.

Satellite hybrid solutions are not expected before 2023-2024 as standardisation work for integration of the satellite in 5G networks will take a few years before it is completed. 3GPP Release 16 will be finalised at the end of 2019 and part of the satellite related items could also be part of Release 17.

Table 13: Satellite use cases

5G Service enabler	5G Use case	5G Use case description	Satellite service
eMBB	Multi connectivity	Users in underserved areas	Broadband connectivity to cells or relay node in underserved areas in combination with terrestrial wireless/cellular or wire line access featuring limited user throughput.
eMBB	Fixed cell connectivity	Users in isolated villages or industry premises (Mining, off shore platform)	Broadband connectivity between the core network and the cells in un-served areas (isolated areas).
eMBB	Mobile cell connectivity	Passengers on board vessels or aircrafts	Broadband connectivity between the core network and the cells on board a moving platform (e.g. aircraft or vessels).
eMBB	Network resilience	Some critical network links requires high availability	Secondary/backup connection (although potentially limited in capability compared to the primary network connection).
eMBB	Trunking	A network operator may want to deploy or restore (disaster relief) 5G service in an isolated area	Broadband connectivity between the public data network and a mobile network anchor point or between the anchor points of two mobile networks.
eMBB	Edge network Delivery	Media and entertainment content transmitted in multicast mode to a RAN equipment at the network edge where it may be stored in a local cache or further distributed to the User Equipment.	Broadcast channel to support Multicast delivery to 5G network edges.
eMBB	Mobile cell hybrid connectivity	Passengers on board public transport vehicles (e.g. high speed/regular trains, buses, river boats) access reliable 5G services. They are served by a base station which is connected by a hybrid cellular/satellite connection.	Broadband connectivity combined with terrestrial cellular access to connect a cell/group of cells or relay node(s) on board moving platforms.
eMBB	Direct To Node broadcast	TV or multimedia service delivery to home premises or on board a moving platform	Broadcast/Multicast service to access points in homes or on board moving platforms.
mMTC	Wide area IoT service	Global continuity of service for telematic applications based on a group of sensors/actuators (IoT devices, battery activated or not) scattered over or moving around a wide area and reporting information to or controlled by a central server.	Connectivity between IoT devices (battery activated sensors/actuators or not) and spaceborne platform. Continuity of service across spaceborne platforms and terrestrial base stations is needed.

5G Service enabler	5G Use case	5G Use case description	Satellite service
mMTC	Local area IoT service	Group of sensors that collect local information, connect to each other and report to a central point. The central point may also command a set of actuators to take local actions such as on-off activities or far more complex actions.	Connectivity between mobile core network and base station serving IoT devices in a cell or a group of cells.
eMBB	Direct to mobile broadcast	Public safety authorities wants to be able to instantaneously alert/warn the public (or specific subsets thereof) of catastrophic events and provide guidance to them during the disaster relief while the terrestrial network might be down.	Broadcast/Multicast service directly to User Equipment whether handheld or vehicle mounted.
eMBB	Wide area public safety	Emergency responders, such as polices, fire brigates, and medical personals can exchange messaging and voice services in outdoor conditions anywhere they are and achieve continuity of service whatever mobility scenarios.	Access to User Equipment (handset or vehicle mounted).
eMBB	Local area public safety	Emergency responders, such as polices, fire brigates, and medical personals can set up a tactical cell wherever they need to operate. This cell can be connected to the 5G system via satellite to exchange data, voice and video based services between the public safety users within a tactical cell or with the remote coordination centre.	Broadband connectivity between the core network and the tactical cells.

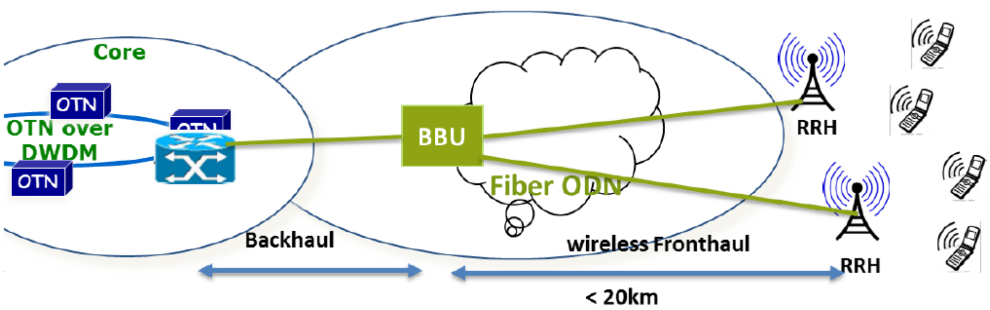
Source: 3GPP TR 38.811V0.3.0 (2017-12) Study on New Radio (NR) to support non terrestrial networks (Release 15)

We do not anticipate any significant development before 2025 for satellite in 5G due to the need for standardisation work and the time-to-market constraints associated with satellites.

Fronthauling/Backhauling

5G will see date rates reaching a few Gbps on the radio link meaning the backhaul and fronthaul links will also grow very rapidly. Solutions for mobile operators in case fibre is not an option will be last-generation microwave links or in-band backhauling using 5G spectrum. Figure 8 below shows the fronthauling and backhauling links in a mobile network.

Figure 8: C-RAN for wireless backhaul and fronthaul



Source: Unified Architectures for Remote PHY Backhaul and 5G Wireless Fronthaul - Yuxin (Eugene) Dai

Backhauling

The backhauling corresponds to the link between the Baseband Unit (BBU) and the core network. In 5G networks, as peak data rates will reach tens of Gbps, the backhauling needs will also rise tremendously even in areas where ultra-dense networks will not be built. Fib backhaul will generally be the preferred option for mobile operators but wireless backhaul links will certainly be an option and could provide an attractive alternative with the use of higher mm-waves bands such as the W-band (92–114.25 GHz) and D-band (130–174.8GHz) for backhauling needs.

Fronthauling

Fronthaul links correspond to the connection between the cell tower radio itself (Remote Radio Head or RRH) and the mobile network control backbone (BBU).

Some R&D projects have been working on the integration of fronthaul and backhaul into an integrated 5G Transport Network. The objective is to get a flexible, reconfigurable, software defined transport architecture.

In this concept, a single network would support a variety of functional splits between the antenna and the packet core. It integrates the evolution of Network Function Virtualization (NFV) and Cloud RAN (CRAN).

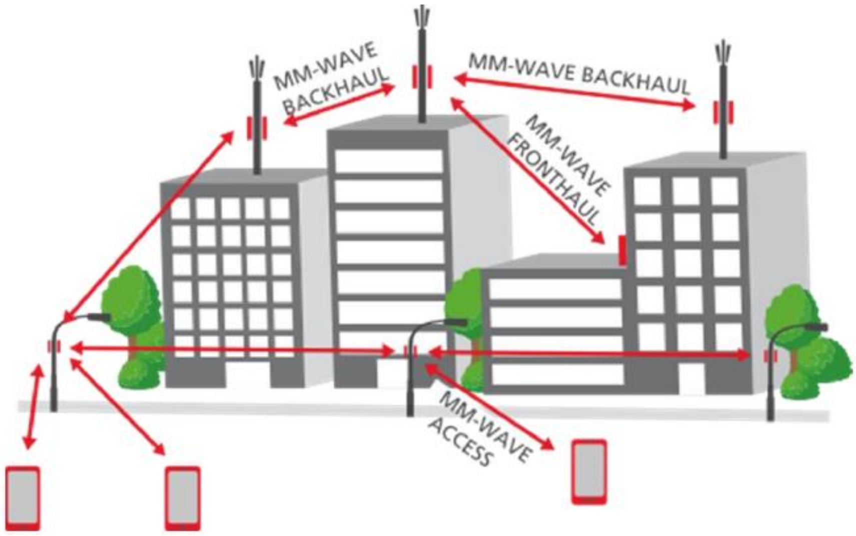
Integrated access-backhaul

The third generation partnership project (3GPP) is working on an integrated access and backhaul (IAB) architecture for 5G networks in which the same infrastructure and spectral resources will be used for both access and backhaul.

In higher bands with MIMO antennas providing “pencil-shape” beamforming, the reuse of time, frequency and/or space resources between access and backhaul can be done more efficiently and with higher precision than in lower bands.

When mm-wave bands become available, large portions of spectrum will make it possible in many locations to use part of the spectrum for backhauling/fronthauling purposes as mobile operators will be able to split the spectrum resource easily between access and back/fronthauling.

Figure 9: Integrated mm-wave 5G access and backhaul

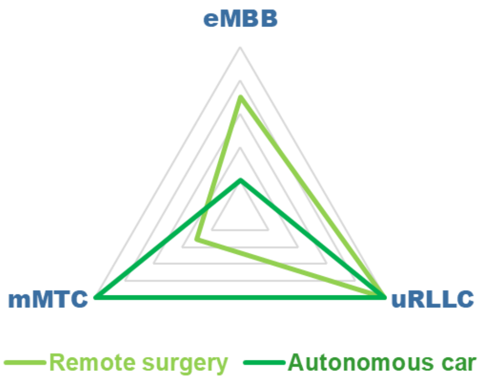


Source: Miweba

Vertical applications in need of URLLC (Ultra Reliable Low Latency Communications)

These are mission-critical IoT applications (mission-critical Machine-Type Communication) that will have very high demands on reliability, availability and low latency down to the millisecond level with lower demands on the volume of data, but significantly higher business value. For some vertical sectors, various 5G capabilities will be combined in order de deliver both high data-rates, reduce latency and high reliability. Figure 10 below shows as examples the cases of remote surgery and autonomous car:

Figure 10: Combination of 5G capabilities for remote surgery and autonomous car



Source: IDATE

Mission-critical IoT applications are envisioned to enable real-time control and automation of dynamic processes in various fields, and typical use cases for URLLC-enabled applications include:

- Process Automation
- Automated Factories
- Transport applications (Driver Assistance Applications, Autonomous Driving, Traffic Management)
- Tactile interaction ("The Tactile Internet")
- Emergency, disasters and public safety
- Urgent Healthcare/ Remote Surgery

Such use cases and mission-critical applications will require high to very-high data rates, low latency and will have strong reliability requirements.

The specific needs for ultra-reliable low latency communications were detailed in the requirements of verticals in section 0 of this report.

The second phase for 5G standardisation (based on NR) will widely address ultra-reliable low-latency communication use cases, such as artificial intelligence (AI) applications.

Some of the above-mentioned use cases will not require very high throughputs but for some specific applications requiring very high data rates (such as critical communications in healthcare, factories, PPDR or automotive), mm-wave bands are likely to be used and could contribute to very low latency.

2.4. The demand for 5G services in the mm-wave bands

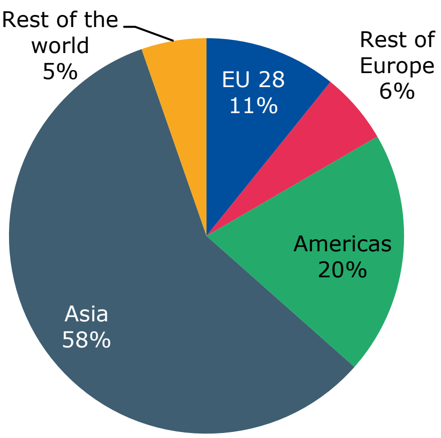
This section presents 5G global market forecasts and the technical estimates for individual 5G services and use cases. We then evaluate the use of mm-wave bands between 2020 and 2025.

2.4.1. Global 5G market forecasts

In 2025, we forecast 1.7 billion 5G subscriptions, 6 years after launch of the first 5G services. EU-28 will represent 11% of the total.

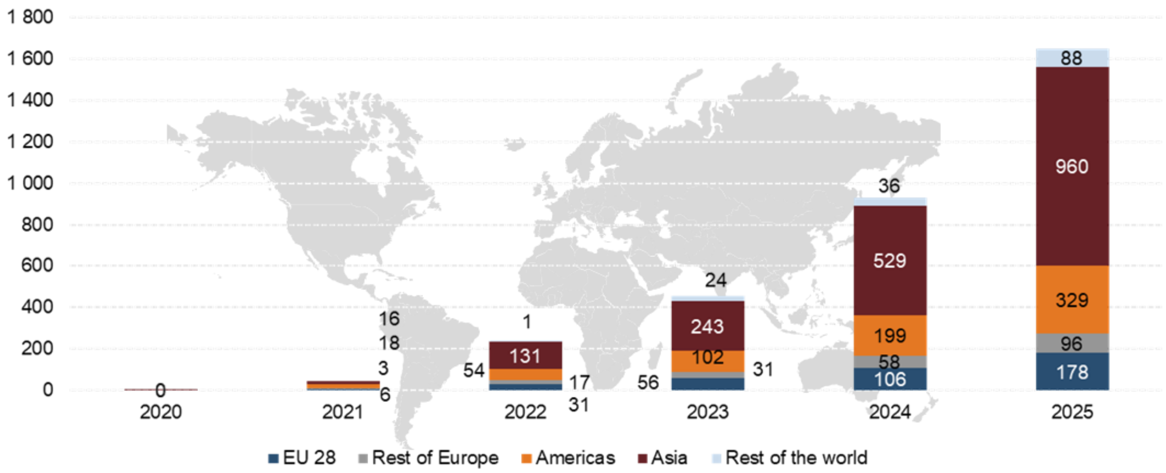
- Launch in 2018-2019 in Asia and the USA, 2020-2021 in Europe
- We expect 5G will have faster adoption than LTE
- Impressive subs growth: 149% CAGR
- 5G should become mainstream in 2023
- Asian push in terms of 5G subscriptions.

Figure 11: 5G forecasts-2025



Source: IDATE

Figure 12: 5G subscriptions[27] forecasts (million)



Source: IDATE

Ericsson forecasts[28] there will be 1.5 billion 5G subscriptions by the end of 2024. These subscriptions will comprise both smartphones, tablets and IoT devices.

[27] 5G subscriptions both cover humans and machines

[28] https://www.ericsson.com/en/mobility-report/reports/november-2018

Potential demand for each 5G use case is evaluated for the 2020-2025 and for the 2025-2030 periods in the table below:

Table 14: Potential demand for 5G use case (expected 5G subscriptions)

Sector/Application	5G use cases	5G forecasts 2020/2025	5G forecasts 2025/2030
eMBB-mobile	Use of mm-wave bands in hot spots (indoor and outdoor small cells)	++	+++
eMBB-Fixed Wireless Access	Use of FWA to deliver HD video	-	+
Automotive	V2V, V2X	+ to ++	+++
Trains and buses	Access and backhauling	+	++
Medical applications	Tactile Internet, remote healthcare	+	++
Manufacturing / industrial automation	Robotics, Tactile Internet, localized real-time control, security, process automation	+	+++
Energy	Smart metering concentrator connection, smart grid	-	+
Smart cities	Digital signage, video surveillance	+	+++
Public safety	Real time video and high quality pictures	-	+
Satellite	Use for hybrid solutions	-	+
Backhauling	For in-band backhauling, for moving hot-spots	- to +	+ to ++

Legend: "+++": very strong demand, "++": important demand, "+": limited demand, "-": very limited demand
Source: IDATE

2.4.2. Forecasts and estimates of demand for individual 5G services and use cases

Not all 5G services are expected to use mm-wave bands. The first services that are likely to be deployed in mm-wave bands are likely to be eMBB (enhanced Mobile Broadband) and backhauling, but no killer application has been identified so far. It will be very challenging to deploy mm-wave systems due to interference in the indoor environment, and range limitations in the outdoor environment.

eMBB

eMBB in urban areas is likely to drive the 5G market during the first two to three years after commercial launch. Both indoor and outdoor usages will be implemented, but they are likely to develop separately from one another due to the poor building penetration of mm-waves. Indoor small cells will use mm-wave bands in order to provide high capacity and data rates in congested areas.

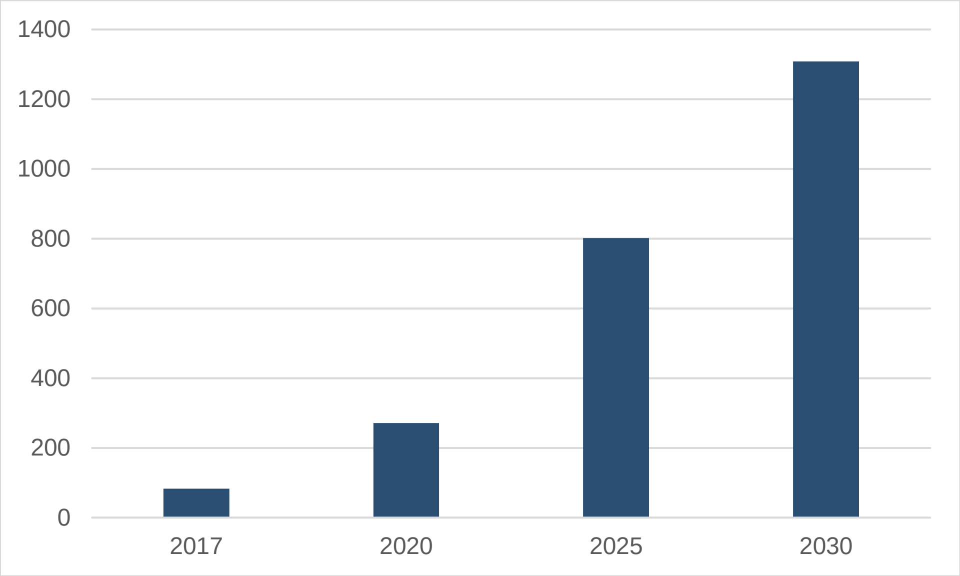
Fixed Wireless Access recently gained more attention as operators estimate it could complement fibre networks in dedicated areas. FWA services will probably use mm-wave bands even though it should be possible to use the 3.5 GHz band in sub-urban and rural areas.

As early 5G commercial launch will focus on the provision of higher throughputs, eMBB traffic will represent the vast majority of 5G traffic between 2020 and 2025.

Automotive

The number of connected cars (defined as cars with a cellular module dedicated to the car) should reach over 1.3 billion in 2030, representing around 25% CAGR over the 2016-2030 period. It is mainly driven by the regulation and public policies (around eCall in Europe).

Figure 13: Market forecasts for connected cars (million units)

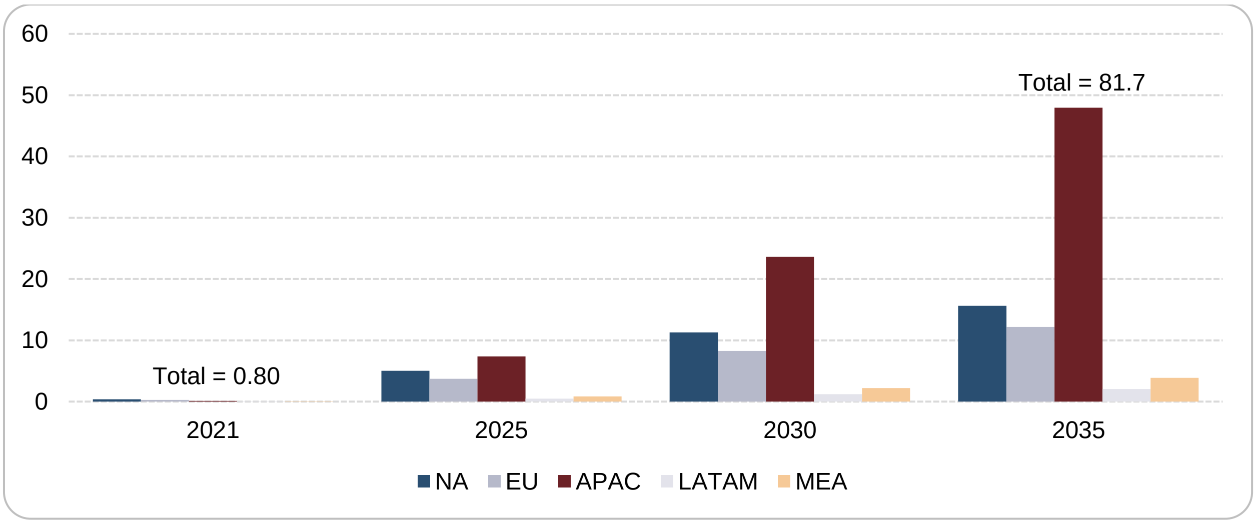


Source: IDATE

Regarding autonomous vehicles, the total number of fully autonomous vehicles (level 5[29]) sold in 2021 is expected to reach 800,000 units. Fourteen years later, in 2035, the number of level 5 cars is expected to reach 81.7 million units.

Figure 14: Sales of autonomous cars (level 5)

(Million units)



Source: IDATE DigiWorld, *Autonomous Cars*, January 2018

Once the autonomous vehicle market has emerged, it is likely that mm-wave bands will be used for 5G communications in congested areas. This would probably take place after 2025. Backhauling links for WiFi hotspot provision and software update downloads should benefit from the high data rates provided by mm-wave bands.

Other transportation

According to IDATE, the number of connected buses should grow from 0.85 million units in 2017 to 3.55 million by 2030, representing a 11.5% CAGR over the period.

[29] There are five levels defined for the autonomous car : level 0 = no automation, level 1 = Driver assistance, level 2 = partial automation, level 3 = conditional automation, level 4 = high automation, level 5 = complete automation

It is likely that trains and buses will be able to use mm-wave bands for these use cases in rural areas. Hybrid systems might play a role here with satellite providing access in areas not covered by cellular networks.

Railways in Europe are only starting to study the use of mm-wave bands for the trains and are not yet able to identify their precise needs as far as 5G connectivity is concerned.

It is expected that mm-wave bands will be used for trains and buses but this is likely to occur after 2025 as investments cycles are very long in the railways sector. Buses could be equipped more rapidly but they will mainly rely on sub-6 GHz bands between 2020 and 2025.

Medical applications

Apart from urgent healthcare and remote surgery robotics-assisted surgery, most eHealth applications will not require very high data rates and it is not expected that mm-wave bands will be heavily used in the coming years.

Manufacturing / industrial automation

The video surveillance market was valued at 30.37 billion USD in 2016 and is projected to reach 75.64 billion USD by 2022, at a CAGR of 15.4% between 2017 and 2022.

The 3.6 GHz band is very likely to be a good candidate for this type of use case and apart from remote operation through virtual reality, industrial automation is not expected to use very high data rates and hence, use of mm-wave bands is likely to be limited. Video surveillance will certainly justify use of mm-wave bands in congested areas.

Energy distribution

The market of smart meters is set to develop rapidly in the next decade, reaching a total around 3.6 billion connected meters by 2030 (all energy included), with a 12% CAGR. In volume, the electric and water meter market dominate clearly. Regarding growth water and gas meter will grow slightly more rapidly than electric meter, as the current installed base of smart meters is higher for electric meters.

The domination of electric meters on the smart meter market is mainly explained by the fact that the value added of connectivity is more important for electric network than water or gas network. Indeed, smart meters in the electricity market are seen as a necessary first step toward a more radical evolution of the power grids (the smart grid) that is considered as compulsory in order to accommodate safely new electricity sources (distributed generation through renewables) and usage (electric vehicles). In the water and gas market, smart meters have clear cost cutting objective (especially in reducing leaks, maintenance and monitoring costs). Breakdowns of electric meters are not considered as vital by energy players so there is not an urgent need for very reliable communication systems in the short term. These markets are thus picking up more slowly but represent significant opportunity in the long run.

Regarding regional disparities, the Asia-Pacific (APAC) zone represents the largest volume opportunity. With China being the largest market. APAC is also the highest growth opportunity as it couples traditional meter replacement with an important part of new deployments (due to population growth, urbanization and development of water and electricity networks in rural areas). But the APAC region is also notably fragmented with countries well engaged in the transition (Japan and China) while other are still lagging behind (India and south East Asia) and likely to catch up in the coming years.

The use of mm-wave bands is likely to be limited as smart grids should develop slowly in Europe and it is not foreseen that very high data rates will be needed.

Smart cities

Public WiFi

The global market for Outdoor Wi-Fi is projected to reach 37.7 billion USD by 2020, driven by the emerging era of digital nomads, extreme remote working, and the growing focus on monetizing outdoor public Wi-Fi. Main drivers include deployment in transportation hubs (train station and airports mainly).

mm-wave bands should provide the ability to use 5G for backhauling needs of public WiFi access points.

Digital signage

There are currently over 200 different companies worldwide that are marketing digital signage solutions and the number is still consistently growing.

The global digital signage market is predicted to attain USD 31.71 billion by 2025, as per a new study by Grand View Research[30]. The market is expected to witness a CAGR of 7.9% over the forecast 2017-2025 period, owing to increasing demand from end-use industries

The reason for the rise is due to the growing demand by companies for the development of digital signage solutions, advertisement displays, and paper wastage reduction.

Video surveillance

The public safety market, which is essentially made up of CCTV in public spaces, is a sector that is expected to grow steadily over the next five years: by an average 20% a year. mm-wave bands should provide the ability to connect displays using 5G technology.

Public safety

The public safety market is small and cannot by itself be a strong driver for global 5G adoption, but it can represent none the less a significant revenue opportunity once efficient business models have been found. A hybrid model mixing the use of commercial networks for bandwidth intensive public safety use cases and ad-hoc networks for mission critical disaster relief use cases can be seen as a promising solution to address the market.

Satellite

Satellite hybrid solutions are not expected before 2023-2024 as standardisation work for integration of the satellite in 5G networks will take a few years before it is completed.

Fronthauling / backhauling

When mm-wave bands become available, large portions of spectrum will make it possible in many locations to use part of the spectrum for backhauling/fronthauling purposes as mobile operators will be able to split the spectrum resource easily between access and backhauling/fronthauling.

Summary of expected demand

Many players in Europe do not expect for the time being massive 5G deployment in Europe. The reasons for that are probably the limited ability to invest in a new network and the difficulty to identify new business opportunities in the short term. Another reason might be the high amount of spectrum available below 6 GHz in Europe with the 700 MHz and the 3.5 GHz bands that will provide a lot of capacity before mm-wave bands are needed.

Use of the mm-wave bands will be progressive in Europe with expected initial adoption by 5G operators in congested hot-spots, roads and major transport paths. Deployment of small cells using the 26 GHz band is expected to start in 2022-2023, but with limited volumes. Significant deployments are likely to start in 2025 or so.

[30] https://www.grandviewresearch.com/press-release/global-digital-signage-market

Table 15: Potential 5G services using mm-wave bands – Summary

Sector/ Application	5G use cases	Use of mm-wave bands (% of total 5G traffic for each application) 2020/2025	Use of mm-wave bands (% of total 5G traffic for each application) 2025/2030
eMBB-mobile (local)	Use of mm-wave bands in hot spots (indoor and outdoor small cells)	++	+++
eMBB-FWA	Use of FWA driven by HD video	++ to +++	+++
Automotive	Hotspot backhaul, V2V, V2X	+	++
Trains and buses	Access and hotspot backhaul	+	++
Medical applications	Tactile Internet, remote healthcare	- /+	++
Transport Backhauling	For in-vehicle (moving) hot-spots	++	+++
Manufacturing / industrial automation	Robotics, Tactile Internet, localized real-time control, security, process automation	+	++
Energy distribution	Smart metering concentrator connection, smart grid	-	-
Smart cities	Digital signage, video surveillance	+	++
Public safety	Real time video and high quality pictures	-	+
Satellite	Use for hybrid solutions	-	+
Cell-site Backhauling/ Fronthauling	Self- backhauling (IAB)	+++	+++

Legend: "+++": 100% use of mm-wave bands, "++": important use of mm-wave bands, "+": limited use of mm-wave bands, "-": very limited use of mm-wave bands

Source: IDATE

2.4.3.5G forecasts in the mm-wave bands

Expected availability of equipment for the 26 GHz band

Device and network equipment manufacturers expect 26 GHz spectrum to be allocated in many European countries in 2018 in order to make sure that the addressable market is large enough. China might also play a role here and have a strong impact on equipment availability if the country initiates early deployment in the 26 GHz band.

Samsung indicates that their trial equipment used with Arqiva in the United Kingdom can operate within the 26.50-29.50 GHz band. It includes chipsets, CPEs (Consumer Premises Equipment), Infrastructure Access Units, Virtualised Core Network and 5G planning tools. Commercial availability of this equipment is planned for 2019 according to Samsung.

According to Ericsson, the expected product availability for commercial 3GPP compliant 28GHz products is just slightly ahead (6 months) of that for 26GHz.

Trends related to the use of sub-6 GHz spectrum

We anticipate mobile operators in Europe to mainly use the sub-6 GHz frequency bands, and especially the 700 MHz and 3.5 GHz bands, between 2020 and 2025. It will be possible for them to re-use the existing cell sites for the new frequency bands: the 800 MHz cell sites for the 700 MHz band and the 2.6 GHz cell sites for the 3.5 GHz bands as the use of massive MIMO will compensate for the transmission loss in the 3.5 GHz band.

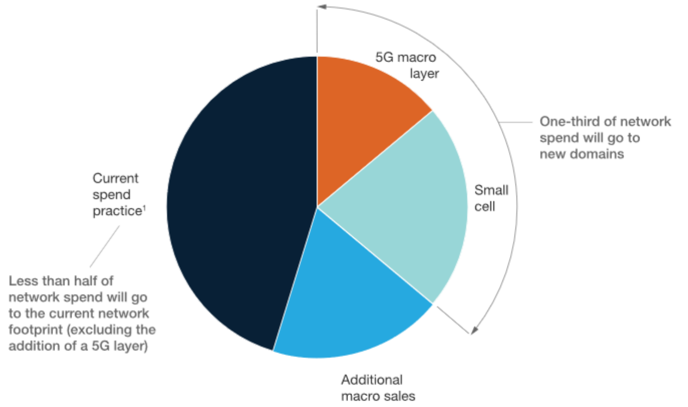
Evaluation of mm-wave bands use based on expected number of 5G cell sites

We anticipate the use of millimetre wave bands to be limited to specific applications and very dense areas (such as stadiums, shopping centers, railways stations, airports…).

mmWave band will be supported by indoor small cells and a limited number of outdoor small cells. In some limited cases (fixed wireless access, coverage of train tracks and road corridors), mm-wave bands will also be used in sub-urban and rural areas.

There are approximately 600,000 cellular cell sites in Europe today. The Small Cell Forum and 5G Americas estimate[31] that there will be 1 million 5G or 5G/multimode non-residential small cells in Europe in 2025. As evaluated by Mc Kinsey[32] there could be the same number of small cells as macro cells in 5G network in 2025.

Figure 15: Spending in 5G and legacy network



Note: Total cost of ownership includes capital expenditures and operational expenditures for radio access network and transmission but not core networks. Data are based on 3 operators in a European country. Results are rounded.
[1]Total cost of ownership of current network footprint, including capacity LTE and LTE-Pro upgrades.

Source: Mc Kinsey

According to Ericsson, 80% of the cell sites will have backhaul capacity below 600 Mbps in 2025. This gives an indication of the cell's capacity and maximum throughput.

Figure 16: Backhaul capacity required for 5G

Advanced mobile broadband	2017	2022	Towards 2025
80 percent of sites	150Mbps	350Mbps	600Mbps
20 percent of sites	300Mbps	1-2Gbps	3-5Gbps
Few percent of sites	1Gbps	3-10Gbps	10-20Gbps

Source: Ericsson, 2017

This certainly means that 80% of the cell sites of 5G networks are not likely to support mmWave bands as backhauling needs directly are linked to the maximum data rate of a cell. For base stations supporting mm-wave bands, capacity is likely to be over a few Gbps.

If we assume that in 2025, half of the cell sites will be small cell sites, the n a rough estimate is that approximately 10% of the 5G cell sites would support mm-waves.

2.5. Evaluation of spectrum capacity in mm-wave bands

In this section, we identify the likely frequency bands for 5G after WRC-19 and spectrum needs expressed by stakeholders in the millimetre wave bands.

[31] http://www.5gamericas.org/files/9815/3547/3006/195_SC_siting_challenges_final.pdf

[32] https://www.mckinsey.com/industries/telecommunications/our-insights/the-road-to-5g-the-inevitable-growth-of-infrastructure-cost

2.5.1. Likely mm-wave frequency bands for 5G after WRC-19

RSPG

The Draft RSPG Second Opinion on 5G networks 26 GHz published on 21 November 2017 is "a further development of the roadmap to facilitate the launch of 5G on a large scale in Europe starting in 2020". The following frequency bands are under study as part of the WRC-19 process:

- 24.25 - 27.5 GHz (26 GHz);
- 40.5-43.5 GHz (42 GHz);
- 66-71 GHz.

If these bands are made available in Europe for 5G use in the coming years, it will represent more than 10 GHz of spectrum and will certainly provide enough capacity for supporting the growth of 5G networks.

It is noted that the 66-71 GHz band has potential as a primary European band for 5G services under general authorisation and there is an interest as it could complete the adjacent WiGig band (57-66 GHz).

The 32 GHz frequency band (31.8-33.4 GHz) that was considered in the first RSPG opinion on 5G is not anymore considered as a priority for studies due to preliminary results of these sharing studies which showed difficulties with incumbent users.

In this regard, WRC-19 will consider other frequency bands are part of the study process which were not identified as "priority bands" by the RSPG:

- 37-40.5 GHz
- 45.5-50.2 GHz
- 50.4-52.6 GHz
- 71-76 GHz
- 81-86 GHz

Initial spectrum for 5G deployment

It is expected that mobile operators in the EU will first use the sub-6 GHz spectrum for initial deployment of 5G networks. The 700 MHz and 3.6 GHz will certainly be the first choice of most operators and the 1.5 GHz band (1452-1492 MHz) should also be attractive as announced in Spain.

The 26 GHz band will be assigned in many EU countries in the coming years and many regulation authorities are currently working on authorisation conditions for this new band.

A number of non-EU countries around the world are planning the use of sub-6 GHz bands for early deployments of 5G networks:

- In the USA, T-Mobile will use the 600 MHz band to provide mainly 5G eMBB services and Sprint will use the 2.5 GHz band;
- The 700 MHz will be used for 5G in most European countries;
- China's Ministry of Industry and Information Technology (MIIT) has officially reserved 3.3-3.6 GHz and 4.8-5 GHz for 5G service, and it will likely free up 3.6-4.2 GHz for future 5G allocation;
- In South Korea, 280 MHz of the 3.5GHz spectrum were auctioned in 2018 to be used for 5G;
- In the middle-east region, UAE and Saudi Arabia will use 3.5 GHz spectrum for 5G.

There is no potential for a national network in mm-wave bands as stakeholders consider the bands above 6 GHz as complements to provide capacity whereas lower frequency bands will provide coverage.

2.5.2. Estimation of the 5G capacity

According to many stakeholders and assuming spectrum efficiency of 5 bit/s/Hz[33], 400 MHz will be needed in order to provide 2 Gbps services. In the 26 GHz in Europe, 1 GHz of spectrum will probably be available in the upper part of the band in the mid-term.

Current standardisation work at 3GPP for equipment using mm-wave bands takes into account channel bandwidth of up to 400 MHz. Lower bandwidths of 50/100/200MHz are also in discussion. Carrier aggregation should be studied in a second step. Many stakeholders in the industry are in favour of allocations of 200 MHz per operator increasing to 500 MHz when more of the 26 GHz band becomes available.

Table 16 below shows that very high spectrum efficiency has to be reached in indoor environment and in dense urban environment in order to fulfil with IMT-2020 requirements.

Table 16: Average spectral efficiency

Test environment	Downlink (bit/s/Hz/TRxP)	Uplink (bit/s/Hz/TRxP)
Indoor Hotspot – eMBB	9	6.75
Dense Urban – eMBB	7.8	5.4
Rural – eMBB	3.3	1.6

Source: ITU *Report ITU-R M.2410-0 (11/2017) - Minimum requirements related to technical performance for IMT-2020 radio interface(s) (TRxP: Transmission reception point)*

Some equipment manufacturers and operators[34] estimate that if 1 GHz is available in the 26 GHz band, it will allow two networks to be deployed with multi-Gbps capability. In many countries, this will lead to network sharing or will lead to sub-optimal allocation to four operators.

Ericsson has a more optimistic view regarding peak data rates for various channel bandwidths:

Table 17: Expected peak data rates according to channel bandwidth – 5G NR (New Radio)

RF channel bandwith	Peak data rates
200 MHz	6 Gbps
400 MHz	12 Gbps
800 MHz	24 Gbps
1000 MHz	30 Gbps

Source: Ericsson (answer to 2017 OFCOM consultation)

Example of capacity per 5G access point

Samsung indicated in its response to the 2017 OFCOM consultation that it carried out a study in the 28 GHz band. The simulation of a 5G hotspot area, comprising a 2 km stretch of *a* crowdy street "with a 300 m width (0.6 km2), show that to support typical services (web browsing, social media, content sharing, UHD video and VR applications), an average access point capacity of 3.1 Gbps needs to be achieved. Having 500 MHz means to support a peak capacity of 7.2 Gbps, which is able to support 94 % data rate requirements of the highest data consuming applications (UHD video)."

Huawei indicated that for fixed wireless access deployments, an average downlink cell throughput of 1.45 Gbps can be achieved with a 800 MHz bandwidth in the mm-wave bands.

[33] this assumption comes from figures provided by equipment providers and it is consistent with IMT-2020 minimum requirements

[34] See section 4.4.5 for more details

Traffic estimates

Application Data Rate

The most demanding applications in terms of data rate should be 8K videos and spherical view for holography, according to ETRI. The data rate could then surpass 1 Gbps.

Table 18: Data rates for different video applications

Service	Data rate
360 view with 4K resolution	65 Mbits/s (H.265) and 130 Mbits/s (VAR for peak).
360 view with 8K resolution	258 Mbits/s (H.265) and 516 Mbits/s (VAR for peak).
Spherical view for holography	4 to 8 times more than 360 views

Source: ETRI

Connection density for various areas are given in the table below:

Table 19: Connection density for different areas

Teledensity	Number of devices per area	Activity factor	Connection density
Overcrowded area	1-4 / m²	90%	225 000 / km²
Dense urban area	5-100 / m²	70%	35 000 / km²
Urban area	20-10000 / m²	50%	2 500 / km²

Source: ETRI

Suitable spectrum for 5G applications

Apart from ultra-high-speed radio links which require very high-capacity radio channels, most of the frequency ranges below 6 GHz are suitable for all deployment scenarios. Propagation above 24 GHz considerably limits range and the mm-wave bands are suitable for specific applications such as outdoor hotspot and indoor micro and pico-deployments.

Table 20: Spectrum Ranges Considered Suitable for 5G Applications

Usage Scenario	High-level Requirement	Potential Spectrum-Related Implications	Spectrum Ranges Considered Suitable
Enhanced mobile broadband	Ultra-high-speed radio links	Ultra-wide carrier bandwidths, e.g. 500 MHz Multi-gigabit front haul/backhaul, indoor	> 24 GHz
	High speed radio links	Wide carrier bandwidths, e.g. 100 MHz Gigabit fronthaul/backhaul	3-6 GHz
	Support of low to high-mobility	Depends on the throughput requirement	All ranges
	Ultra-low latency	Short range implications	3-6 GHz, > 24 GHz
	Low latency	Mid-short-range implications	3-6 GHz
	Ultra-high reliability radio links	Severe impact of rain and other atmospheric effects on link availability in higher frequencies, e.g. mm-wave, for outdoor operations	Severe impact of rain and other atmospheric effects on link availability in higher frequencies, e.g. mm-wave, for outdoor operations
	High reliability radio links	Impact of rain and other atmospheric effects on link availability in higher	< 6 GHz

Usage Scenario	High-level Requirement	Potential Spectrum-Related Implications	Spectrum Ranges Considered Suitable
		frequencies, e.g. mm-wave, for outdoor operations	
Ultra-reliable Communications	Short range	Higher frequencies, e.g. mm-wave	> 24 GHz
	Medium-Long range	Lower frequencies, e.g. sub-6 GHz	< 6 GHz
	Ground/obstacle penetration	Lower frequencies, e.g. sub-1 GHz	< 1.5 GHz
Massive Machine-Type Communications	Operation in cluttered environment	Diffraction dominated environment in lower frequencies Reflection dominated environment in higher frequencies	All ranges
	Operation near fast-moving obstacles	Frequency-selective fading channels	All ranges, especially below 6 GHz
	Mesh networking	High-speed distributed wireless backhauls operating in-band or out-of-band	> 24 GHz

Source: 5G Americas

The need for contiguous spectrum is highlighted by many stakeholders even if there is prospect of Carrier Aggregation as an alternative (albeit less efficient) to usage of a contiguous block of 26 GHz spectrum.

Spectrum needs estimates

We summarised in this section the various spectrum need estimates in mm-wave bands published by ITU, METIS-II and ETRI.

ITU-R

ITU-R Working Party (WP5D) finalized in February 2017 its evaluation work on spectrum needs for 5G/IMT-2020 for frequency ranges between 24.25 and 86 GHz.

The work in WP5D was based on the Framework and overall objectives of the future development of IMT for 2020 and beyond[35] which identifies three main usage scenarios currently envisaged for 5G/IMT-2020.

WP5D considered various approaches and examples to determine the spectrum needs of 5G/IMT-2020 for xMBB use cases in frequency ranges between 24.25 and 86 GHz [ITU17-WP5D]. The results are summarized in Table 21 below:

Table 21: Spectrum needs for different frequency ranges between 24.25 GHz and 86 GHz

Teledensities	24.25-33.4 GHz	37-52.6 GHz	66-86 GHz	Total
Overcrowded, dense urban and urban areas	3.3 GHz	6.1 GHz	9.3 GHz	18.7 GHz
Dense urban and urban areas	2.0 GHz	3.7 GHz	5.7 GHz	11.4 GHz
Highly crowded area	666 MHz	1.2 GHz	1.9 GHz	3.7 GHz
Crowded area	333 MHz	608 MHz	933 MHz	1.8 GHz

Source: ITU

[35] ITU15-2083

Results for the « application-based » approach show very significant needs for frequency bands above 24 GHz. For EU-28, the expected availability of at least 1 GHz in the 26 GHz band in 2020 will provide sufficient initial capacity for progressive 5G deployment. After 2025, traffic requirements will probably mean that the whole 26 GHz and some higher bands are needed.

METIS-II spectrum demand evaluation

The METIS-II H2020 project investigated the spectrum bandwidth demand for 5G. Two xMBB scenarios involve mm-wave spectrum:

- UC1 Dense Urban information society Scenario (Macro-layer with Inter Site Distance of 200m + 3 small cells per sector)
- UC2 Virtual reality office Scenario (12 sites per floor with ISD of 20m)

The evaluation is made for a single mode configuration (with only below or above 6 GHz) and for multiple bands (both below and above 6 GHz) in Table 22:

Table 22: Spectrum bandwidth demand with single band/multiple bands

Use case	Spectrum bandwidth demand below 6 GHz only	Spectrum bandwidth demand above 6 GHz only
UC1 Dense Urban Scenario	2350.39 / 2355.56 MHz	2350.39-7051.17 / 2198.52-6595.56 MHz
UC2 Virtual Reality Office Scenario	4857.14 / 630.00 MHz	4857.14-14571.43 / 3433.00-10299.00 MHz

Source: METIS II (Deliverable D3.2 Enablers to secure sufficient access to adequate spectrum for 5G – v1.0 – 2017-06-30)

ETRI (South Korea)

ETRI published its 5G spectrum needs estimates in 2017[36]. The following assumptions were made by the research institute:

- Augmented Reality / Virtual Reality streaming data rate: 516 Mbps
- Inter-site distance 50 m in stadium (dense urban inter site distance is 200 m)
- Connection density:
  - Overcrowded: 88800 / km² : 6 persons in 1 m² * 10^6 (km²) * activity factor (0.0148)
  - Highly crowded: 400 / km² : 25400/km² * activity factor (0.0148)

Spectrum needs according to ETRI are the following:

- Stadium (overcrowded): 4.23 GHz (6 persons in 1m²), 2.83 GHz (4 persons in 1 m²)
- Dense urban (highly crowded): around 300 MHz

5G EC study

In the utilities use case, the study « Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe « shows a need of between 0.8 GHz and 3.3 GHz depending on spectrum sharing conditions between mobile operators ».

In the motorway use case, a need of between 9.6 GHz and 38.4 GHz has been identified depending on spectrum sharing conditions between mobile operators.

In the healthcare use case, a need of between 0.5 GHz and 1.8 GHz has been identified depending on spectrum sharing conditions between mobile operators.

Conclusion on available capacity

The framework for using existing spectrum for 5G is considering 2020 for availability in EU-28 countries.

[36] Spectrum need estimates and K-ICT plan for 2020 (5G Forum, Korea - Prof. Een-Kee Hong – May 2017)

For EU-28, the expected availability of at least 1 GHz in the 26 GHz band in 2020 will provide sufficient initial capacity for the progressive 5G deployment. The 3.3 GHz figure for the 24.25-33.4 GHz portion of spectrum might not be reached in 2025 but one should consider all the frequency bands (licensed, licence exempt, below 6 GHz and above 6 GHz) available in European countries for the provision of 5G services.

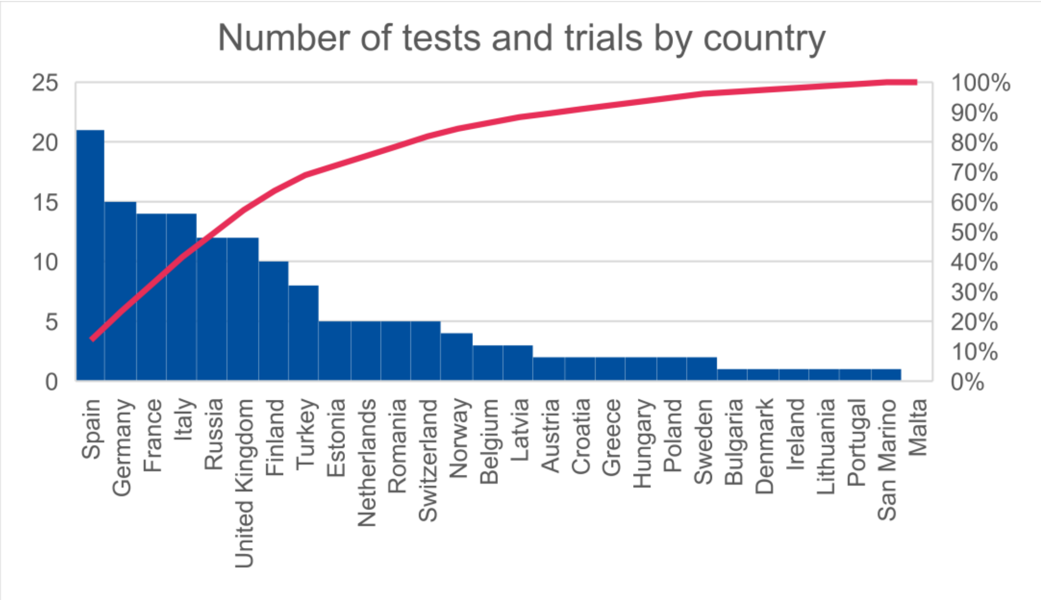
2.6. Trials and plans for 5G services

Tests of the 5G technology started a few years ago and now many mobile operators are implementing trials in order to evaluate the technology and the associated use cases and business models.

Early 5G tests in Europe

In early November 2018, more than 154 5G tests and experiments had been identified in Europe, Russia, Norway, Turkey and Switzerland in the 5G Observatory[37]. Among them, 125 were carried out in EU-28 countries.

Figure 17: 5G tests and trials in Europe



Source: IDATE

The main target of the current trials in Europe is to demonstrate the key features for 5G technology: high data rates and low latency communications. In 2017 there were only a few 5G Private trials including vertical stakeholders. Trials in 2016-2017 have been focused on enabling technologies related to the radio interface (high throughput, millimetre-waves and other new large spectrum bands, antenna technologies…), the network architecture (virtualization, cloudification, network slicing, edge computing…) and the introduction of new technologies dedicated to specific use cases (technologies for IoT, for automotive…).

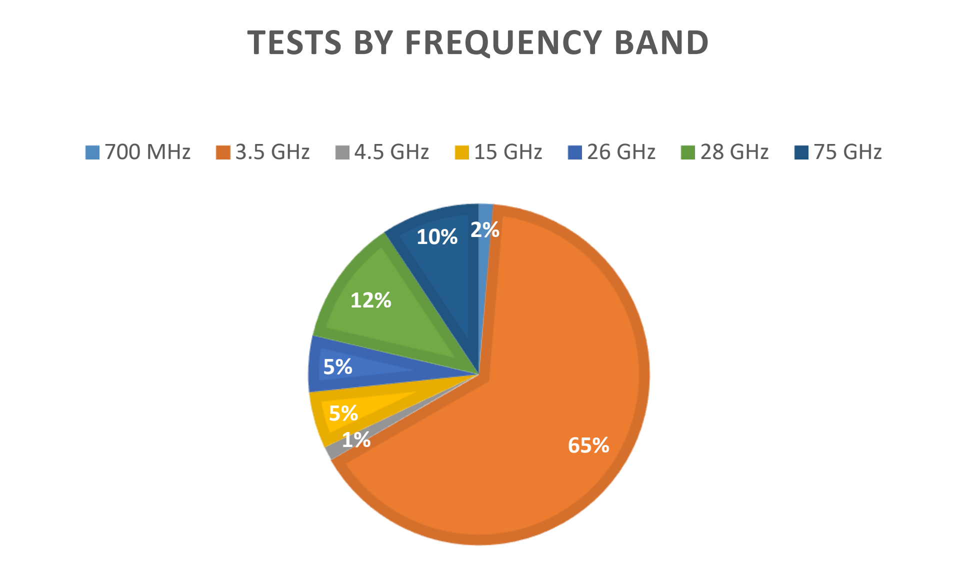
Tests launched in 2018 frequently involve a vertical player in order to validate the use cases with mobile operators. Media and entertainment (30 trials), other transport (23) and automotive (17 trials) are the most represented verticals. The other verticals identified in the trials are agriculture, eHealth, energy, industry 4.0, public safety[38], smart cities, and transport.

[37] http://5gobservatory.eu/

[38] The "5G Smart Tourism" led by the West of England Combined Authority will also address public safety through the use of network slicing to provide capacity for emergency services.

The analysis of trials by frequency and used show that the majority of the trials are using the 3.4-3.8 GHz band (when the frequency band has been identified).

Figure 18: 5G trials in Europe – tests and trials by frequency band

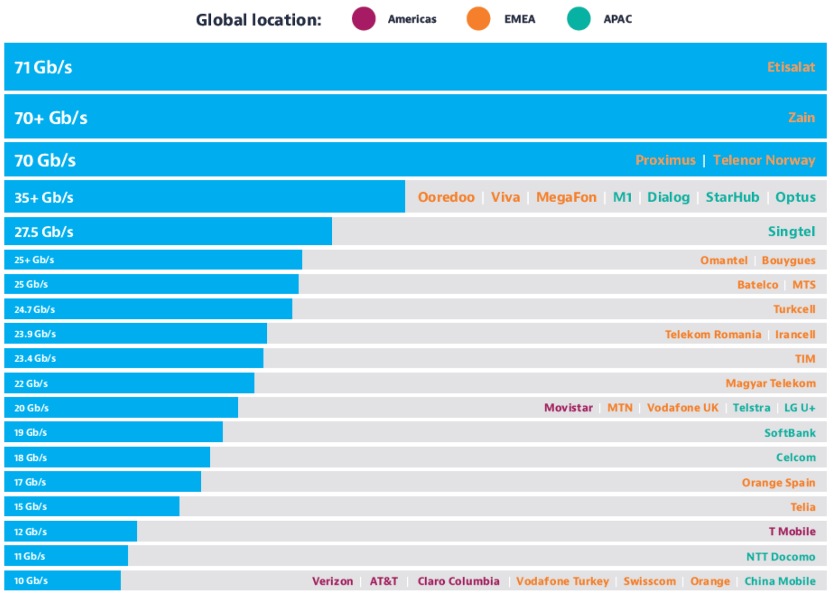


Source: IDATE

It is surprising to see that there is no test in the 26 GHz band in Europe. 26% of the tests identified in September 2018 in Europe, Russia, Turkey, Norway and Switzerland were using mm-wave bands. There were 4 tests in the 26 GHz band and 9 in the 28 GHz band. This is probably linked to (very) limited availability of devices for testing in the upper part of the frequency band (26.5 to 27.5 GHz). It seems that there are concerns from equipment manufacturers regarding the use of the lower part of the band associated with the ECC protection parameters for the lower band (passive EESS).

Speeds achieved during the tests around the world show that the 70 Gbps threshold has been achieved by Etisalat.

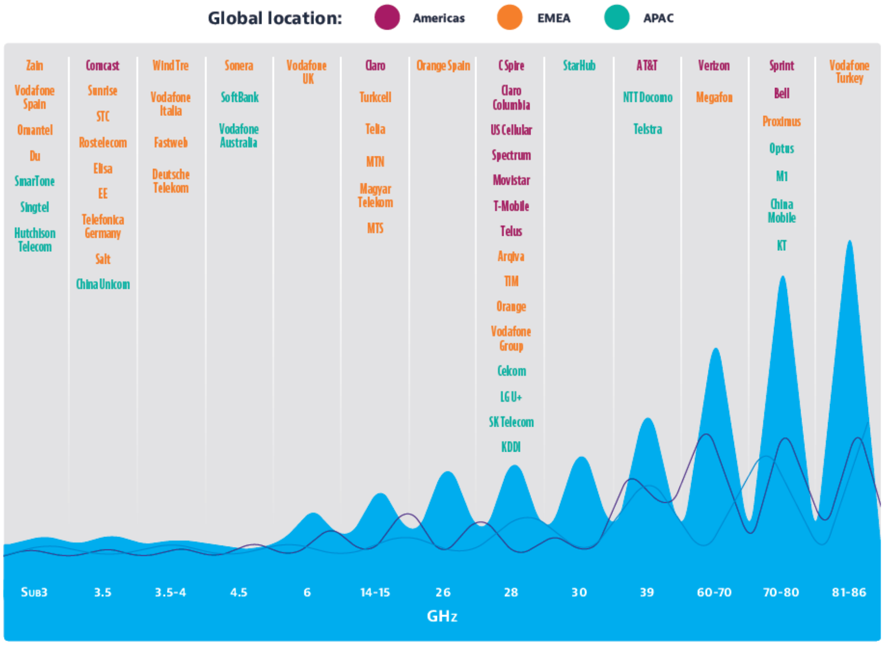
Figure 19: 5G tests - speeds



Source: Viavi

The mm-wave bands are used in many experimentations according to the above figure and it is interesting to note that the 28 GHz has attracted a lot of attention around the world.

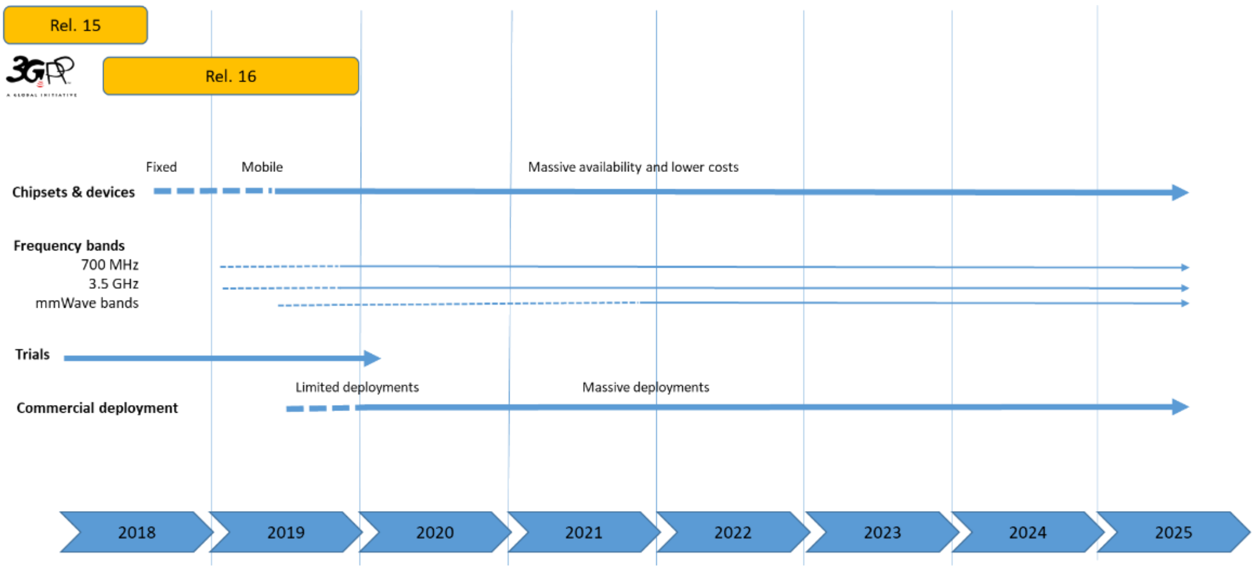
Figure 20: 5G tests – frequency bands



Source: Viavi

5G roadmap in Europe will see first commercial deployments in 2019/2020 with massive deployments in 2021/2022. Massive availability of 5G chipsets and devices is expected in 2021 and will fuel 5G growth in Europe.

Figure 21: 5G roadmap in Europe



Source: IDATE

Announced deployment plans

Verizon announced it has launched 5G service using 28 and 39 GHz spectrum in selected neighbourhoods of four cities (Houston, Indianapolis, Los Angeles, and Sacramento) in the USA on October 1st, 2018. Verizon 5G home service is a 5G fixed wireless access service delivering average speeds of 300 Mbps and peak speeds up to 1 Gbps with unlimited data usage, no data cap and no annual contract. The 5G home plan is a data-only plan, which is subscribed separately from other Verizon plans. The service is free of charge for the first three months. After the promotion time, it will cost 50 USD per month for current Verizon subscribers and 70 USD per month for non-Verizon subscribers.

In the USA, AT&T is also planning to use mm-wave bands for 5G commercial service at the end of 2018.

2.7. The impact of 5G on growth, employment and competitiveness

Section 0 showed expected 5G services in the mm-wave bands and section 2.4 detailed the expected demand for 5G services. In this section, we detail expected qualitative and quantitative socioeconomic and environmental effects of 5G on growth, employment and competitiveness.

2.7.1. Qualitative socioeconomic and environmental effects of 5G on growth, employment and competitiveness

The study “Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe[39] ” published in 2016 identified ten 5G capabilities:

- 5G aims to enable a truly pervasive video experience;
- 5G will enable a revolution in the smart office;
- 5G goal is to deliver 50 Mbps everywhere;
- 5G will allow you to create your own network if you that is what you want to do;
- 5G will support dynamic increase of capacity on the fly;
- 5G will enable a working solution on planes, trains and cars;
- 5G will deliver a single scalable solution for sensor networks and the IoT;
- 5G will enable an ultra-reliable network for mission critical applications;
- 5G will make the realization of the tactile internet possible;
- 5G will deliver a meaningful and efficient broadcast service

It is anticipated that 5G deployment should have positive impacts on the provision of innovative services and applications, on improved connectivity and coverage, on support for large scale M2M/IoT networks, on serving vertical sectors’ needs, on employment and on competitiveness.

Improved connectivity and coverage

The provision of 50 Mbps everywhere, a true ubiquitous coverage, is a condition for 5G to be successful and will allow many Member States to overcome the digital divide caused by poor broadband coverage, particularly in rural areas.

Improved connectivity along rail routes and roads is also expected with 5G networks. It will help to improve safety for cars and trains.

Support for massive IoT

5G will support large scale Internet of Things (IoT) networks which will serve vertical sectors needs in the coming years. It is expected that autonomous vehicles, transport, smart grid, drones, industrial automation and healthcare (telehealth, remote patient monitoring) will benefit from the new infrastructure and capabilities of 5G networks.

[39] SMART number: 2014/0008

Support for URLLC

Ultra tactile Internet probably has the potential to unlock more futuristic applications and services. Ultra tactile Internet allows for a wireless network to be used for control purposes. For real-time sense-respond-actuation cycles that enable both human-device control interactions and device-device interactions.

Provision of innovative services/applications

5G expected benefits include new B2B and B2B2C services, fixed broadband services, management of massive IoT, improved indoor coverage, improved connectivity for railways, V2X services and mission critical use cases.

Innovative services and applications on 5G networks are described in section 0 of this report. The use of millimetre wave bands for 5G networks will contribute to the provision of innovative services and innovation:

- Answer the specific needs of vertical sectors with the help of network slicing. It is also expected that some countries might assign spectrum to vertical players. In that case, there might be no need for network slicing within a private 5G network;
- Provision of new business models (including self-provisioning by direct access to spectrum).

Table 23: 5G: expected qualitative benefits and affected stakeholders

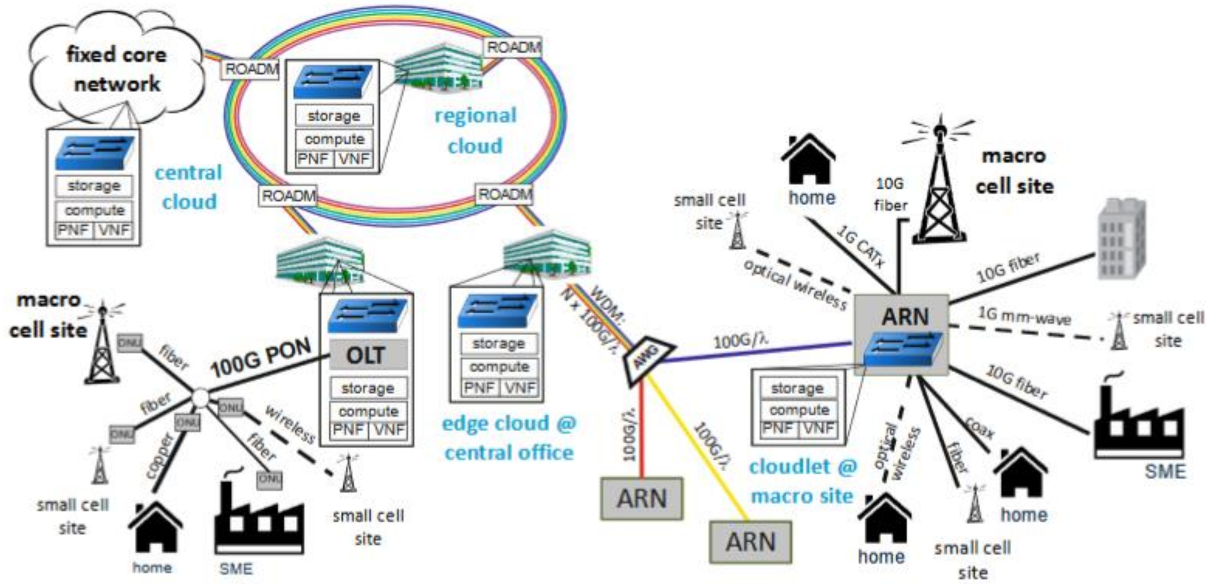
Innovative service/applications	Benefits	Affected stakeholders
New B2B and B2B2C services	A variety of new services in new sectors of the economy	Telecom operators, vertical sectors
Fixed broadband services	High data rate services	Telecom operators
Higher (multi-Gb/s) data rates	Consumers and businesses	
Massive IoT	5G is expected to address new use cases for IoT	LPWA operators
Improved indoor coverage	The use of mm-wave in indoor locations will provide very high data rates and capacity	Landlords, mall managers, stadium managers…
Improved connectivity		
Improved connectivity for railways	Possible replacement of GSM-R, higher data rate services for passengers	
V2x	Improved safety on roads	Car manufacturers, car equipment manufacturers, road managers
Mission critical use cases	Autonomous vehicles, industrial automation, telehealth & remote patient monitoring	Operators of PMR networks

Source: IDATE

Better integration with fixed and satellite networks

5G will minimize dependencies between Access Network (AN) and Core Network (CN). 5G architecture principles target seamless integration of fixed and mobile users via converged fixed-wireless technologies.

Figure 22: Physical architecture of a converged fixed-mobile network for 5G



Legend: ARN (Active Remote Node), PNF (Physical Network Function), VNF (Virtual Network Function), ROADM (Regional Optical Add Drop Multiplexer), WDM (Wavelength Division Multiplexing), AWG (arrayed waveguide gratings)

Source: 5G PPP (5G PPP Architecture Working Group-View on 5G Architecture)

As satellite communication technologies provide higher bandwidth with High and Ultra High Throughput Systems (HTS/UHTS), the satellite is expected to play an important role for enabling more demanding broadcast/broadband services and reaching a large population of users and machines.

Hybrid satellite/terrestrial architectures for 5G are under development and ESOA (EMEA Satellite Operator's Association) indicates that satellite would form 'the invisible overlay' for 5G services. The overlay would provide an additional / alternative transmission medium for backhaul and trunking and, in the case where there is limited or no terrestrial mobile service, access to high speed data services.

Convergence is expected between 5G and satellite technologies to form a unique platform building on heterogeneous technologies. Software Defined Networking (SDN) and Network Function Virtualization (NFV) paradigms are expected to be enablers of this integration. The softwarization trends initiated by these technologies will enable an overall ecosystem more flexible and tunable to user demands and service characteristics. It will be possible to create slices of networks with satellite being part of the integrated network. Satellite should be able to provide complementary access directly to existing terminals used by terrestrial 5G networks. The same hardware should be used with specific satellite-software add-ons.

It is expected that specific slices of 5G networks will be proposed in order to cope with the dedicated requirements of verticals, especially in terms of bandwidth, whether very large (for video applications for instance) or very small (for IoT for instance). There will be a need for seamless management and orchestration of heterogeneous satellite and terrestrial network components. The 5G goal of "reducing the average service creation time cycle from 90 hours to 90 minutes" will be achieved if the orchestrator is allowed to manage the satellite and terrestrial technologies in an automated manner.

Serving vertical needs

The study "Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe » identified the most important 5G verticals. The conclusions of the study are presented hereafter:

Automotive

Automotive appears to be probably the most important vertical in Europe as the industry quickly identified the opportunity for collaboration with the telecommunications sector and created in 2015 the 5GAA (Automotive Association).

The above mentioned study identified two barriers and key disruptors:

1). Business model flexibility: New and disruptive business models were envisaged. There is a need for open ecosystems and clear regulatory frameworks supporting investment for automotive mobility systems that can save increasingly expensive fuels and present options for the sector in relation to solutions for mass transportation.

2). Data privacy: There are concerns about who will own/commercialise emerging data-driven services, particularly as a result of more open systems and platforms.

Healthcare

Healthcare is one of the less cited verticals. The most optimistic scenario was one in which there is widespread acceptance of technology-driven innovation with health practitioners and patients are open to change, new business models emerge and they are supported by strong, clear regulations. In this scenario systematic change is possible and healthcare is not just treating illness but also in preventing illness and proactively enhancing wellbeing and quality of life.

A key disruptor in the healthcare vertical was thought to be data privacy, particularly in the light of wearable technologies collecting personal health data in non-clinical settings. Guidance and regulation of data privacy will be important.

Transport

Transport is an industry with a rich innovation roadmap spanning both infrastructure and ICT where numerous new connected devices and services could be supported and enhanced by 5G capabilities. In the most optimistic scenario transport data flows freely between once closed sub-transport sectors enabling new collaborations and application possibilities.

Transport could be heralded as one of the first industries to deliver a true "IoT" experience enabled by a Pan European Integrated Transport system connecting everything (roads, cars, trains, planes, bikes etc.). Data and advanced data products (provided by analytics) are acknowledged by all stakeholders and protected as the fuel in the new value chain. In this vertical, more so than the preceding two examples, transport data sharing and access is fundamental to benefits realisation.

Utilities

Utilities are a frequently cited sector, mainly because of considerable growth in smart meters and IoT devices and sensors that will be connected in smart homes by 2020. EC research predicts 2.95 billion smart home sensors and devices by 2025. The optimistic scenario envisages high levels of connectivity supported by a strong regulatory environment.

There will be inter-vertical and cross-vertical collaboration, interoperability and integration, driving a new ecosystem of devices and networks designed to meet user needs.

Key disruptors were thought to be an over-emphasis on renewable energy and a weak regulatory environment. Economies of scale could be lost if a more local focus becomes prevalent, for example as a result of local generation and micro-grids based local energy distribution.

The positive effects mentioned earlier will benefit Member States/groups of Member States that will invest massively in 5G networks and that will provide extensive 5G coverage in order to foster 5G adoption by consumer as well as business users.

Impact of mm-wave bands

As identified in Section 2.3.1, mm-wave bands will enable the provision of very-high data rate services. Among the vertical sectors mentioned in the study, the utilities sector will probably not require such high speeds but the other sectors (automotive, transport and to a lesser extent healthcare) will probably find use cases that will require the use of mm-wave bands.

2.7.2. Quantitative socioeconomic and environmental effects of 5G using mm-waves on growth, employment and competitiveness

Mobile and 5G investments

In September 2016, Commissioner Oettinger indicated that € 500 billion will be necessary in Europe to deploy 5G networks. However, it is expected by the EC that €155 billion will lack in terms of 5G investments.

According to GSMA, mobile operators will invest globally $500 billion between 2018 and 2020 excluding spectrum acquisitions.

Analysts of Bank of America estimate global telecom CAPEX at $300 billion in 2017 and wireless CAPEX at $60 billion (including $18 billion for EMEA region).

IHS Markit expects that seven countries will lead 5G development: the USA, China, Japan, Germany, South Korea, the United Kingdom and France. Between 2020 and 2035, these countries should spend an average $200 billion annually in 5G R&D and CAPEX.

The study "Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe » estimates that in EU28 Member States the total cost of 5G deployment will be approximately €56 billion in 2020. Input-output analysis suggests that 5G investment will lead to multiplier effects with a value €141 billion. These effects are likely to create 2.3 million jobs in EU28 Member States.

Even though we are not able to comment the assumptions used for these studies, 5G will certainly require very significant investments. It should be noted that indoor coverage would be one of the most important parameters here. Building the first 5G networks using sub-6 GHz frequency bands and existing cell sites should be quite fast and will not require huge investments. In a second step, adding capacity and building indoor coverage should be much more expensive and should be a very lengthy process.

The expected investment figures from GSMA and the EU seem to be consistent if we compare them with Deutsche Telekom's plans for Germany: in September 2018, DT confirmed plans to invest 20 billion euros in Germany by 2021 in 5G technology.

Another important assumption is network sharing and how 5G network operators could share investments between them. Another question is how will network operators share the investment with other players such as smart cities, road management, industry, in-building…

5G investments in small cells supporting mm-wave bands will play an important role in the provision of very high data rate services and capacity in hot-spots. Based on our evaluation in section 2.4.3, approximately 10% of the 5G cell sites would support mm-waves in 2025.Quantitative effects of 5G on the European economy.

Estimates of the societal benefits of 5G deployment vary over a huge range. Some are more plausible than others.

Qualcomm/IHS

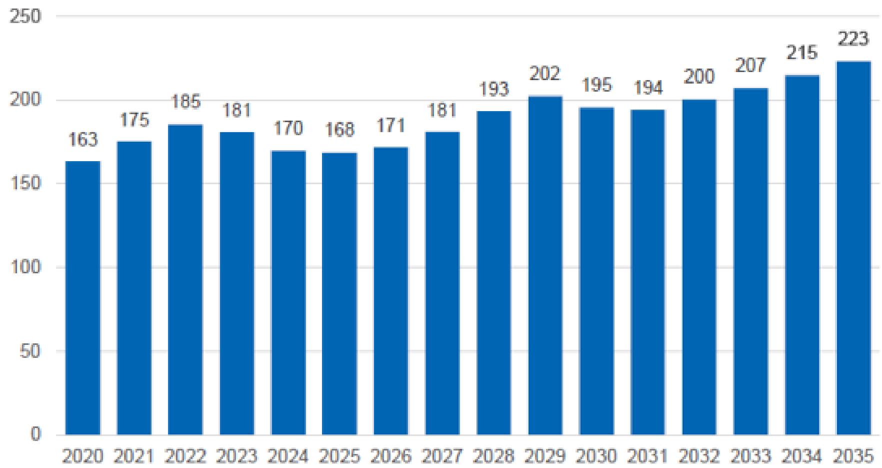
The 5G economy[40] study conducted by IHS Markit and conducted on behalf of Qualcomm in 2017 makes the following claims:

[40] The 5G economy - How 5G technology will contribute to the global economy (IHS for Qualcomm – January 2017)

- "In 2035, 5G will enable $12.3 trillion of global economic output. That is nearly equivalent to US consumer spending in 2016 and more than the combined spending by consumers in China, Japan, Germany, the United Kingdom, and France in 2016.
- The global 5G value chain is said to generate $3.5 trillion in output and support 22 million jobs in 2035. This figure is larger than the value of today's entire mobile value chain. It is approximately the combined revenue of the top 13 companies on the 2016 Fortune Global 1000.
- The 5G value chain will invest an average of $200 billion annually to continually expand and strengthen the 5G technology base within network and business application infrastructure; this figure represents nearly half of total US federal, state and local government spending on transportation infrastructure in 2014.
- Moreover, 5G deployment should fuel sustainable long-term growth to global real GDP. From 2020 to 2035, IHS Markit claims that the "total contribution of 5G to real global GDP will be equivalent to an economy the size of India".

IHS Markit also claims that "5G contribution to the global GDP (Gross Domestic Product) for the 2020-2035 period would represent 0.2% out of an average annual rate of 2.9%". This estimation suggests that 5G would contribute 7% of the overall GDP growth rate.

Figure 23: Annual net contribution of 5G to global growth (2016 US$ billions)



Source: IHS

The IHS Markit study also evaluates 5G impact on value chain employment in 2025 and expects 22 million jobs will be related to 5G (other sources do not provide detailed estimates on employment):

Table 24: Global 5G value chain employment in 2035

Country	Employment (in million)
World	22
France	0.396
Germany	1.2
United Kingdom	0.605

Source: Qualcomm/IHS

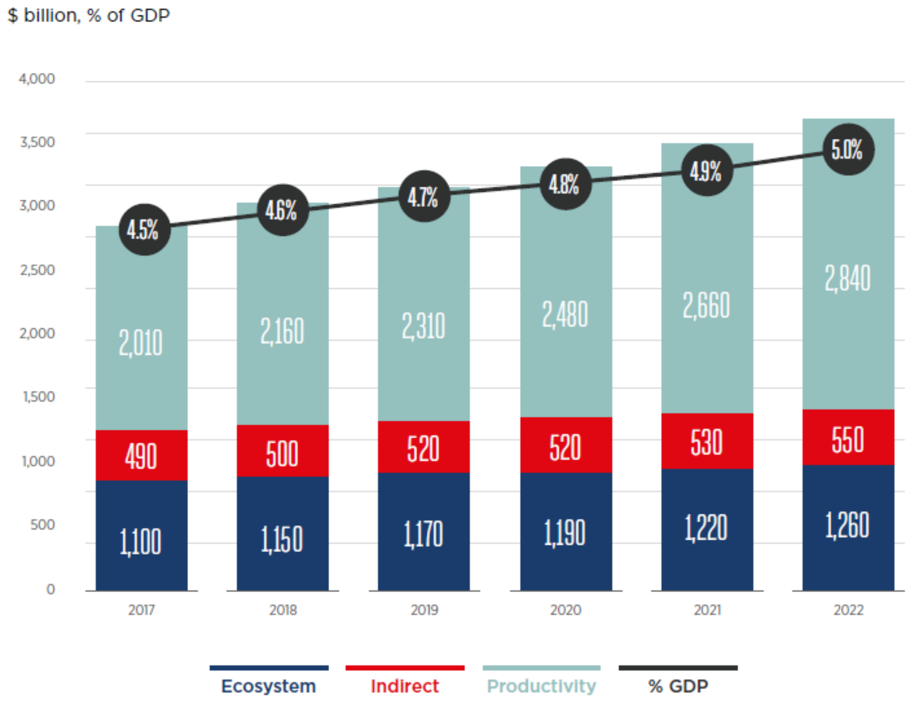
GSMA

GSMA[41] expects the global economic contribution of the mobile ecosystem to continue to increase in both relative and absolute terms. In value-added terms, GSMA estimates that mobile will contribute $4.6 trillion to the global economy by 2022 (5% of GDP), up from $3.6 trillion in 2017 (4.5% of GDP). Most of this value-added increase will be due to

[41] The mobile economy 2018

productivity gains. In the developed world, the adoption of M2M and IoT solutions will drive increased productivity. In developing countries, productivity growth will be mostly driven by the adoption of mobile internet services

Figure 24: Global economic contribution of the mobile ecosystem – Outlook to 2022, value added



Source: GSMA

Apart from these global forecasts, Spain provides some estimates on the impact of 5G[42] at national level.

5G Americas

5G Americas[43] provides forecasts for the Americas region on the expected deployment of 5G networks and services on the economy:

- Investment: wireless operators expected to invest $275 billion over 7 years to build out 5G
- Jobs created: 350 K construction jobs, 850 K new supplier and partner jobs and 2.2 M jobs in communities
- GDP growth: deployment of next 5G wireless networks adds direct and indirect potential benefits of $500 billion

O2 UK

In March 2018, O2 UK[44] indicated 5G could generate £6 billion in productivity savings for the UK economy if the country comes together to take full advantage of the new technology.

[42] In Spain, MINETAD indicates that 5G technology is definitely a cornerstone of digital transformation mainly in 4 different vertical industries: the automotive, health, transport and public services. 5G could have positive effects on these verticals and also at domestic level of 14.6 billion EUR before 2025. 5G is also recognised as a potential source of new jobs

[43] Accenture Strategy, January 2017 https://newsroom.accenture.com/content/1101/files/Accenture_5G-Municipalities-Become-Smart-Cities.pdf

[44] The value of 5G for smart cities and communities (2018) - https://d10wc7q7re41fz.cloudfront.net/wp-content/uploads/2018/03/Smart-Cities-Report.pdf

As an example, the mobile operator evaluates that 5G-enabled road management systems, capable of reacting to traffic volumes, will reduce the time spent stuck in traffic by 10 per cent for the UK's 5.6 million vehicle commuters.

Table 25: Productivity savings

Description	Savings (£ million)
Building a 5G-enabled road ecosystem to enable a reduction in commuters' time spent sitting in traffic by 10%.	£880
Introducing 5G sensors to help reduce avoidable cancellations and delays through predictive maintenance.	£440
Helping cities manage the likelihood of blackouts and brownouts.	£3,400
Replacing just 5% of GP visits with telehealth services	£1,300
TOTAL	£6,020

Source 02 Telefonica

Accenture

The white paper on Smart cities[45] published by Accenture in 2017 evaluated the benefits brought by 5G on investment, employment and GDP growth in the USA. It indicates that telecom operators in the USA could invest approximately $275 billion over seven years to deploy 5G networks. Of that $275 billion, $93 billion is expected to be spent on construction, with the remainder being allocated for network equipment, engineering, and planning. This investment could create up to 3 million jobs and boost GDP by $500 billion in the USA.

EC 5G study

The study "Identification and quantification of key socio-economic data to support strategic planning for the introduction of 5G in Europe" quantified economic benefits of 5G[46]. There are both direct economic benefits attributed to each sector, and secondary socio-economic and environmental benefits arising from four "environments": Smart Cities, Non-Urban, Smart Homes and Workplace.

The first order economic benefits account for €62.5 billion of the identified total €113.1 billion benefits by 2025 and are distributed as follows:

- Automotive: €42.2 billion
- Transport: €8.3 billion
- Healthcare: €5.5 billion
- Utilities: €6.5 billion

Second order benefits arise from the different environments totalling €50.6 billion. They are broken down as follows:

- Workplace: €30.6 billion
- Non-Urban: €10.6 billion
- Smart City: €8.1 billion
- Smart Home: €1.3 billion

Conclusion on quantitative socioeconomic and environmental effects of 5G using mm-waves

Estimates of the societal benefits of 5G deployment vary over a huge range and do not address the question of mm-wave bands use. However, investments in 5G will have a very significant impact on many sectors of the economy with important job creations and GDP

[45] Smart cities – how 5G can help municipalities become vibrant smart cities (2017)

[46] Study carried out for the European Commission by Tech4i2, Real Wireless, CONNECT, Trinity College Dublin, InterDigital

growth. In Europe, mm-wave bands will play a very important role in the provision of very high data rates and capacity with an expected growing impact after 2024-2025 when European 5G networks are widely deployed.

3. Analysis of potential co-existence scenarios and assessment of the prospects for the evolution of the business environment

3.1. Introduction

This chapter provides a detailed, but selective, review of the work undertaken within ECC PT1 and ITU-R TG5/1 concerning potential spectrum allocations for 5G millimetre-wave services.

The aim of this review was to give an indication of the likely constraints, both spectral & geographical, that will be imposed on occupants of these bands in the future.

This information, combined with knowledge of the telecommunications market across Europe and our awareness of technical network options, has allowed us to study options for the evolution of the business environment in the bands affected. It was intended that this modelling should include:

- The baseline 'no 5G' option;
- A 'maximum compatibility' scenario (in which 5G use respects all incumbent use); and
- A 'maximum transition' scenario in which the spectrum is optimised for 5G use.

It is arguable that the baseline option is no longer applicable; several administrations (e.g. France, UK) have expressed an intention to re-farm 26 GHz fixed links to other bands, such as 32 GHz, and the associated administrative and engineering costs are already being incurred.

Furthermore, the 'Maximum Transition' scenario appears to have been ruled out by the recent decision by the ECC plenary meeting (Rome, 3-6 July 2018) to apply stringent limits to protect the passive EESS at 23.6-24.0 GHz (see below).

In other cases, a quantitative assessment will be difficult or impossible; this would be the case, for instance, for passive Earth sensing satellites in adjacent bands where the 'maximum transition' scenario could lead to increase in the uncertainty of the budget for a variety of meteorological products. The societal impact of such a degradation is impossible to quantify in a way that would be commensurate with, for instance, the need to relocate fixed links or provide additional screening for an Earth station receiver.

The text in the remainder of this chapter therefore concerns only the pragmatic 'maximum compatibility' option.

NB: The regulatory documents referred to below relate formally to 'wireless broadband (WBB) electronic communications services (ECS)', to 'Mobile/fixed Communications Networks (MFCN)' or to IMT-2020. Purely for ease of reading, these are generally referred to below as '5G services', but it should be borne in mind that the terms are not strictly equivalent.

3.2. Summary of findings

The overall goals of this part of the study were to understand the coexistence landscape in the proposed millimetre-wave bands and thus to consider constraints, costs and opportunities for incumbent services.

- Of the potential coexistence issues, only that with 26 GHz fixed links appears to require significant study.
- The decision to protect the EESS (passive) service below 24 GHz with a stringent out-of-band emission limit at 26 GHz has enforced a 'maximum compliance' approach, with implications for the practical availability of the lower part of the 26 GHz band. This may have an impact more in terms of the administrative process for spectrum assignment (i.e. block sizes available for operators) than on constraining capacity, given the relatively long period foreseen to build demand at mm-wave.
- Co-ordination with receiving (EESS, SRS) and transmitting (FSS) Earth station is not expected to be a significant constraint on 5G deployment, due to the small number[47] of sites involved and their rural location. CEPT Report 68 also notes the "*need to maintain the possibility for additional earth stations to be deployed in the EU Members States…*". The necessary technical tools for coordination with these services exist.
- Studies in PT1 and elsewhere indicate that no significant co-existence issues are envisaged with respect to the 40.5 – 43.5 GHz band identified in the RSPG 'second opinion' as a priority band for second-stage deployment.
- The 66-71 GHz band, identified as the other 'second-stage' 5G band is attractive partly by virtue of its adjacency to the existing 57 – 66 GHz licence exempt band. The potential for adjacent band interference between the two allocations is under study, but is unlikely to be more problematic than that between different users within the unlicensed band.

3.3. Current service landscape in mm-wave bands

There is a mix of incumbent services in the 26 GHz band. The details and density of usage varies significantly by Member State. For example, in Ireland, the band below 26.5 GHz is heavily used for fixed links in urban areas[48], but spectrum at 26.5-27.5 is currently empty. In the Netherlands, the whole 26 GHz band is widely used for cellular backhaul and it is planned to start a transition of services from the upper

1 GHz to clear that spectrum for 5G use. In Finland the entire band (24.25-27.5 GHz) is currently clear. In the UK, the upper 1 GHz is assigned to the military, but is very lightly used. In the lower 2.25 GHz, there are 2,800 fixed links licensed across the UK, mostly in suburban and urban areas and a single satellite Earth station used for receiving EESS data. In addition, there is sporadic use for temporary broadcast (PMSE) video links. In some countries the band is virtually clear and in others there is usage by several services including fixed links, satellite and the military.

The satellite industry would like protection of existing services and clear parameters for introduction of new services (including satellite services) into the band on a protected basis (based on limited input).

There is a growing consensus that the upper 1 GHz of the band could be made available relatively easily for transition to 5G but that it will be much more difficult to make the lower part of the band available. Mobile operators see the upper part of the band as being useable if 1 GHz of contiguous spectrum can be made available on a non-shared basis. They are more nervous about sharing scenarios lower in the band but have not ruled out use of sharing (based on limited input). This is consistent with the views emerging through CEPT and other bodies.

[47] There are five major Ka-band receive Earth stations operating in the EESS and SRS within Europe (see Section 3.6.2)

[48] Note that ComReg has recently awarded spectrum in the 26 GHz band for fixed links.

There is little information on possible transition scenarios available so far. Migration, compensation and incentives, while mentioned, do not appear to have been thoroughly studied. There are contradictory studies available from equipment vendors and others on the coexistence scenarios that could work.

There is ongoing discussion on the use of the 28 GHz band in the UK, but this doesn't appear to be replicated in any other EU28 state.

A wide variety of other existing services occupy the other millimetre-wave bands under consideration. The passive science services are generally the most severe constraint on use for IMT-2020 services, but safely-of-life concerns associated with aeronautical and car radar, and the ubiquity and commercial importance of fixed links ('Fixed Services' or FS) must also be taken into account.

3.4. Work in ITU, CEPT and other bodies

Two related international streams of work are relevant to the discussion of co-existence scenarios; firstly, the World Radio Conference (WRC-19), to be held in Egypt next year, has an agenda item[49] on the identification of frequency bands for 5G services. The second stream of work is being undertaken within CEPT Project Team 1 (PT1), which is both coordinating a common European position regarding the WRC agenda item and addressing a mandate from the EC on the technical harmonisation of 5G.

Work in both these groups has been split on a band-by-band basis, with 26 GHz attracting by far the greatest number of inputs.

3.4.1. World Radiocommunication Conference (WRC-19)

Technical issues for a WRC are studied within ITU-R Study Groups and Task Groups, and the results summarised in a report to a Conference Preparatory Meeting (CPM). For WRC-19, the CPM will be held in Geneva, in February 2019.

For issues relating to Agenda Item 1.13, technical studies were delegated to Task Group 5/1 (TG5/1), set up for the purpose of developing CPM text on the topic. This work required a substantial programme of compatibility studies for the different bands and services to be considered under the Agenda Item. The work of TG5/1 concluded, after two years, at their sixth meeting, in Geneva in August 2018.

In the Draft CPM text, methods to satisfy the agenda item are given for each of the candidate bands, with the first option, in all cases, being to make no change to the Radio Regulations. For the other bands, with the exception of 32 GHz, a second option identifies the frequency band for IMT (and allocates it to the Mobile Service on a primary basis in the table of frequency allocations, as required) with appropriate conditions to protect other services.

3.4.2. EC mandate to CEPT PT1

In addition to work within the ITU-R towards WRC-19, PT1 also undertook studies on the 26 GHz band under a mandate from the EC to '*study and assess the 24.25-27.5 GHz … frequency band as a 5G pioneer band'* (task 2), To '*develop channelling arrangements and common and minimal (least restrictive) technical conditions'* (task 3) and '*Assess requirements for cross-border coordination'* (task 4)[50].

The mandate was issued in January 2017 and the results presented in **CEPT Report 68** in July 2018. This report notes that 5G services will mostly use the 26 GHz band for 'hotspot' connectivity in urban areas and that it will not be used for wide-area, contiguous coverage.

[49] Agenda Item 1.13 "*to consider 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)*"

[50] 'Task 1' related to the 3.6 GHz band

The report summarises existing use of the 26 GHz band, and goes on to examine compatibility issues with regard to these other services, and to define the consequent technical conditions for 5G use that should be harmonised.

The findings of the report are captured in two regulatory documents:

- ECC Decision (18)06 on 'harmonised technical conditions for Mobile/Fixed Communications Networks (MFCN) in the band 24.25-27.5 GHz' was adopted by the ECC plenary meeting in Rome in June 2018.
- A draft Implementing Decision, RSCOM18-41, published by the Radio Spectrum Committee of the EC in October 2018.

These two documents, and Report 68, essentially specify identical co-existence requirements and technical conditions, as summarised below.

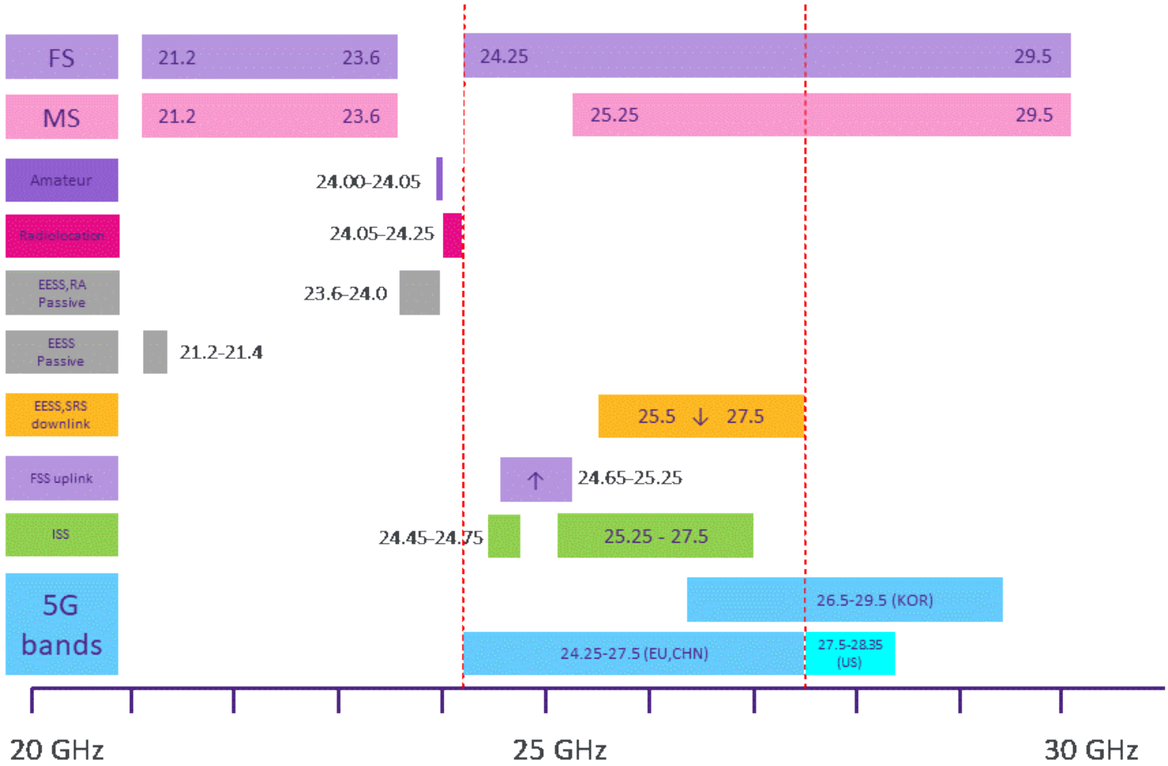
3.5. CEPT and EC decisions regarding the 26 GHz band

As noted above, the text in CEPT Report 68, ECC Decision (18)06 and RSCOM18-41 regarding the use of the 26 GHz band is essentially identical. It is summarised below.

3.5.1. Existing services at 26 GHz

The allocation of radio Services in this frequency range is indicated in Figure 25 below.

Figure 25: Spectrum allocations at 26/28 GHz



The following radio services should to be considered when defining coexistence and coordination in the 26 GHz band.

- The Fixed Service (FS): Microwave fixed links used for point-to-point or point-multipoint connectivity. Report 68 notes heavy use in some CEPT countries, with a concentration in urban areas. Many of these links are used for infrastructure and backhaul in mobile networks.

- Earth Exploration Satellite Service (EESS)/Space Research Service (SRS): These services operate downlinks of scientific data from satellites to a relatively small number of receive-only Earth stations in the 25.5-27.0 GHz band.
- Inter Satellite Service (ISS). Communications between satellites, typically non-geostationary sensors to geostationary 'data relay' satellites. Operation at 24.45-24.75 GHz and 25.25-27.5 GHz.
- Fixed Satellite Service (FSS): Communications uplinks operate at 24.65-25.25 GHz.
- Automotive short-range radar (SRR) operates at 24.25-26.65 GHz, but is being phased out in favour of 77-81 GHz.
- Short Range Devices (SRD) including ultra-wideband sensors for tank level determination which operate throughout the band as an 'underlay' service and 'transport and traffic telematics devices' such as automotive radars at 24.25-24.5 GHz. These devices operate on a non-protected and non-interference basis.
- Systems in adjacent bands, in particular the passive satellite service in the 23.6-24.0 GHz frequency band.

3.5.2. Least restrictive technical conditions

The report and decisions specify the following harmonised technical conditions, intended to ensure compatibility with existing services while allowing the deployment of 5G.

The frequency arrangement will be unpaired TDD, with a block size of 200 MHz. Smaller blocks of 50 MHz may be used to maximise spectrum utilisation. TDD operation shall be synchronised between operators.

The technical conditions assume that an 'Individual Authorisation' regime will apply in the 26 GHz band. The motivation for this is to allow control of the sharing environment to be maintained as the 5G market develops and to permit site-specific co-ordination with individual Earth stations.

To protect satellite receivers in the ISS and SSS, it is required that active antenna systems should only transmit with the main beam pointing below the horizon, and that the antenna shall also be mechanically pointed below the horizon[51].

To afford further protection to satellite receivers, 5G uplink transmissions to unmanned aerial vehicles (UAV) are not permitted (transmissions from the UAV are allowed, however).

An emission mask is specified, with the following elements:

- A region up to 50 MHz above or below the channel in use in which the total radiated power is limited to -12dBm/50MHz to protect networks in adjacent blocks.
- A limit of 4dBm/50 MHz to protect other networks within the band
- An additional limit of -42dBW/200 MHz to protect satellite passive sensors operating at 23.6-24.0 MHz.

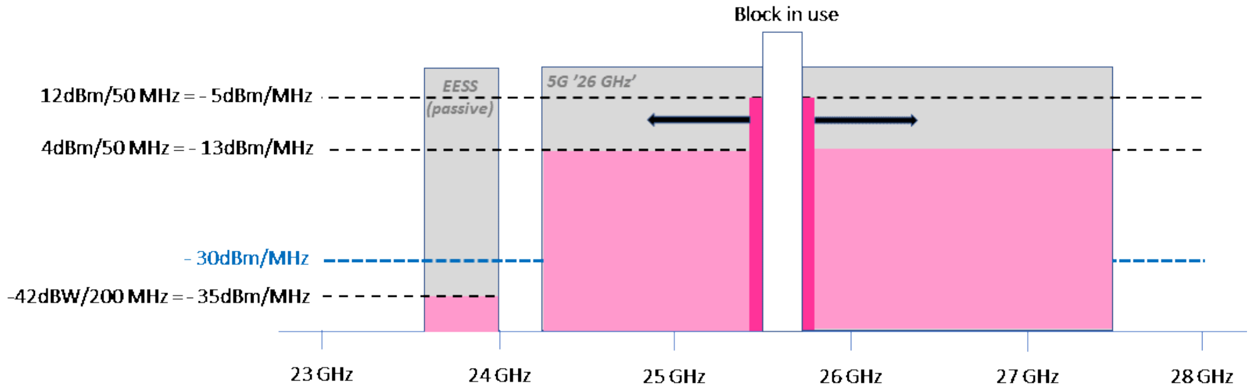
The figure below shows these emission limits, as they would apply for a 5G transmission operating in a 200 MHz block centred at 25.6 GHz. The applicable powers have all been normalised to terms of dBm/MHz.

Also indicated in the figure is the -30dBm/MHz limit that applies generally to out-of-band emissions[52]

[51] The requirement for mechanical down-tilt seems surprising in the context of an array antenna.

[52] See CEPT/ERC Recommendation 74-01

Figure 26: Emission mask applicable at 26 GHz



Source: Plum

Note that, for 'terminal stations' the emission limit in the 23.6-24.0 band is relaxed by 4dB.

The adoption of the -42dBW/200 MHz limit is controversial as it is not mirrored by regulatory requirements elsewhere in the world. The technical justification for the choice of this figure is somewhat opaque, although a precautionary approach may be justified by the strategic importance of Earth sensing systems at 23.6 GHz.

Operators and equipment vendors have expressed[53] the view that this requirement will "*lead to a situation where the lower part of the 26 GHz band cannot be used for outdoor 5G base stations*".

This is based on the fact that such base stations will employ active antenna technology, in which each of the elements of a phased array will be directly driven by an active semiconductor device. This implies that it will be unfeasible to implement effective bandpass (or band-reject) filtering after the final amplifiers of the base station to control out-of-band emissions.

This may be a pessimistic view; it may be possible to achieve the linearity of operation to meet the emission limit by appropriate circuit design (possibly with a power consumption penalty), but the practical impact may not become clear for some time. The forecasts presented in the previous chapter, combined with the efficiency of spectrum re-use at millimetre wave, suggests that it will be some years before operation at 26 GHz becomes constrained by available bandwidth.

Following the RSPG Opinion noted above, those administrations who have publicly state a policy have generally undertaken to release 1 GHz of spectrum, in all cases in the upper part of the band (26.5-27.5 GHz) for 5G services.

3.5.3. Policy opinions

RSPG Opinion 18-005 recommends that Member States should make a '*sufficiently large*' portion of the band (e.g. 1 GHz) available for 5G by 2020, '*in response to market demand*'.

Similarly, the draft European Electronic Communications Code (EECC) stipulates that the use of 'at least 1 GHz' should be allowed, '*provided there is clear evidence of market demand and absence of significant constraints for migration of existing users or band clearance'*.

The caveats regarding 'market demand' seem relevant in light of the relatively slow pace of announcements regarding spectrum authorisation at 26 GHz.

[53] https://www.gsma.com/gsmaeurope/wp-content/uploads/2018/06/CTO-high-level-letter-26-GHz-technical-conditions.pdf

3.6. Specific sharing constraints at 26 GHz

3.6.1. Fixed service

As briefly noted in Report 68, the 26 GHz band is intensively used for fixed links in some European states. A useful source of information on this topic is ECC Report 173 "*Fixed Service in Europe Current use and future trends post 2016*". This report was originally published in 2012 and was updated in 2018 to take account, in particular, of the impact of 5G on the Fixed Service. It is reported that the main trend seen in most bands is "*an ever increasing provision of high bandwidth capacity for the mobile networks infrastructures*".

From the spreadsheet of link assignment statistics embedded in the Report, it appears that around 60,000 assignments are made in the lower band (24.5 – 26.5 GHz) and around a tenth of that figure in the upper band (above 27.5 GHz). No civil fixed link use is recorded at 26.5-27.5 GHz. The only use at 24.25-24.5 is in Russia.

The median 'typical' hop-length in this band is 4km, with median 'maximum' recorded as 10km. These bands are well harmonised, according to Recommendation T/R 13-02 (and ECC/REC/(11)01 for PMP)

Examining the statistics between 1997 and 2016 shows that the '25 GHz' band experienced much the greatest rate of growth although the overall number of links is still less than half the number in any of the 18 GHz, 23 GHz or 32 GHz bands.

A leading wireless backhaul provider, Ceragon, notes that "*Mass deployment of street level sites will require high capacity non-line-of-sight wireless backhaul links, as well as quickly installed, low footprint, low-power consumption equipment*"[54]

The architecture required to provide backhaul or fronthaul connectivity to a very dense network of mm-wave outdoor small cells located on street furniture will need to evolve from the current pattern of traditional wireless point-point links or fibre connectivity. If gNodeB's are to be located on every other lamp-post, ease of installation will become key, as will small size.

Figure 27: Point-to-point backhaul solutions (Ceragon, Cambium)

Traditional link terminals, as shown above are unlikely to be suitable for such dense deployment; although the form-factor can be expected to shrink there is a fundamental issue with the requirement for careful installation and alignment, particularly in view of the mechanical flexibility of likely support structures.

An alternative that is growing in relevance is the use of adaptive mesh-networking, using beamforming adaptive antennas and network intelligence to provide self-configuration.

[54] Ceragon White paper '*What You Need to Know About 5G Wireless Backhaul*' February 2016

Such approaches are set to become very cost effective as they will apply the same technologies that will be deployed for 5G millimetre wave access nodes.

While many infrastructure networks for small-cell deployment may operate in the unlicensed 60 GHz band, or make use of the higher bandwidths available under light-licensing regimes at E-band (80 GHz), W-band (100 GHz) and even D-band (150 GHz), the use of lower frequencies will offer cost and reliability advantages.

Figure 28: 'Metnet' In-band 26 GHz backhaul node

Source: CCS Limited

Given (i) the existing density of fixed link deployment below 26.5 GHz, (ii) the decisions that have been made on initial spectrum release for 5G above 26.5 GHz by administrations, and (iii) the alleged difficulty of meeting the emission limits for gNodeB's in the lower part of the band, it seems possible that the band below 26.5 GHz might be attractive spectrum for outdoor small-cell infrastructure links. It is even possible to conceive of devices that use the same antenna arrays to synthesise both user links and backhaul infrastructure links.

An important point to note is that transmit nodes operating in the Fixed Service would not be subject to the -42dBW/200 MHz limit at 23.6-24.0 GHz, but would be covered by the generic requirements which are relaxed by 5dB, making this a potentially efficient fit of usage to regulatory restriction.

Report. 68 and the associated decisions note that "*CEPT is currently developing a "toolbox" to help the national decision/application process supporting the introduction of 5G in 26 GHz where Fixed Service is in operation, providing mechanisms which allow for continued Fixed Service operation, where necessary*.". This work is being carried out within PT1, with a target deliverable date of June 2019.

The draft text suggests that the 18 GHz or 32 GHz bands might be appropriate as bands in which to re-farm existing 26 GHz fixed links. One co-existence option discussed is a 'phased approach' in which (as outlined) above, FS use continues in the lower part of the band while 5G services are deployed above 26.5 GHz. At some point there would be a second-phase assignment of the remaining part of the 26 GHz to 5G, but in the interim it would be necessary to characterise the adjacent-band sharing constraints between FS and 5G services (i.e. to characterise transmit and receive filtering characteristics).

The draft report examines case studies and modelling from a number of administrations, suggesting co-channel separation distances of tens of kilometres would be required, and that sharing in urban areas would not be feasible. Adjacent band sharing is more feasible, but still challenging.

This work is ongoing, but the most useful practical results will probably come from Monte Carlo modelling that captures the great complexity of the sharing environment (including dynamic beamforming, urban clutter statistics, etc.).

The current schedule expects that the first version of the 'toolbox' report will be released for public consultation in January.

3.6.2. Coexistence with EESS/SRS Earth station receivers

The 26 GHz band is an important resource for the download of scientific data from satellite sensors, mostly intended for monitoring of the Earth, its atmosphere and its oceans. Much of this data, from European programmes such as Copernicus and missions such as Sentinel, is downlinked via the European Data Relay System (EDRS)[55]. Much of the Copernicus data today is downloaded directly via dedicated Earth stations, while the European Data Relay System (EDRS) is used for 30-40% of the Sentinel 1 and Sentinel 2 data. Growing use of the EDRS service should, however, be considered for the future.

These ERDS Earth stations are located at Weilheim (Germany), Redu (Belgium) and Harwell (UK). As can be seen from the images below, all these sites are located in rural areas.

In addition to operation within the EDRS, European Earth stations may also be required to receive data directly from NGSO satellites operating in the EESS and SRS. The latter are particularly challenging, as the required antenna pointing may be very dynamic and the link budgets challenging. Earth stations[56] operating in the SRS are generally in more remote areas, such as Cebreros (Spain) and Kiruna (Sweden).

It should be noted that the number and distribution of future Copernicus Earth station sites still needs to be determined as part of the definition process of the evolution of Copernicus.

Figure 29: DLR Earth station at Weilheim, Germany

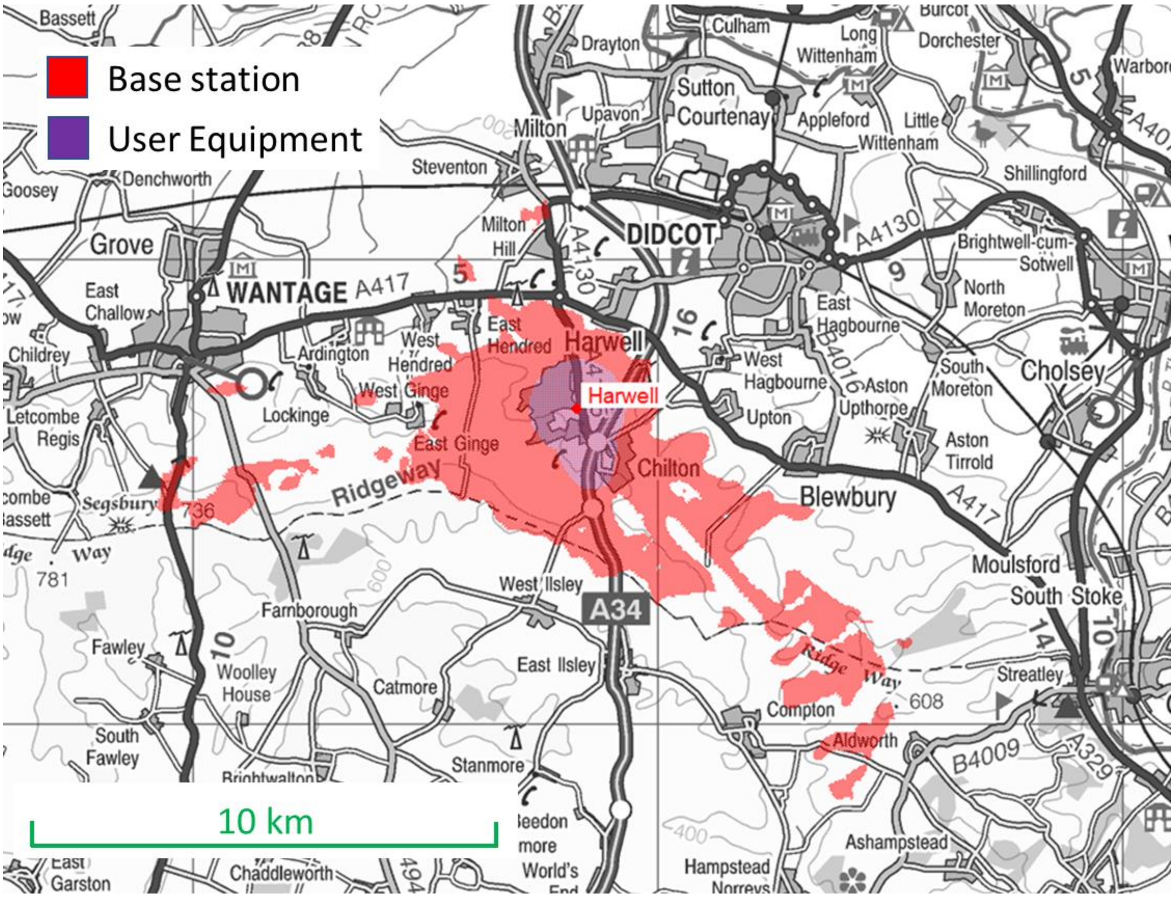
[55] This system includes two geostationary satellites (at 9° East and 31° East) that can gather data from non-geostationary (e.g. polar-orbiting satellites) via radio or optical links and downlink it to any of the three Earth stations that form part of the system.

[56] European Earth stations may also be required to receive data directly from NGSO satellites operating in the EESS and SRS

Report 68 notes "*that the use of the 25.5-27.0 GHz band by EESS systems is now in an early phase…"* and that *"there is also a need to maintain the possibility for additional earth stations to be deployed in the EU Members States when needed*."

Co-existence with the EESS/SRS should be addressed by *'applying technical constraints to the deployment of terrestrial services in a limited geographical area around a satellite earth station*'. Such co-ordination of receive Earth stations with other terrestrial users is a well-established process, and an example of the coordination zone that may be required around a 26 GHz Earth station is given in Figure 30 below.

Figure 30: Coordination zones around Harwell Earth station



Source: Plum

It can be seen that the area affected extends only to a maximum of around 10km from the site; most of this area is, in fact, unpopulated hill country.

The September 2018 Meeting of PT1 finalised a draft new ECC Recommendation[57] on the protection of EESS/SRS receiving earth stations. Three annexes of this report describe methods to determine the coordination zones required around Earth stations operating in the SRS, the NGSO EESS and the GSO EESS. The maximum radii of such zones range from a few km for the GSO EESS to around 25km for the SRS.

A fourth annex describes the detailed methodology to be used to assure co-existence of 5G sites within the coordination zones determined in the other annexes. Such toolkits provide the methodologies to be used by administrations to ensure coexistence with, and further deployment of, EESS/SRS receiving earth stations.

[57] See document ECC PT1(18)264 Annex 4

3.6.3. Satellite receivers (FSS and ISS) and FSS uplinks

Protection of satellite receivers in FSS & ISS is feasible, though elevation of 5G transmit antennas must be considered. Co-ordination distances are expected to be similar to those for the GSO EESS downlink case, i.e. up to around 10km.

Footnote 5.532B of the Radio Regulations limits use of this band to Earth stations with antennas with a minimum diameter of 4.5m, to ensure that narrow beamwidths ease compatibility with other services (particularly the ISS). This relatively large diameter is likely to ensure that such terminals do not become widespread.

As for the cases above, PT1 is developing a report on methodologies to ensure coexistence between 5G networks and FSS earth stations; Completion of this work for public consultation is currently planned for January 2019.

3.6.4. Coexistence with passive EESS (23.6-24.0 GHz)

The implication of setting the emission limit for base stations in the passive band to the relatively low level of -42dBW/200 MHz is that passive sensors will be adequately protected under any plausible deployment strategy. A limit of −38 dBW/200MHz has been set for emissions from user terminals.

This decision corresponds to the adoption of a 'maximum compatibility' scenario and has potentially-serious implications for the deployment of 5G systems in Europe. It is noteworthy that less stringent limits are applicable to devices operating in other services (e.g. the Fixed Service), or in the Mobile Service in other bands (e.g. 4G terminals), presumably because the population of transmitters is expected to be smaller and the frequency separation is dramatically greater, respectively.

The operational impact of any interference to EESS sensors is not readily quantifiable; such interference would essentially increase the uncertainty of measurements made of environmental parameters within the pixels from which the interference emanates (likely to be in the most dense urban areas). In many cases, the measurements being made in the 26 GHz band may not relate directly to the parameter of interest, but may be needed to resolve uncertainties or ambiguities in intermediate variable.

3.7. Review of international work on IMT candidate bands (WRC agenda item 1.13)

3.7.1. 24.25-27.5 GHz

The main issue is sharing with satellite passive sensors of the Earth Exploration Satellite Service (EESS) operating in the band 23.6-24.0 GHz and the degree to which out-of-band emissions from IMT terminals in the band 24.25 -27.5 GHz would need to be attenuated. A great deal of detailed technical work on this topic was undertaken within both the ECC and ITU-R groups, but no consensus was reached.

WP7C (the Working Party on 'Remote sensing Systems' in the ITU-R) has defined a range of representative passive sensor types. The most sensitive to interference is 'F3', which is flown on a LEO satellite at 828 km altitude and has an elliptical footprint of 12 x 7 km (169 square km^2) with a very high gain (52 dBi) antenna. It is not clear whether such a sensor is, or is currently planned to be, operational.

The EESS has a protection criterion[58] of -166 dBW/200 MHz which may only be exceeded for 0.01% time and 0.01% area. As the assumed measurement area is 2 million km^2 (i.e. approximately half the area of the EU), this equates to only being able to have interference in 200 km^2 (i.e. one pixel). This pixel size equates to the size of major cities such as London

[58] See: Recommendation ITU-R RS 2017-0 "Performance and interference criteria for satellite passive remote sensing", Geneva, 2012

and Paris. In principle, the EESS seek zero interference but studies have considered 1%, 5% and 10% probability of interference for city pixels from IMT. At the 1% probability level, the criterion of a single interfered pixel or city[59] would imply that there would need to be 100 cities in the area considered; the number of cities therefore became a much-discussed factor in the meetings.

On the IMT system side, a figure of 2dB additional protection to allow for channel aggregation has been accepted in both PT1 and TG 5/1, but the apportionment between services remained a major point of disagreement, with figures between 1dB and 5dB proposed by terrestrial and space interests respectively.

An even more contentious issue has been that of antenna modelling: the issue is that IMT terminals are expected to use dynamic beamforming, which might be expected to offer significant protection in directions other than the wanted link. Outside the nominal antenna tuning range, however, this beam forming will degrade and sidelobes will increase. There has therefore been a great deal of discussion regarding the extent of this degradation; the pessimistic and optimistic camps are separated by some 12dB.

As usual with these situations, there is considerable debate as to the likely number of terminals and users. One French study suggested a much larger population of base stations in Paris than previously assumed.

As a result of these debates, an impasse was reached within PT1 regarding the necessary emission limits for base stations. Figures proposed ranged from -32dBW/200 MHz (GSA) to -44dBW/200 MHz (several European administrations); ESA have also proposed that lower limits are necessary. The matter was resolved at the ECC plenary meeting in July 2018, and CEPT Report 68 now specifies a maximum total radiated power of -42 dBW/200 MHz for base stations, and -38 dBW/200 MHz for terminal stations (Annex 2, Tables 4 and 6). This is significantly more stringent than the values likely to be confirmed in other regions (i.e. -32 to -37 dBW/200 MHz), and, as discussed above, may mean that only the upper portion of the band will be viable in the European Union. The implications for 5G deployment are discussed below; the implications for the spacecraft sensors of different limits are hard to quantify, as they are based on different assumptions regarding 5G deployment and 5G equipment performance that are presently unknowable.

The assertion that filtering issues in practical 5G terminals will preclude the use of frequencies below 26.5 GHz has not, as far as the authors are aware, been independently verified. A number of manufacturers (e.g. Qualcomm) are currently announcing the availability on the market of new transceiver modules, with tuning ranges covering 26.5-29.5 GHz (3GPP band n257) and 27.5-28.35 GHz (3GPP band n261) with 800 MHz instantaneous bandwidth.

Figure 31: Qualcomm QTM052 millimetre wave antenna module

Source: Qualcomm

It will be important to understand what difference exists in practice between the performance of devices such as these and what would be required to permit operation below 26.5 GHz while protecting the EESS to the comparatively stringent levels set in Europe.

[59] In other words, a pixel from which interference is so strong as to obscure the measurement that the sensor is trying to make.

In addition to the direct impact on EESS sensors, the risk also exists that the widespread deployment of IMT systems will constrain the deployment of new receive Earth stations for data downlink from the EESS. As noted in Section 3.6.2, however, such stations will generally be sited in rural areas while deployment of millimetre-wave IMT services is envisaged primarily in the most urban areas or in industrial scenarios. Even where this is not the case, the necessary geographical separation required to ensure protection is generally modest (a few kilometres). The question of future Earth station deployment has also been considered in relation to authorisation and licensing regimes (see Section 4.4.4).

3.7.2.31.8-33.4 GHz

Studies undertaken in TG5/1 have concluded that the use of this band for IMT would not be compatible with the use of ground movement radars at airports. The draft brief for the agenda item (Document CPG(18)017 Annex IV-13) states:

"The *Radionavigation service is allocated on a worldwide basis and used in a number of countries for ground-based airport surface detection equipment (ASDE) radar, mainly to detect traffic at airports and by aircraft radars for ground mapping, weather avoidance, to calibrate aircraft on-board navigation systems for accurate aerial delivery in adverse weather conditions and for Enhanced Flight Visibility Systems (EFVS).*

EFVS system generates navigation information and a synthesis image of the external scene in the cockpit with the main purpose to permit, in poor visibility conditions, landing (and potentially providing assistance for taxiing), where landing would not be safe otherwise (in particular for airport not equipped with ground landing assistance systems such as ILS).

The band offers a good compromise between resolution and atmosphere penetration in bad weather conditions.

All technical studies presented in TG5/1 have shown the incompatibility between IMT and radionavigation service in the 32 GHz band, in particular in the case of aircraft radars for which coordination/exclusion zones approaching 100 km around any small airport cannot be envisaged."

This proposed band is also adjacent to the passive allocation at 31.3-31.8 GHz, and all studies have shown that protection of the EESS sensors in this band would require a drastic reduction in the likely adjacent band emission levels (to circa -58dBW/200 MHz for base stations).

As a result, the Draft European Common Position (ECP) is for no overall change to the Radio regulations under WRC Agenda Item 1.13 (see ECC PT1 document (18)264 Annex 44).

3.7.3.37.0-40.5 GHz

EESS sensors use the sub-band 36.0-37.0 GHz, with a power limit (-166dBW/100 MHz) similar to that at 23 GHz, but with a greatly relaxed time/area criterion (0.1%, 10km^2). This difference would imply that up to 66 pixels could be lost due to interference, but considerations of population density imply that this is unlikely to be a threat.

The band is also used by the Space Research Service (SRS) for downlinks. Separation distances of the order of 30-100km would be required to protect the small number of affected Earth stations. The draft CPM text from TG5/1 indicates that "*studies have shown that the separation distance for interference free operation of SRS earth stations is low and the issue will be mainly at a national leve*l."

3.7.4.40.5 – 43.5 GHz

This spectrum was identified as '*a viable option in the longer term, for 5G use*' in the 1st RSPG Opinion.

A sub-group in WG1 in PT1 are studying sharing above 40.5 GHz with the Fixed Satellite Service (FSS). There have been positive margins (e.g. of 20 dB) from all studies except for one (from Russia).

The Draft European Common Position (ECP) for this band is that it should become a joint-primary Mobile Service allocation, and identified for IMT use (see ECC PT1 document (18)264 Annex 45).

The preliminary CEPT position is not to oppose the identification of the entire range 37.0-43.5 GHz for IMT-2020, so as to allow benefit of manufacturing scale for devices with this tuning range. There is no intention to allow use below 40.5 within the CEPT.

3.7.5.45.5 – 50.2 GHz

Studies in both CEPT and ITU-R suggest that current IMT-2020 unwanted emissions (UWE) levels would not be sufficient to protect EESS (passive) sensors in the 50.2-50.4 GHz band and that a drastic reduction of UWE would be required.

3.7.6.66-76 GHz

There are still some issues to resolve in this band regarding sharing between IMT and the Fixed Service. The possibility of interaction with automotive radar (76-81 GHz) has also been studied.

The Draft ECP of CEPT is to identify 66-71 GHz, which is already a primary Mobile Service allocation, for use by IMT. The need to ensure compatibility with co- or adjacent (57-66 GHz) use of the band for ‘Multi-Gigabit Wireless Services’ (MGWS) such as 801.11ad/ay ‘WiGig’ is also noted.

No change is proposed to the Radio Regulations at 71-76 GHz. Although currently a Primary Mobile allocation, the expected growth of fixed service links in this band, together with the need to protect automotive radar, make it unattractive for IMT use.

3.8. Implications

The planning by most spectrum management agencies (SMA) seems still to be at a relatively early stage, and any developments will be conditioned by the recent ECC decision on 26 GHz out-of-band limits.

It may be the case that the ‘maximum transition’ scenario will still emerge, if device performance is found to be better than is currently assumed.

Given the early stage of thinking around these issues, the variation by Member State with deployed services (e.g. fixed links and point to multi-point) and the partial availability of migration plans, it is difficult to develop a representative model for transition scenarios.

With the exception of the EESS sensor issue at 24 GHz, compatibility issues are likely to be a very local concern, with in-band re-use distances (FS, EESS/SRS downlink) being very modest.

The main asymmetry between Member States due to co-existence issues relate largely to the different patterns of current fixed service deployment across Europe. Initially, at least, there should be no issues at 26 GHz, as the upper 1 GHz is unused in all states. The ease of clearance of the lower part of the band, if required to meet market demand or spectrum allocation strategy, will, however, vary between states. For example, while Germany operates over 18,000 fixed links at 24.5-26.5 GHz, there is only a single link recorded in Finland[60].

[60] See ECC Report 173.

4. Allocation and authorisation of mm-wave spectrum for 5G

4.1. Introduction

This chapter covers allocation and authorisation of mm-wave spectrum for 5G. There is already a good background of literature on these topics and, where appropriate, this is cited in the text. It is not the intention here to reproduce the work already done – only reference its outcomes and comment as required. Key inputs are:

- The RSPG Second and Third Opinions on 5G networks. [61],[62]
- CEPT Report 68 as the basis for a forthcoming Commission Decision (also related to the non-binding ECC Decision (18)06[63])
- The European Electronic Communications Code (EECC).[64]

In this chapter the current position on allocation and authorisation is reviewed based on the literature, research interviews undertaken as part of the study, the outcome of the workshop held on 30th May 2018 and consultation and other documents published by SMAs in recent months. It should be noted that this area continues to develop with further outputs expected from SMAs.

When considering allocation and authorisation of mm-wave spectrum it is important to take account of the differences between this spectrum and mobile spectrum allocated in frequency bands below 6 GHz. The main differences are the characteristics of the spectrum (its propagation characteristics are shorter range than sub 6 GHz mobile spectrum)[65], and access to larger bandwidths will support higher throughput and lower latency The traffic density supportable by mm-wave will be considerably higher than that provided by existing mobile infrastructure.

As a result, mm-wave spectrum lends itself to small area high capacity use and it will require sufficiently large allocations to enable efficient deployment. Opinions vary on the amount of spectrum required by each operator but in the research undertaken, channel bandwidths of between 400 MHz and 1 GHz were noted, with the possibility of smaller local deployments in channels of 200 MHz or less (for small local self-deployed networks, for example).

The 5G Action Plan[66] set out key issues for 5G including "alignment of roadmaps and priorities for a coordinated 5G deployment across all EU Member States..." Also, the need to "work toward a recommended approach for the authorisation of the specific 5G spectrum bands above 6 GHz." Further, the Action Plan refers to the identification of the pioneer spectrum bands for the initial launch of 5G. The mm-wave pioneer band identified by RSPG, which is the primary focus of this chapter, is 24.25-27.5 GHz (the 26 GHz band). Other mm-wave bands are considered where appropriate.

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[61] RSPG Strategic spectrum roadmap toward 5G for Europe. RSPG18-005 Final.

[62] RSPG (18) 36 Final.

[63] Harmonised technical conditions for Mobile/Fixed Communications Networks (MFCN) in the band 24.25-27.5 GHz.

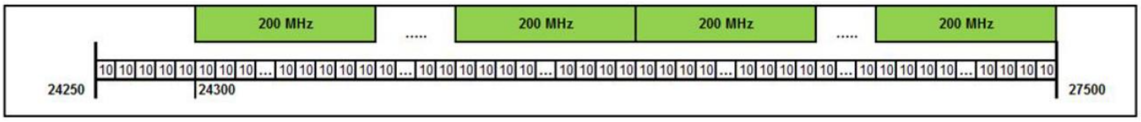
[64] Text adopted: P8_TC1-COD(2016)0288. Position of the European Parliament adopted at first reading on 14th November 2018.

[65] The range provided by the mm-wave spectrum mean it is more likely to be deployed to serve hot spots and the impact of potential interference will be over a smaller geographic area compared with mid and low frequency bands.

[66] COM(2016) 588 final 5G for Europe: An action plan. "Action 2" is identification of pioneer spectrum bands and "Action 3" is agreement by the end of 2017 on the full set of bands to be harmonised to support 5G networks in Europe and work toward a recommended approach for authorisation.

Article 54 of the EECC covers coordinated timing of authorisations for specific 5G bands. It requires the use of at least 1 GHz of the 24.25-27.5 GHz frequency range (26 GHz band) to be allowed for 5G, provided that there is clear evidence of market demand and absence of significant constraints for migration of existing users or band clearance, before 31st December 2020.

ECC Decision (18)06 Annex 1 sets out a harmonised frequency arrangement for the 26 GHz band as shown below.



- The frequency arrangement is a TDD arrangement with a block size of 200 MHz.
- The block size could be adjusted to narrower blocks (multiples of 50 MHz) adjacent to other users to allow full use of spectrum if required.
- If blocks need to be offset to accommodate other uses, this shift should be done in 10 MHz steps.

The findings of the study for allocation and authorisation of mm-wave spectrum for 5G are set out below.

4.2. Summary of findings

Below is a summary of the findings on allocation and authorisation.

- There is recognition among SMAs that the 26 GHz band is a priority band for 5G and that it should be made available when demand occurs.
- Member States indicated that they will make at least 1 GHz of the 26 GHz band available before the end of 2020 in line with the Code and this is likely to be the frequency range 26.5-27.5 GHz as recommended by RSPG.
- The sub-band below 26.5 GHz is more problematic to make available in the near term in Member States due to both the presence of incumbent services and the requirement to protect space sensors of the EESS.
- In line with good practice, the least onerous and most flexible access mechanism should be adopted as a default for authorisation of mm-wave spectrum. However, most SMAs have yet to publish proposals on this.
- For the 26 GHz band, there are authorisation challenges resulting from protection of incumbent and out of band services, including the EESS. This tends to point toward use of an IA or light licensing approach for this band.
- Subject to study of local circumstances, different authorisation approaches may be possible for indoor vs outdoor services. Consideration should be given to GA for indoor if protection requirements can be met (subject to retaining a common band plan).
- Consideration should be given to authorisation mechanisms to enable regional and local operators as well as industry vertical to access mm-wave spectrum on a location basis. Use of a GA or light licensing approach could enable access for these players.
- While there may be legitimate reasons for differences in authorisation approaches between Member States based on local conditions, there is a need for consistency and coordination between Member States to avoid fragmentation and reducing investment incentives, in particular for services with a pan-European dimension (for example services that are used either side of a country border such as for railways).
- Authorisation in the 26 GHz band could be based on the use of a mechanism based on advanced database techniques (e.g. LSA) to provide the required flexibility and adaptability over time as demand for both 5G and incumbent services develop.

- The position on authorisation of other mm-wave bands is less clear but there appears to be a consensus emerging on use of GA for the 66-71 GHz band.

4.3. Allocation of mm-wave spectrum

4.3.1. Summary of research findings

The research undertaken with SMAs has identified the following in respect of the availability of mm-wave spectrum and in particular the 26 GHz band. It should be noted that while the potential use of other mm-wave bands over time is acknowledged by SMAs, there is currently little output at the time of writing in respect of these bands.

- Most SMAs are considering the early release of at least the upper 1 GHz of the 26 GHz band. The following SMAs have issued consultations or call for inputs which include 26 GHz:
  - Belgium (closed on 17th August 2018).
  - Finland (Digital infrastructure strategy published 1st October 2018)
  - France (Published November 2018).
  - Germany May and November 2018.
  - Ireland (closed on 30th July 2018)
  - Italy (Award concluded September 2018)
  - Poland (closed on 8th August 2018)
  - Sweden (closed on 14th March 2018)
  - UK (Call for inputs closed on 22nd September 2017)
- More generally there is a mixed picture on the availability of the 26 GHz band. In some Member States point to point or point to multipoint links are deployed (e.g. Hungary), whereas, in other Member States, there is little or no use of the entire band (e.g. Finland, Croatia). There are also ground earth stations for satellite services deployed in the band at locations across Europe together with other satellite / space services.
- Some Member States mentioned military use in the upper part of the 26 GHz band (e.g. UK, Germany, Netherlands, Portugal, Slovenia). While no specific details were disclosed, it is expected that these services can be migrated or accommodated through sharing mechanisms.

Current use and migration options are explored more fully in chapter 3.

There was no consensus from SMAs on the potential use of the 28 GHz band for 5G. There are no definite plans identified to allocate this spectrum for 5G services within the Union, although there are 5G trials taking place in the 28 GHz band; for example, in the UK there is a trial of 5G FWA being supported by Arqiva and Samsung, which will use 28 GHz spectrum already licensed to Arqiva. 5G-PPP maintains a list of 5G trials taking place in the European Union,[67] although it should be noted that most of the trials are focused on mid and low-band spectrum rather than mm-wave, except for trials using 66-71 GHz.

Views from other research respondents (e.g. equipment vendors and mobile network/satellite operators) on the 26 GHz band include:

- The need for protection of the EESS and FSS in or adjacent to the 26 GHz band. ECC decision (18)06 delivered clarity on the protection criteria for the EESS. Space operators voiced the strongest views in this regard but in some cases were not entirely against provision of mobile services in the 26 GHz band, provided coexistence is properly managed. This matter is covered further in chapter 3.
- Issues with the tuning range of equipment and the impact on usability of spectrum bands creates an operational issue for 5G network operators. One network equipment vendor, for example, said that it will initially manufacture equipment with a tuning range of 26.5-29.5 GHz. While this accommodates the upper 1 GHz of the 26 GHz band, it restricts access to the lower part of the 26 GHz band. Similar views have been expressed

[67] https://5g-ppp.eu/5g-trials-2/#1512735204240-3eb10a7b-5bdb

by other equipment vendors, including Qualcomm.[68] Commercial deployment of equipment covering the full 26 GHz tuning range is currently expected in the early 2020s.[69]

The position on allocation of other mm-wave bands is less well developed than that for 26 GHz and to date there have been no consultations identified except for Ofcom in regard to the 66 – 71 GHz band. This provides for use of the band for:

- For short range wideband data transmission extending the current licence exemption and technical conditions (from 57 – 66 GHz) up to 71 GHz; and introducing new technical conditions to allow licence exempt use of lower power equipment operating in a fixed outdoor installation in the 57 – 71 GHz band.
- For fixed wireless systems extending the current licence exemption (from 57.1 GHz – 63.9 GHz) to 70.875 GHz, and by doing so, change the current authorisation approach for fixed wireless systems operating in the 64 – 66 GHz band from light licence to licence exempt; and extending the current technical conditions (from 57.1 – 63.9 GHz) up to 70.875 GHz.

4.3.2. Conclusion: allocation

There is recognition among SMAs that the 26 GHz band is a priority band for 5G and that it should be made available when demand occurs. While SMAs are either already consulting on the allocation of the 26 GHz band or plan to do so, most of their attention at present is taken up with progressing mid-band (3.4-3.8 GHz) and low-band (700 MHz) spectrum matters. However, although some SMAs indicated that at least the upper 1 GHz of the26 GHz band would be made available reasonably quickly in line with the requirements of the EECC, there is a differing picture across Member States of what can be achieved and by when. This is in part driven by incumbent services (mainly fixed link[70] and point to point services[71] and some satellite services) and the need to migrate these where appropriate.

The band below 26.5 GHz is more problematic to make available in the near term in some Member States due to both the presence of incumbent services (again, mainly fixed links and point to multi point links and in some cases satellite ground earth stations) and protection of out of band EESS sensors.

There was a lack of information to hand for analysis regarding the availability of other mm-wave bands as SMAs are less advanced with their evaluation and plans. In the case of 66-71 GHz, there appears to be little to prevent the band being made available and there is an expectation that these bands will be the subject of future public consultation by SMAs.

In some cases, SMAs indicated that they are awaiting the outcome of WRC19 on the allocation of mm-wave bands. In this respect, affirmative action is necessary by Member States for the pioneer bands at WRC19 but the requirement of Article 54 of the EECC regarding availability of at least 1 GHz of the 26 GHz band creates conditions in the Union for early access for 5G to the 26 GHz band.

4.4. Authorisation of 5G services

4.4.1. Background

This section addresses the requirement for authorisation of spectrum that will support 5G services. The 5G Action Plan encourages the development of a recommended approach for

[68] https://www.qualcomm.com/products/qtm052-mmwave-antenna-modules

[69] It is not clear whether this equipment will meet the protection criteria for EESS specified by the ECC Decision or whether it will meet the less stringent requirements being adopted elsewhere (e.g. Middle East and African countries).

[70] The fixed links in the 26 GHz band are often used for mobile backhaul.

[71] The point to multi-point links are often used for fixed wireless access and mobile backhaul.

authorisation of 5G services. It also raises the question of whether a method of spectrum authorisation could be applied to serve the needs of industry verticals. When addressing all requirements for authorisation of spectrum it is important to recognise the requirement for service and technology neutrality.

4.4.2. The impact of 5G services in mm-wave spectrum

mm-wave spectrum potentially enables a range of services including eMBB, massive machine type communications and ultra-reliable low-latency communications. The spectrum may also facilitate fixed wireless access and backhaul services. It could be used in both indoor and outdoor environments, support public telecommunications services provided by mobile network operators, services supported by smaller local operators (possibly new entrants) and potentially private network services supporting vertical applications (e.g. automotive, industrial automation) provided by industry verticals or third-party providers (if not provided by mobile network operators). See chapter 2 for further details of 5G services and demand.

A key aspect of spectrum management is to make the most efficient use of spectrum. Also, the management of harmful interference (both to the service being authorised and to other services). Supporting the range of service and use possibilities enabled by 5G in mm-wave spectrum suggests that careful consideration should be given to the spectrum authorisation regime to be adopted. Simply following past practice may not deliver the best outcome given the fundamentally different nature of mm-wave solutions based on small high-capacity cells with limited coverage and potentially denser deployment in places with high capacity demand requirements.

Management of harmful interference includes the requirement for protection of in-band services and of services in adjacent bands. For mm-wave 5G services operating in a shared spectrum environment[72], this could mean imposing location specific coexistence conditions. For example, if mm-wave 5G services are to be deployed at a location where there is limited risk for harmful interference to other services, operating in the same or adjacent bands there may be a higher amount of spectrum available for use than in a location where there is high potential for interference to other services (e.g. where an extensive set of incumbent services are deployed).

Consideration of coexistence (shared spectrum use) on a localised basis is already common practice, for example, for fixed link and satellite / space services. However, it has not been the norm for the deployment of mobile services in sub 6 GHz spectrum where other services are generally cleared prior to award of spectrum to mobile operators with appropriate provisions made for protection of services in adjacent bands. To date, much of the non-mobile in-band sharing that has taken place is based on static rules; 5G services in mm-wave spectrum are an opportunity to use more advanced methods of spectrum sharing. Database and light licensing solutions could be used by SMAs or third-party band managers to facilitate such sharing.

4.4.3. Authorisation options

The range of options for authorisation of spectrum was set out in the regulatory framework for electronic communications and is maintained in the EECC. Options range from General Authorisation (GA) to Individual Authorisation (IA), in cases where specific definition of rights is objectively justified. In general, the most appropriate and least onerous authorisation system possible should be applied to maximise flexibility, sharing and efficiency in the use of radio spectrum. The choice of regime should be based on:[73]

- The specific characteristics of the radio spectrum concerned.
- The need to protect against harmful interference.

[72] It is assumed that 5G will coexist in mm-wave bands with incumbent services, especially outside of the top 1 GHz of the 26 GHz band (26.5-27.5 GHz).

[73] See Article 46 1. (a) to (f).

- The development of predictable and reliable sharing conditions.
- The need to ensure technical quality of communications or service.
- Objectives of general interest as defined by Member States in conformity with Union law.
- Safeguarding efficient use of spectrum.

Where individual rights of use of radio frequencies is necessary (as is currently the case for the public mobile service), authorisation of such rights is to be done under GAs, and that additional conditions / obligations may be imposed on these rights (individual spectrum licences).[74] The maximum set of conditions/obligations for GAs and rights to use frequencies is set out in Annex 1[75] to the EECC. The obligations / conditions that are most relevant to mobile services include the following:

- Obligation to provide a service or to use a type of technology within the limits of Article 45 of the EECC including, where appropriate, coverage and quality of service requirements.
- Effective and efficient use of spectrum in conformity with the EECC.
- Technical and operational conditions necessary for the avoidance of harmful interference and for the protection of public health against electromagnetic fields.
- Maximum duration in conformity with the EECC, subject to any changes in the national frequency plan.
- Transfer or leasing of rights at the initiative of the right holder and conditions for such transfer in conformity with the EECC.
- Usage fees in accordance with Article 42 of the EECC.
- Any commitments which the undertaking obtaining the usage right has made in the framework of an authorisation or authorisation renewal process prior to the authorisation being granted or, where applicable, to the invitation for application for rights of use.
- Obligations to pool or share radio spectrum or allow access to radio spectrum for other users in specific regions or at national level.
- Obligations under relevant international agreements relating to the use of frequencies.
- Obligations specific to an experimental use of radio frequencies.

For mm-wave 5G services, there is no evidence from the research undertaken to suggest that a different approach is required at the legislative level to that already in place. However, and especially for the case of cross border services that may develop, it will be important that there is consistency between Member States with the application of the principles for authorisation of 5G mm-wave services.

4.4.4. Influencing factors for the choice of authorisation option

Scarcity

A key input to choose the method of authorisation and more specifically award of spectrum, is whether there is likely to be scarcity or excess demand. If scarcity/excess demand is not foreseen a GA approach should be considered (with appropriate technical protections) or a simple award mechanism such as FCFS could be a way forward. If scarcity is foreseen, it will be necessary to consider approaches to award spectrum that lead to efficient outcomes (i.e. some form of competitive method).

[74] Where there are specific risks to the avoidance of harmful interference, insurance of technical quality of service, safeguarding of efficient spectrum use or the fulfilment of other objectives of general interests as defined by the Member States' Community Law, individual rights of use for frequencies and numbers may be granted.

[75] Annex 1. D.

Assessing scarcity requires an understanding of the nature of mm-wave spectrum, the amount of spectrum an efficient operator is likely to require and the level of potential competition for the available spectrum. This information should be sought by SMAs through consultation to assess demand. It should be noted that scarcity could be created by minimising the amount of spectrum that is brought to market. This may be due to constraints driven by incumbent service usage reducing availability, the need to protect services in adjacent bands (although hopefully efficient solutions will be devised for this over time) or artificial restrictions on spectrum supply (i.e. holding back spectrum). The latter would not be in the interest of market development.

Quality of service

GA may not be robust enough to provide adequate assurance of QoS for protection of some incumbent services if 5G is introduced to a band, on a shared basis (i.e. specific coexistence conditions may be necessary for authorisation). Assessing this will require study on a case by case and band by band basis to establish whether sharing can be managed through GA and appropriate technical conditions, or whether a more stringent requirement is necessary that will form part of an IA. It should be noted, however, when considering use of IA that Article 46 of the EECC requires Member States to take account of technological solutions for managing harmful interference in order to impose the least onerous authorisation regime possible. This means that Member States should consider whether there are specific reasons as set out in Article 46 1. (a) to (f) to justify the use of IA, as shown in 4.4.3 above.

The Radio Equipment Directive (RED)

The RED Directive entered into force in June 2014 and since 12 June 2017 manufacturers placing radio equipment on the market will be required to comply with both transmitter and receiver minimum technical requirements[76] [77]. The RED clearly was developed to enhance sharing possibilities and to avoid excessive guard bands. No doubt over time it will achieve this and allow for more equipment to have a 'light touch' regulation. The timeline for this will be very different for the different sectors of radio communication and will depend on the expected life time of equipment. Some will however be forced to update equipment; one example is the MSS MESs where the use of IMT in the adjacent band hopefully will lead to a quicker replacement cycle for this type of equipment.

It can be envisaged that if sharing potential is enhanced whilst at the same time mitigating the risk of interference, then over time it may be possible to move away from an IA to a GA approach for some 5G spectrum authorisation. Currently the impact of the RED Directive is not sufficiently advanced to advocate such an approach in the short term.

Standards are in preparation for mm-wave (EN) are being developed for 26 GHz equipment.[78]

The 26 GHz band

If one focuses on the 26 GHz band, there are several incumbent services likely to require protection.[79] Most problematic of these is protection of out of band passive sensors for the EESS. While there is no firm view on the impact of the protection requirement for the latter on the reduction in the amount of spectrum available for mobile use in the 26 GHz band,

[76] There is some radio equipment that is excluded from the requirements of the RED Directive – see Article 1.3 and Annex I.

[77] ETSI equipment standards have been updated to include receiver characteristics.

[78] See https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=54728 and https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=54786

[79] Examples of services needing protection are the Fixed Service (FS) – point to point and point to multi-point links, the Earth Exploration Satellite Service (EESS), the Inter-Satellite service (ISS), the Fixed Satellite Service (FSS), Automotive Short Range Radar (SRR), Short Range Devices (SRD) and out of band passive satellite services (e.g. at 23.6-24.0 GHz).

anecdotal information from network equipment vendors suggests that the impact could be to restrict or prevent use of the lower 1.25-1.5 GHz of the band outdoors. Given the propagation characteristics of 26 GHz, services used at low power indoors may not be subject to such restriction.

Based on the above, a number of authorisation scenarios appear to be possible for the 26 GHz band:

- If only 1 GHz of spectrum is available in the band,[80] quality of service considerations, timescales for improvements to equipment receivers for equipment sharing the spectrum in band or in adjacent bands and scarcity (the authorisation of enough spectrum to mobile operators to provide viable services), point toward the use of IA. This will probably be with the use of a selection mechanism to award the spectrum given there may be scarcity in areas of high demand.
- Where the whole band would be in principle available, but where protection of the EESS prevents use of the lower part of the band and leaves up to 2 GHz of spectrum available in the upper part of the band, this would increase the spectrum that mobile operators and others could potentially access compared to the first scenario. However, in the outdoor environment the requirement to protect the EESS and to share with other incumbent services may still point to use of IA for the band, despite the reduction of scarcity and the introduction of the RED which is unlikely to lead to more resilient EESS receivers in the short to medium term.
- In the indoor environment a more flexible sharing environment could be foreseen, as sharing can be more easily achieved due to building penetration losses (potentially making available more spectrum in the band than is possible outdoors and still meeting relevant protection criteria)[81]. Subject to study by SMAs confirming the sharing possibility, a GA approach could be proposed for indoor use. However, if such an approach is to be considered, there is a need to ensure a consistent band plan across the indoor and outdoor environments. An alternative for indoor use could be an advanced database sharing solution that assigns spectrum on request (on a GA/light licensed basis). There are already examples of such databases including those that have been developed for White Spaces and for CBRS in the United States. However, these solutions are not yet sufficiently mature to deliver automated assignments on a wide scale. Therefore, for the time being, such assignments are expected to be made administratively for light licensed regimes.

Similar considerations apply to the mode of authorisation to be adopted in other mm-wave bands, where there is likely to be the need to protect incumbent or out of band services. This matter is not analysed in more detail here as, at the time of writing, there are less details of plans for use of other mm-wave spectrum for 5G. However in the specific case of the 66-71 GHz band GA could be a way forward.

Local vs national authorisation

The local nature of deployment of mm-wave supported 5G services in locations with very high demand means that they will not be deployed to provide coverage in a nationwide sense. This requires a different approach to coordination and authorisation, which in part is dependent on how local is defined (e.g. whether it is specific areas defined by the spectrum management authority or whether the areas are self-defined by where operators seek to deploy their equipment). In either case though, it should be possible to characterise the nature of transmissions (e.g. for example, for small cell or FWA and incumbent services), the protection required (using the least onerous approach) and define appropriate planning criteria, which could be implemented in a software driven coordination and assignment tool. This is like the automation that has occurred with planning and authorisation of fixed links and satellite service ground earth stations. It is a matter for

[80] Based on the likely initial use of the 26.5-27.5 GHz frequency range.

[81] This requires further study across a range of potential use environments.

individual SMAs whether they take on this function themselves, devolve it to a third-party manager or have it operated on a collaborative basis between operators. This is different to the approach adopted for most other spectrum bands used for mobile. Taken to an extreme it could suggest that authorisation should be done on a local basis using defined rules where demand requires it. This could provide flexibility to allow more users to enter the market, including those making use of mm-wave spectrum for provision of services to industry verticals or entities wishing to provide service to local communities not otherwise covered.

However, mobile operators require a reasonable expectation of being able to deploy across their area of operation. This could potentially be facilitated by an arrangement that allows them access to spectrum where needed, but potentially makes spectrum available to others (for example, to vertical service providers or even other compatible services)[82] where demand does not fully utilise available spectrum. It would also provide a means to share with incumbent users[83]. Two examples of this are the "club" arrangement applied for 26 GHz lots in recent 5G auction in Italy and the local application procedure proposed in Germany.

4.4.5.Spectrum sharing

Spectrum sharing is not a new concept and mm-wave spectrum characteristics lend it to sharing. More flexible / dynamic sharing using methods such as white space and licensed shared access (LSA) have been developed and trials have been carried out.[84] Evolution of LSA for the 5G environment is under discussion.

Sharing approaches may be categorised by considering whether there is active interference control and the authorisation approach employed (GA or IA). A summary of possible approaches to sharing is shown below. The approaches summarised in the table could potentially apply to any frequency band.

	General Authorisation (GA)	Individual Authorisation (IA)
Licence exempt	• No individual licence requirement. • No requirement for active interference control.[85] • Technical parameters may be defined for operation of the band.	• N/A
Light licensed	• Provides a level of protection from harmful interference (e.g. through use of a geolocation database). • Needs agreement between spectrum users to work.	• Light licensed could also operate through individual authorisations – if the SMA controls access.
Licensed	• N/A	• Specific licence(s) with conditions (rights and obligations) set out.

GA works well where there is not a requirement for a specified quality of service or to limit the number of services attempting to operate in a band. The requirements for operation of this could be set by individual Member States, by the operators themselves or for new technologies / services in the standards process. It enables a low barrier to entry, subject to technical conditions and could enable local area operations, but it provides no guarantee of risk from harmful interference or the delivery of a specified QoS for any user of the

[82] Compatible meaning there is the potential to share on a co-channel, geographic basis.

[83] Most likely non-mobile services such as fixed links.

[84] There have been several pilots / trials, including in Italy, France, Finland and the Netherlands.

[85] Licence exempt use relies on their being no active interference control and users operating within defined technical limits. It is possible to operate licence exempt use with active control. For example, some white space sharing relies on a channel being assigned at a location through a database and the station transmitting on that channel within technical limits. Systems using sensing may be able to modify assignments or require transmission to cease in the presence of other defined signals.

band. This, for example, would not work with sharing for some satellite services, where the use of an IA approach is assumed when setting technical conditions. GA would be suitable for mm-wave spectrum where the nature of use (for example over short distances indoors) will allow acceptable QoS to be delivered with a minimum potential for interference to other services. However, as noted above it is unlikely to be suitable in bands with specific and potentially stringent incumbent protection criteria.

LSA is an example of a sharing technique that could be operated under IA that will provide QoS. The concept of LSA is to allow a limited number of additional users into a band on an IA basis and it was designed as a mechanism to enable mobile operators to access spectrum that has been harmonised for mobile broadband but where there are incumbent or adjacent services which are hard to move and that require specific protection.

LSA delivers defined QoS to both the incumbent and sharing services. SMAs will define access rules in conjunction with users (entrants and incumbent(s)) and these rules would be facilitated by a geo-location database (sometimes described as a repository) that would grant user rights to access spectrum at given locations, at given times or both.

Enabling an LSA or similar advanced database sharing solution requires detailed consideration of the co-existence characteristics of all services likely to use a band and the requirement for coexistence with services in adjacent bands. For the 26 GHz band, for example, this includes the FS, FSS and EESS and others together with 5G.

Use of an advanced database approach could also be the key to provision of authorisation on a local basis where demand requires. This could be achieved through a light licensing approach.

While there is significant efficiency and value to be gained through use of advanced sharing techniques, their use should be justified through an appropriate impact analysis. The technical solution and the development of rules for the database must be feasible, the solution must cater for the changing nature of demand over time, and there are costs and complexity associated with implementation that need to be outweighed by the advantages obtained through use of sharing.

Light licensing

Light licensing is a combination of licence-exempt-use and provision of protection for spectrum users (it could operate under either a GA or IA regime depending on the QoS required, although some spectrum users may dispute the use of a GA concept for light licensing for IMT[86]). It could potentially be applied to any mm-wave band for 5G which is not foreseen as operating under a simple GA regime or where there is no likelihood of significant scarcity (this may make its use problematic for the initial 1 GHz of the 26 GHz band if scarcity is foreseen). Light licensing, with use of a simple application procedure, may be applicable to indoor use of mm-wave or for other entrants such as industry verticals. Light licensing could be supported by an LSA solution as described above.

[86] The objection has its roots in the potential for harmful interference that could arise if the light licensing coordination procedures fail. However, this could be mitigated with appropriate regulatory oversight and controls on who can enter the arrangement and access spectrum.

4.4.6. Research input

Key points from the research undertaken for the study in respect of authorisation are set out below. In addition to research among stakeholders in the Union, the study team examined examples of approaches being taken by some leading countries elsewhere. The primary focus of the research was on the 26 GHz band.

Key points from 26 GHz awards and consultations

In Italy AGCOM has recently awarded 26 GHz spectrum in the frequency range 26.5-27.5 GHz. The award was based on regional authorisations but with a provision for spectrum users to share spectrum in regions outside of their own authorisation subject to there not being excess demand. The spectrum was split into five 200 MHz lots and an operator could acquire up to a maximum of 400 MHz. Access, to spectrum outside of the region in which the operator was awarded, would be subject to demand on a non-discriminatory basis, and commercial agreements between the 26 GHz spectrum holders

In Germany, Bundesnetzagentur has proposed that 26 GHz spectrum should be assigned on a regional basis and that local authorisations could be accommodated under an application procedure. This recognises the potential for entry of smaller local operators and industry verticals providing private 5G services. At the time of writing, the details of the application procedure are not published. The spectrum would be structured using the block structure defined by CEPT.

In France, Arcep is consulting on the likely spectrum and access arrangements for 5G including 26 GHz. Again, the block structure proposed is that defined by CEPT. At this time, Arcep has not proposed detailed measures for award but it is seeking stakeholder input on what the parameters might be, including for example, the need for synchronisation between networks (TDD), criteria for sharing with satellite earth stations, likely frequency requirements of operators and spectrum caps.

Views from SMAs

There were a range of views from SMAs, many of who at the time of writing have yet to fully consult on this matter.

Views on appropriate measures differed by the band being considered. In general, there was a preference for IA in the 26 GHz band (driven by protection of incumbent services, QoS and potential scarcity if spectrum supply in the band is limited). For the 66-71 GHz band there was a preference for GA. Views on the 42 GHz band were less clear.

- However, there were differing views expressed by SMAs on the 26 GHz band based on the likely interference environment for the band in any given Member State. In those where there is a high probability of harmful interference from 5G to other services, there was a preference for IA to ensure that appropriate protection is defined (and to take account of any increase in demand for the incumbent services). For those where there is less likelihood of harmful interference to other services the attitude of SMAs was more relaxed in terms of the approach to authorisation. Also, some SMAs suggested they are prepared to consider different approaches for indoor and outdoor authorisation of mm-wave spectrum as discussed in Section 4.4.5.
- There were differing views on national vs regional or localised licensing. Some SMAs see dedicated national licensing for mm-wave spectrum as being potentially inefficient, given that the nature of deployment will be small cells and that there is unlikely to be contiguous national deployment. mm-wave infrastructure will be focused on high capacity demand situations and it will not be provided for coverage purposes and there appears to be no need for national coverage conditions. Conditions incentivising use such as “use it or lease it” were raised. The research suggested that Member States where regions are responsible for control of aspects of spectrum authorisation are more likely to award spectrum on a local or regional basis.
- SMAs that had considered the matter believe that a service specific authorisation approach would be problematic. Such an approach would not be consistent with the

principle of service neutrality. There were also concerns about specifying the parameters of such an approach for industry verticals (e.g. what verticals, who would do it, fees?) and the harmonisation required to enable it. In general, there is a preference among SMAs for a minimum level of harmonisation in this area. Were a service authorisation approach to be used, there appears to be a preference for this to be done through GAs rather than specific licenses. For other reasons set out above, this may not be appropriate in the 26 GHz band (at least to start with given the limited amount of spectrum likely to be available). Before approaching the concept of service specific authorisation there is a need to define services that are likely to fall within the remit of such an approach (to avoid it either being too generic or there being too many service categories) and to be clear about what aspects of the service require harmonisation of authorisation. For example, services that operate across borders (such as rail and automotive) and therefore require consistency of terms and quality of service to provide end-to-end service between Member States.

- A range of opinions were expressed on award mechanisms in bands where IA could be used (e.g. 26 GHz and possibly 42 GHz). In some cases, SMAs are advocating an auction approach (i.e. stick to the known formula). This was the case in the recent 5G auction in Italy. In others, the idea of FCFS, or other flexible approaches were raised. However, there appear to be few firm plans on approaches to award at present excepting Germany, which has proposed regional and local authorisation.
- Some SMAs thought that the nature of awards, and particularly auction prices or fees should be handled in a way to encourage investment. This view is based on a perception that key to deployment of 5G infrastructure is being able to establish a viable business case for investors, especially in the case of a progressive evolution of 5G services. mm-wave spectrum is likely to have a much lower value than sub 6 GHz spectrum (in general evidence suggests that the value of spectrum declines as frequency increases).
- On technical harmonisation, in general, there is a desire for a minimum level of harmonisation (e.g. that the European Commission should set timelines and technical rules in line with CEPT but refrain from setting additional rules, for example, on authorisation).
- ComReg consulted on the 26 GHz band and has auctioned the spectrum in the frequency range 24.745-25.277 GHz paired with 25.753-26.285 GHz for renewal of expiring fixed link licenses. The consultation for the award contained a provision that the spectrum could be designated technology neutral, should the need arise in future. However, we understand that spectrum in the range 26.5-27.5 GHz is available for use in Ireland[87]. ComReg indicated that it may consider a GA regime for this frequency range.

Views from other industry players

Views on authorisation from other research respondents (e.g. equipment vendors and mobile network / satellite operators) include:

- The timing of spectrum awards should be carefully considered. It needs to fit with availability of the mm-wave ecosystem.
- Provision of protection to other services within 5G mm-wave bands and in adjacent bands is a paramount consideration. For this reason, the use of GA is not seen as a viable approach by these stakeholders except for the 66-71 GHz band (although even here some players had reservations). Satellite operators, in particular, were concerned about the potential harmful impact of the use of a GA approach in the 26 GHz band.
- Mobile operators and equipment vendors were in favour of the use of dedicated national licensing for mm-wave spectrum (except for 66-71 GHz). They consider this necessary to achieve the required technical quality of service for mobile networks and to manage

[87] See ComReg document 18/31. Section 2.2. 1207 MHz of contiguous spectrum is available in the upper part of the 26 GHz band and another 345 MHz of contiguous spectrum is available in the lower part of the 26 GHz band and this should more than satisfy any requirement to make 1 GHz of the entire 26 GHz band available for 5G by 2020.

interference requirements of other services. They also believe that spectrum should be made available and awarded in a reasonably quick time to provide certainty for development of the 5G mobile ecosystem and to provide investment stimulation / certainty. In this respect there is also a suggestion that the mm-wave bands should be considered hand in hand with spectrum in the 3.4-3.8 GHz range as both form part of the 5G ecosystem.

- In general, there was resistance from network operators to the concept of regional / local licensing and of specific licensing for industry verticals. For the latter, mobile operators prefer to consider leasing spectrum to others if such access is required. However, use of this approach would require improvements to leasing processes, particularly if many requests of this nature are to be handled.
- Authorisation should be done in a way that encourages investment, particularly in mm-wave bands. It should also consider the need for cross border consistency, particularly for services provided to the automotive / transport and other sectors that provide cross border services.

As described above, questions were raised around the amount of spectrum for viable provision of services (with a range of 400 MHz to 1 GHz per operator being mentioned). The availability of spectrum in mm-wave bands, especially early on with 5G deployment may not be able to support such large authorisations. Equipment vendors believe that the authorisation of less spectrum to mobile operators may lead to a sub-optimal service outcome. For example, the upper 1 GHz of the 26 GHz band may only be able to fully support 2 network operators if the Qualcomm bandwidth figure is used and one if the Huawei assumption is used.

This raises two questions:

- How much spectrum is realistically required per operator?
- If it is not possible to support say 3 or 4 operators (i.e. the current mobile players in any country), what happens?

Answering the first question requires further technical research. The second question implies that some form of wholesale or network sharing arrangement may be required for all operators to gain access to mm-wave spectrum. This could be achieved through spectrum sharing arrangements (e.g. wholesale of access from the operator(s) that are assigned the spectrum – for example on a MVNO basis) or through a third-party neutral host arrangement.

There was a feeling among the MNOs approached that a neutral third-party network may not be the best solution, but this option has yet to be studied in detail[88]. One network operator interviewed raised the idea of considering solutions adopted in other industries (e.g. where banks share each other's cash machine networks). This is a form of "sharing" that requires further study to establish whether it is applicable to the concepts being discussed for 5G.

Activity outside the European Union

Hong Kong

In Hong Kong, the Government recently announced proposals for the award of spectrum in several 5G bands, including the 26 GHz band.[89] For the 26 GHz band it is proposed that spectrum will be made available on a FCFS basis at no fee if demand for the spectrum does not exceed 75% of the spectrum available in the band. 100 MHz blocks are proposed. The Communications Authority is planning to make the spectrum available in 2019.

[88] Concerns arise from the access rules that may apply with such a network, whether these are commercially defined or operated within regulatory controls, how demand management would operate and the ability to innovate at the transport level.

[89] Proposed Allocation of the 26 GHz and 28 GHz Bands to Mobile Service and the Associated Arrangements for Spectrum Assignment and Spectrum Utilisation Fee. Consultation Paper. 26 July 2018. https://www.coms-auth.hk/filemanager/en/content_711/cp20180726_e.pdf

Australia

The ACMA (Australian Regulator) has recently consulted on "Options for wireless broadband in the 26 GHz band". The consultation as well as posing questions on emission limits and appropriate lower and upper boundaries, also considers possible licensing options. The ACMA notes that "While 5G technologies are beginning to take shape, potential business models are not yet so clear" – in particular how closely they will align with the traditional MNO model.

For licensing, the ACMA noted that currently there are 3 different licence types that might be used for the 26 GHz band, namely spectrum, apparatus and class licensing. Also, there is the possibility of using two or more licence types and different licence types could apply in either different frequencies and / or geographic areas or be used in the same frequencies / geographic areas based on specifying licence sharing conditions. The approach hinges on what is the expected proliferation of / demand for services deployed under apparatus and / or class licensing. The options for licensing need to strike the right balance to enable and encourage the 26 GHz band to move to its highest value use.

United States

The United States (US) is auctioning spectrum in the 24 GHz, 26 GHz and 28 GHz bands over the 2018/19 timeframe. The aim is to make available to the market spectrum that can be used for fixed or mobile applications.

FCC Auction 101[90] covers the frequency range 27.5-28.35 GHz, which is being awarded on a local basis in 2 blocks of 425 MHz. There will be 1,536 licenses available on a county basis for each block.

FCC Auction 102[91] covers the frequency ranges 24.25-24.45 GHz and 24.75-25.25 GHz in 7 blocks of 100 MHz. The licenses will be local, and 2,909 licences are available for award.

Auctions 101 and 102 are in process at the time of writing.

4.5. Conclusion: authorisation

26 GHz

Authorisation proposals are being developed by Member States for consultation (mainly for the 26 GHz band) but overall, this activity has not yet reached a developed state (although in the case of one Member State, Italy, a 5G spectrum award including 1 GHz of 26 GHz spectrum has recently taken place). The following text primarily addresses the 26 GHz band.

It is expected that development of proposals for the 26 GHz band will progress over the next 12 months and a range of outcomes appear possible (e.g. IA under conditions where there is scarcity and a requirement for protection of incumbents, and potentially GA or a light licensing approach in other circumstances, for example indoor deployments, where there is no scarcity envisaged or for industry verticals).

There are legitimate reasons why Member States would take different approaches based on their respective demographic and economic positions, together with assessment of demand and the situation relating to the presence and protection of incumbent services. However, there is a risk of a fragmented approach to authorisation occurring across Member States, which could create tensions for investment incentives and business models. This suggests a need for consistency and coordination between Member States on authorisation of spectrum and awards to avoid significant divergence. For example, with the application of coexistence conditions to protect the EESS and, approaches to handling of scarcity.

[90] https://www.fcc.gov/auction/101.

[91] https://www.fcc.gov/auction/102.

The 26 GHz band presents authorisation challenges. A working assumption is that the frequency range 26.5-27.5 GHz will be made available when demand requires with as few restrictions to being able to access the spectrum in a timely manner as possible, to comply with Article 54 of the Code. However, protection required for the EESS (passive) below 24 GHz, could result in stringent technical conditions in the bottom 1.25 GHz of the band, which may render 5G inoperable there (at least in the outdoor environment) if equipment meeting the required protection criteria is not available. If there are other services requiring protection below 26.5 GHz (e.g. fixed point to point and point to multipoint, satellite earth stations), this too could result in coordination requirements for 5G services, including exclusion areas at specific locations, if incumbent services are not migrated.

The above, taken together with the likely evolution path of 5G equipment (i.e. covering the frequency range 26.5-29.5 GHz in the first instance followed later by equipment with a wider tuning range across the 26 GHz band) points to the progressive utilisation of the 26 GHz band by 5G and potentially different technical conditions (for coexistence) applying in specific frequency ranges at various locations. This could include authorisation differences between indoor and outdoor use. These conditions may evolve over time as the use environment in the band changes. Such a scenario requires flexibility on the part of SMAs and industry players when considering what authorisation options to apply and specifically the conditions for IA.

Given the expected nature of mm-wave services and their provision to support high capacity, it is necessary to ensure that authorisations are sufficiently large to support this aim (there were differing views on what is an optimum amount of spectrum for an operator). For the 26 GHz band, ECC has recommended the use of 100 MHz blocks, although vendors and operators have suggested that for realistic service deployment contiguous bandwidths of 400 MHz to 1 GHz may be required. This may result in a situation where in a 3 or 4 mobile operator market there is potential for scarcity in a given band. The effects of this on infrastructure provision and sharing requires further study by SMAs/NRAs.

As noted in a study report for BEREC[92], there may also be restrictions with the physical deployment of infrastructure required for 5G, which may lead to infrastructure sharing scenarios or perhaps provision of services through a neutral host. There was resistance to the idea of neutral host or 3rd party wholesale networks from MNOs, but it is worthy of study by SMAs/NRAs to create a working definition, establish the rules and how spectrum could be deployed in this scenario, if it provides a means of allowing efficient access.

Given the current state of play for 26 GHz and its likely evolution, an IA authorisation scheme, possibly operated with a light licensing component may be required if just the top 1 GHz of the 26 GHz band is available for 5G services. This would enable QoS to be managed and appropriate protection would be afforded to incumbent services. However, this regime should not be viewed as static and account should be taken of the likelihood of 2 GHz rather than just 1 GHz being available as the network and device equipment ecosystem develops. A flexible authorisation system (for IA / light licensing) could be supported by an advanced database approach such as LSA evolved for 5G.

Consideration should also be given to the operation of 26 GHz 5G services in locations where the risk of interference with other services is reduced (e.g. indoors), where services could potentially be operated either under a light licensed or GA regime.

When considering the authorisation regime for mm-wave spectrum consideration should also be given to enabling mechanisms for smaller local / regional operators, industry verticals and other private operators to obtain spectrum in a way that enables the business case for their ecosystem (e.g. as proposed in Germany). This could either be through a FCFS or light licensing approach to authorisation that enables a wider range of applicants

[92] Study on implications of 5G deployment on future business models. Dot-econ and Axon study for BEREC, 2017/02/NP3, March 2018.

to apply for access to spectrum (especially if fees are low). It could also potentially be enabled via a "spectrum as a service" concept[93].

Other mm-wave bands

For other mm-wave bands, most SMAs have yet to release detailed proposal for authorisation. However, the general principles set out in this chapter for 26 GHz could be applied depending on analysis of the use environment to establish the applicability of GA, light licensed or IA approaches. This is an area for further work by SMAs and other bodies. Based on the research, a consensus appears to be emerging on the use of a GA model for the 66-71 GHz band.

[93] Models could develop for spectrum as a service that provide network operators (traditional MNOs and new entrants) with means to access spectrum. In such a model spectrum would be obtained (GA or IA) by a wholesaler, who would then provide spectrum on a locally traded or more likely leased basis to those seeking access to spectrum.

5. Assessment of the prospects for the development of hybrid scenarios or systems

5.1. Introduction

In this chapter the prospects for the development of hybrid scenarios or systems in the European 5G context are considered, together and their impact on efficient spectrum use.

5.2. Summary of findings

Below is a summary of the findings on allocation and authorisation.

- That developments on satellite hybrid solutions are taking place (with a global emphasis as well as Europe).[94] However, there seems to be a lack of awareness among many of what is happening (albeit at an early stage) and these developments are behind terrestrial ecosystem developments.
- Further analysis is required of the potential satellite use cases that hybrid solutions potentially enable in the European context, given the high penetration of terrestrial solutions.
- No interest was expressed by any of the stakeholders approached in broadcast/ terrestrial 5G convergence.

5.3. Hybrid scenarios

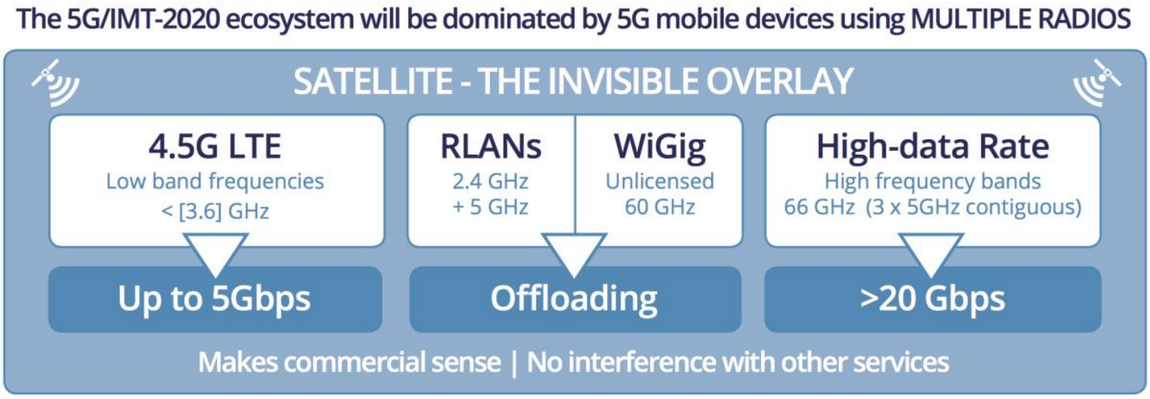
There are several possibilities for hybrid scenarios. A hybrid system is the combination of different technology or service approaches into a single cohesive ecosystem. For example, terrestrial 5G and satellite or terrestrial 5G and (satellite?) broadcasting. A draft ECC report[95] has been developed for satellite solutions and it identifies four primary use cases:

- Communications on the Move.
- Hybrid Multiplay.
- Trunking and Head-end Feed.
- Backhauling and Tower Feed.

ESOA has proposed that satellite would form 'the invisible overlay' for 5G services as shown below. The overlay will provide an additional / alternative transmission medium for backhaul and trunking and, in the case where there is limited or no terrestrial mobile service, access to high speed data services. This could be of considerable value where the logistical and cost implications of providing a fully terrestrial network are difficult to justify. An overlay could also provide a valuable emergency capability for backhaul in the event of natural disaster or other events disrupting elements of the terrestrial network.

[94] For example, the Sat5G project, which is addressing 6 pillars of work including SDN/NFV for satellites, network management and network orchestration, multilink and heterogeneous transport, harmonisation of satcom and the 5G user plane. Also, Satis5 – a demonstrator for satellite – terrestrial integration in the 5G context.

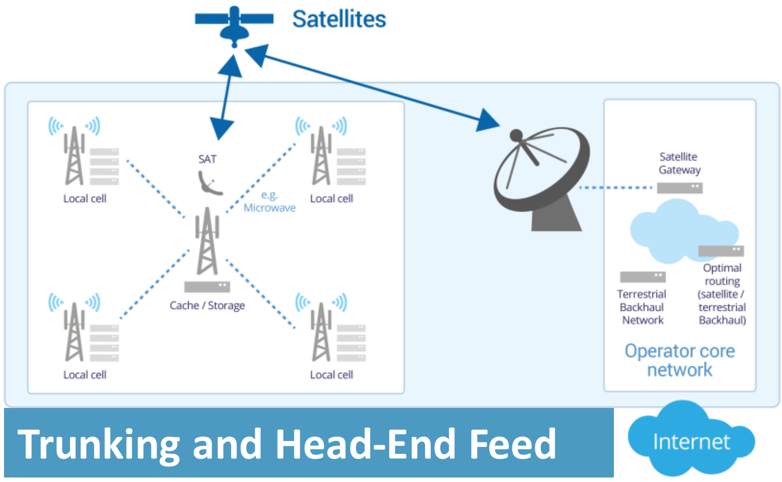
[95] ECC Report 280

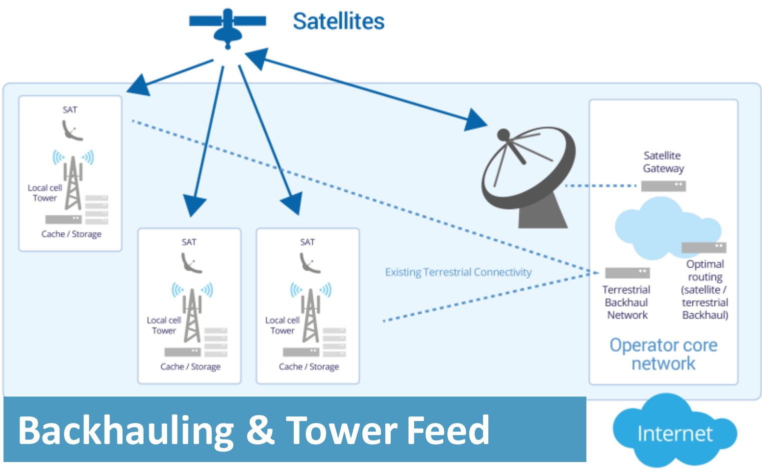


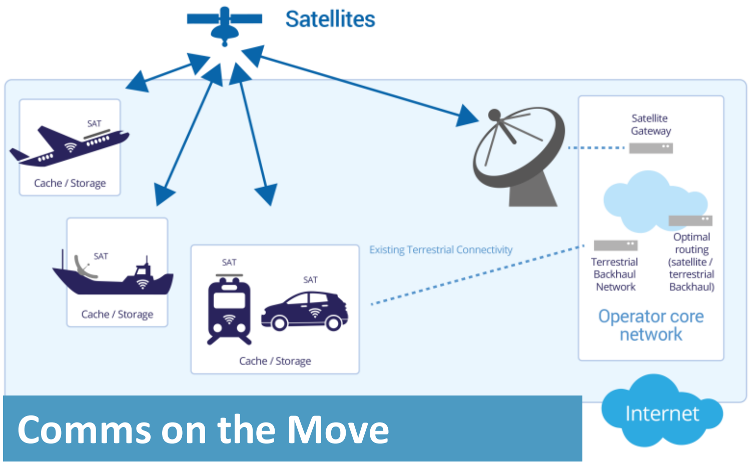
5.4. Summary of research findings

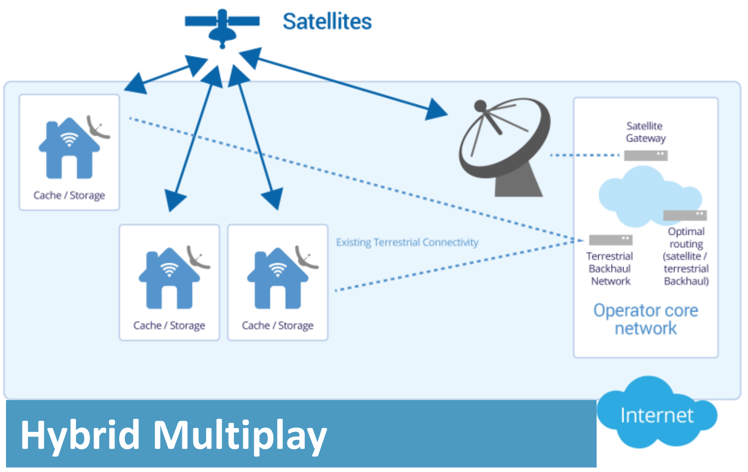
The research undertaken for the study has identified the following in respect of hybrid scenarios.

Interviews with the satellite industry highlighted a number of potential application use cases. These are illustrated below (source ESOA).









The above cases leverage the capabilities of ubiquitous coverage and the ability to leverage the increasingly high bandwidth that will become available from satellite services. This could provide an alternative means to access 5G services in remote rural areas subject to transponders being available and an appropriate cost point for delivery of the service.

- Many SMAs were of the view there is little or no activity in this area. While seeing that there may be possible opportunities, there was scepticism how they could really apply in the European context with many questioning the need for these solutions given the geographic enhancement of terrestrial mobile coverage taking place in Europe. The satellite players, on the other hand, made the case for consideration of these concepts, indicating that they will mature over the next 5 years or so.
- The key areas where satellite services could be applied appear to be backhauling in rural areas, massive IoT, PPDR, automotive and other verticals with disparate distributions of end user terminals. However, the development of these capabilities is seen to be some way behind terrestrial 5G solutions.
- 3GPP will integrate a satellite segment into the 5G infrastructure (in Release 16). There were differing views on whether there would be any 5G satellite capable terminals in the near term, with most believing this will not occur.
- Use cases cited for 5G include content delivery to network edge, public aeronautical telecommunications services.
- The key limitation noted is the data capacity that could be supported by satellite solutions. Satellite players highlighted that more capacity is being planned through future launches.

- There was some questioning by SMAs of whether this is a policy matter of whether it should be left to the market to develop.

6. Implications of exposure to electromagnetic fields (EMF)

6.1. Introduction

As regards wireless services in general and mobile services in particular, there have been long-standing public concerns over possible health effects due to exposure to electromagnetic fields (EMF). These concerns have led to the definition of general advisory limits on permissible EMF levels throughout the EU, as we explain in greater detail in Section 6.4.

The constraints on the deployment of terminals and other equipment that may be needed at 'traditional' versus millimetre-wave frequencies can be quite different, due to differences in absorption of radiation by the human body, differences in the boundary of the far-field radiation region, and the expected forms of antennas for mm-wave terminals (see the discussion of the *Specific Absorption Rate* (*SAR*) in Section 6.4).

The shift to 5G implies the need for some re-thinking of EMF limits. The expectation is that 5G will operate not only in current lower bands such as 700 MHz, but also in bands such as the 3.6 GHz band and also in much higher bands such as the 26 GHz. Transmitters in these bands will necessarily be much closer to the public in light of the much shorter propagation distance of higher frequency waves (which implies advantages in terms of frequency re-use and capacity, but also disadvantages in terms of the cost of coverage). In dense centre city areas, large numbers of cells smaller than those in use today are to be expected. At the same time, the small cells will necessarily operate at much lower power levels than those of the macro-cells of today, and at higher frequencies. The use of higher frequencies itself implies health effects that are different from those of waves in current cellular bands (see Section 6.5).

The combined effects of closer proximity, lower power, increased efficiency (bits/second/Hz), and the different health effects of higher frequency waves have not been studied in terms of their implications for public policy. Our task here is to shed light on these issues.

6.2. Summary of findings

- As regards wireless services in general and mobile services in particular, there have been long-standing public concerns over possible health effects due to exposure to the electromagnetic fields (EMF).
- Various global and regional bodies have studied EMF effects, including the World Health Organisation.
  - A quite huge literature exists on the analysis of overall health effects of EMF associated with mobile services. A number of rigorous studies have been conducted, including epidemiological cohort and incidence time trend studies and animal studies. In this chapter, we review a number of the most recent and most highly respected results (see especially Section 6.5.1).
  - There are diverging views on the interpretation of the results of this research.
  - Existing literature seems to indicate that current scientific evidence has not conclusively demonstrated that wireless and mobile communications cause harmful health effects in humans when operated within established limits; however, risks cannot be excluded.
  - Health effects associated with mm-waves are distinct from those in the traditional mobile bands because mm-waves have little ability to penetrate the skin. Even though mm-waves have not been used for mobile services, there is a body of research on potential health effects due to the use of mm-waves in Eastern Europe

for medical purposes; however, very little reliable and reproducible data is available. Among these, the most reliable research results are associated with pain relief (analgesia). (Le Dréan et al. (2013))

- Other than heating effects (which are not significant at the power levels to be expected for 5G), no harmful mm-wave health effects have been demonstrated in humans to date. (Le Dréan et al. (2013)) Many assume that health effects would be limited to the skin and eyes, due to the limited penetration; however, the use in Eastern Europe of mm-waves for pain relief raises the possibility that there might also be effects that are transmitted in other ways. (Le Dréan et al. (2013))

- In Europe, EMF guidelines for non-ionising[96] EMF are primarily based on the guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The current ICNIRP guidelines are reflected in a 1999 Council Recommendation[97] on the permissible level of emissions for equipment to be deployed. Article 58 of the newly enacted European Electronic Communications Code (EECC) effectively requires Member States to notify the Commission of draft measures where the Member State intends to deviate from the Council Recommendation, and empowers the Commission or other Member States to propose amendments to the draft measure in order to remove or reduce barriers this might create to the free movement of goods.
- Some Member States, and some regions or municipalities within Member States, impose EMF limits one or even two orders of magnitude more restrictive than the Council Recommendation of 1999. At these levels, 5G deployment would likely be seriously impeded.
- The move to 5G will be accompanied by a move to large numbers of small cells, some of them operating in the mm-wave bands. Exposure of the population to EMF is less than linear in the number of base stations; nonetheless, the shift is sure to change exposure. Transmit power in the mm-wave bands will be much lower than is typical in the macro cellular network today, but the presence of large numbers of base stations in conjunction with beam-forming means that exposure at any given instant in time could vary greatly depending on where an individual is relative to the base stations, and which locations they are sending to at that moment.
- Our modelling results suggest that any increase in exposure of the population to EMF caused by the shift to 5G and small cells is likely to cause only a very modest increase in exposure of the population to EMF. This is broadly in line with measurements conducted in a measurement study relating to the deployment of small cells in the town of Annecy by the French ANFR,[98] which found an increase in EMF associated with the move to small cells of only 0.1 V/m (to a maximum of 0.5% of the ICNIRP limit). The ANFR study represents only a single small city under a 4G small cell deployment scenario that may or may not prove to be fully representative of 5G deployments, but it nonetheless represents an important datum to the extent that it embodies experience in a real world setting.
- The characteristics of 5G raise new issues for the measurement of EMF. Simply measuring the power delivered to the antenna is of limited value in a setting where beam-forming plays a key role; moreover, 3GPP specifications for base stations operating above 24 GHz assume that no antenna connectors will be available and that power must therefore be defined in terms of Over-the-Air (OTA) performance (see Section 6.8). Measurement is therefore possible only where a user terminal is present. Standards bodies including 3GPP are currently studying these issues. The recommendations that we make in this report reflect the contingency that the standards

[96] Non-ionizing radiation is the term given to radiation in the part of the electromagnetic spectrum where there is insufficient energy to cause ionization. It includes electric and magnetic fields, radio waves, microwaves, infrared, ultraviolet, and visible radiation (see https://www.who.int/topics/radiation_non_ionizing/en/).

[97] European Council (1999), Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz), (1999/519/EC).

[98] See https://www.anfr.fr/fileadmin/mediatheque/documents/Actualites/2017-04-26 - Rapport résultats Annecy.pdf.

bodies might not settle on a solution to this problem as quickly as Europe needs or desires it.

- In order to ensure that EMF limits are respected it is likely that national authorities will find it necessary to place greater reliance on field tests than in the past. Exchange of best practice among national authorities will probably be needed (as suggested by COCOM),[99] possibly accompanied by action on the part of the Commission.

6.3. Approach taken in this study

As we explain in Section 6.4, deployment of new 5G services might be delayed by unnecessarily stringent EMF limits. At the same time, there are public concerns over potential health effects that are not fully understood and therefore particular precautions may be needed to a certain extent.[100]

As is generally the case, there is a risk of Type 1 error and of Type 2 error. In general terms, this means that there is the risk that a true null hypothesis is incorrectly rejected, and the risk that a false null hypothesis is retained (see Figure 33). In the context of this study,

- Type 1: There is a risk that the increase in spectrum band use and EMF associated with 5G could be *overestimated* and wrongly assumed to be severe, leading to overly stringent EMF l limits that would tend to impede 5G deployment. This would increase the deployment time of 5G services and delay associated consumer benefits.
- Type 2: There is a risk that the increase in spectrum band use and EMF associated with 5G could be underestimated and that the exposure to EMF could be incorrectly assumed to be low. This would tend to lead to the promotion of widespread deployment, with the attendant risk that the consequent increase in EMF exposure levels could prove to be problematic.

Figure 32: Possible Type 1 and Type 2 errors in the assessment of EMF risk.

	EMF risk believed to be low	EMF risk believed to be high
EMF risk is truly low		Type 1 error
EMF risk is truly high	Type 2 error	

Source: Marcus

As with any risk assessment, risks need to be understood in terms of (1) the *probability* that the problematic event is in fact experienced; (2) the *harm* that the problematic event occurs; and (3) the cost of *remediation*. Given the huge uncertainties in this case, each of these must be seen not as a neat single number, but rather as a probability distribution.

[99] COCOM Working Group on 5G (2018), "Report on the exchange of Best Practices concerning national broadband strategies and 5G "path-to-deployment", COCOM18-06REV-2.

[100] Rainer Nyberg and Lennart Hardell on behalf of 180 oncologists (2017), "Scientists warn of potential serious health effects of 5G".

In line with the precautionary approach defined by the Commission in its Communication 2000/1[101], the risks of EMF have already been subject to evaluation and, based on scientific evidence, appropriate measures have been taken to manage the risk.

As a result, EU regulation is to ensure consistency and predictability throughout the Union regarding the way the use of radio spectrum is authorised in protecting public health against harmful electromagnetic fields (0 Hz- 300 GHz), which led to the precautionary approach taken in Directive 2013/35/EU and in Council Recommendation No 1999/519/EC. As stressed by the 1999 Council Recommendation, 'actions on limiting the exposure of the general public to electromagnetic fields should be balanced with the other health, safety and security benefits that devices emitting electromagnetic fields bring to the quality of life, in such areas as telecommunications, energy and public security'. This balance is essential in any policy development.

Some proposals that have been made are likely to imply far greater cost than others. For instance, one prominent appeal urges the EU "*to take all reasonable measures to halt the 5G RF-EMF expansion until independent scientists can assure that 5G and the total radiation levels []*", and also "*to favor and implement wired digital telecommunication instead of wireless*".[102] Depending on how it is implemented, the second (an overall shift away from wireless services) might have far greater consequences than the first, and thus would appear to imply a greater need for certainty, a greater burden of proof (although both potentially have large consequences).

Conversely, other proposals might imply lesser cost, and thus presumably face a lower burden of proof. For instance, many of us choose to avoid keeping the smart phone close to our head for more than a few seconds.

We cannot hope to provide a neat solution to all of this in this study, but we can provide policymakers with a sound and objective factual and quantitative basis for taking decisions, and perhaps with thought models that are helpful in assessing any risks. *The ultimate decisions will presumably need to be taken by policymakers at the political level.* With that said, we provide initial recommendations for policymakers in section 7.6.

We have not attempted to assess health effects in any detail. The authors of this study are experts in wireless services and spectrum management policy, not health sciences professionals. We are limiting ourselves to providing a brief assessment of the state of knowledge based on a review of a few items of key literature, and critical review based on the application of general scientific principles.

Where we *can* add value is with critical analysis overall, and with a quantification of likely EMF exposure levels under various 5G deployment scenarios, taking into account geographical distributions and various 5G use cases. This requires that we make a number of assumptions, including for instance about broadcast power levels.

A first consideration is the degree to which 5G traffic is likely to differ from current traffic. It is important to bear in mind that *not all 5G traffic is new traffic and not all 5G traffic occupies new frequency bands*. Much of the traffic that 5G networks carry would replace in the longer term traffic carried by existing 2G/3G/4G networks by reusing (re-farming) the same spectrum. It is likely that 5G services (and successors) will replace existing 2G/3G/4G services only after a long period of coexistence. Some estimates suggest that the global tendency is for 3G traffic to continue to increase for some time, as depicted in Figure 33. If 5G is carrying more traffic than current networks, it will presumably be either because (1) current networks would have been unable to carry so much traffic, or (2) 5G networks enable new applications that would not have been possible with current networks.

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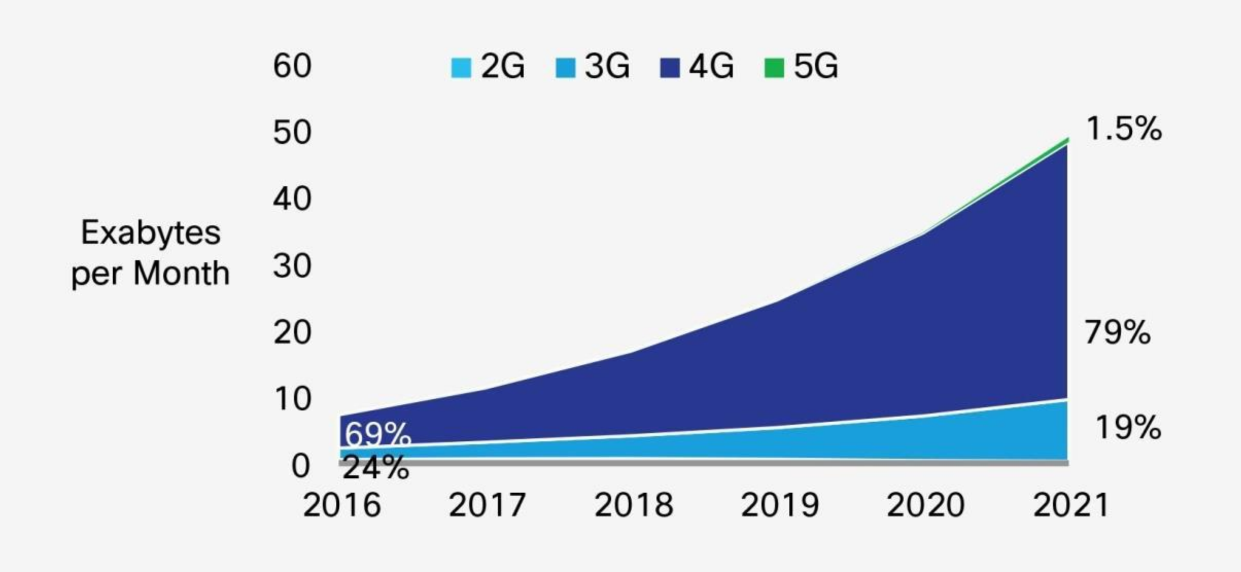
[101] "The precautionary principle, which is essentially used by decision-makers in the management of risk, should not be confused with the element of caution that scientists apply in their assessment of scientific data. Recourse to the precautionary principle presupposes that potentially dangerous effects deriving from a phenomenon, product or process have been identified, and that scientific evaluation does not allow the risk to be determined with sufficient certainty."

[102] Rainer Nyberg and Lennart Hardell on behalf of 180 oncologists (2017), "Scientists warn of potential serious health effects of 5G".

Both of these are relevant to the current study, because mm-waves are likely to be important for both.

Figure 33: Project global mobile traffic by connection type.



Source: Cisco (2017), "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2016–2021".

Increased traffic does not necessarily imply a corresponding increase in EMF exposure. Technological improvements (e.g. in the number of bits that can be encoded per Hz) are one of several factors that can offset this tendency. As regards exposure to EMF for mobile services, the *Scientific Committee on Emerging and Newly Identified Health Risks* (or *SCENIHR*, an independent advisory panel to the Commission) has observed that net exposure did not increase substantially in previous migrations from one generation to the next: *"The environmental exposure from sources is dominated by broadcasting antennas, antennas from private and governmental telecommunication services and mobile communications base stations. Historical data from spot measurement campaigns and continuous radiation monitoring systems indicate that the introduction of new mobile telecommunication technologies after the deployment of the GSM and UMTS systems did not substantially change the average levels of EMF in the environment. At the same time, other technologies, like digital broadcasting, have in some regions contributed to the reduction of EMF exposure from far field sources*." As regards indoor exposure, they noted an increased number of sources and increased proximity to the human body, but concluded that "*the emitted EMF from these devices, even when combined, still results in a marginal exposure compared to reference levels of European and international guidelines*."[103]

6.4. Background on EMF limits in Europe today

Various global and regional bodies have studied EMF effects, including the World Health Organisation (see Section 6.5).

In Europe, EMF limit guidelines for non-ionising EMF are primarily based on the guidelines of the *International Commission on Non-Ionizing Radiation Protection* (*ICNIRP*).[104] For existing cellular bands, these limits are specified in terms of *Specific Absorption Rate* (*SAR*), which measures the power absorbed in a mass of tissue. ICNIRP limits at higher

[103] Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) (2015), "Opinion on Potential health effects of exposure to electromagnetic fields (EMF)", pages 4-5.

[104] International Commission on Non-Ionizing Radiation Protection (ICNIRP) (2009), "Statement on the "Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)".

frequencies are specified in terms of power flux density because radio energy at millimetre wave does not penetrate far beyond the surface (see Section 6.5.3).

EMF concerns have appeared in numerous policy documents at European level, but the normative effect of these instruments is limited in practice. For equipment to be deployed, a Council Recommendation on the permissible level of emissions has been in place at European level since 1999.[105] The Council Recommendation sets forth a general framework in the context of minimal harmonisation.[106] Article 58 of the new European Electronic Communications Code (EECC) creates a new mechanism whereby the Commission (and other Member States) can attempt to intervene if a Member State seeks to impose a draft measure that diverges from the Council Recommendation.

6.4.1. Current ICNIRP limits

The 'International Commission on Non-Ionizing Radiation Protection' (ICNIRP) was founded in 1992 by the 'International Radiation Protection Association' (IRPA), which represents national radiation protection societies.

ICNIRP is an independent organisation, funded by subsidies from national and international public bodies. The 13 members are typically senior academics or employed in public research institutes. Members do not represent their country or institution and may not "*hold a position of employment or have other interests that compromise their scientific independence*".

ICNIRP publish guidance relating to exposure to static electrical and magnetic fields, and to electromagnetic radiation at frequencies up to the infrared. Of present concern is the range classified as 'High Frequency' (HF) by ICNIRP, and covering 100 kHz – 300 GHz.

The key document is the "ICNIRP Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)" published in 1998. Ten years later, ICNIRP carried out a review of new scientific evidence, with the results published 2009 as a report[107] and as a brief 'Statement'[108] in which ICNIRP reconfirmed the 1998 'Guidelines' until further notice.

In July 2018, ICNIRP published new draft Guidelines for public consultation. The consultation closed on 9 October 2018. No publication date has yet been set for the publication of the final version of the new Guidelines.

The guidelines[109] identify thresholds for exposure, based on known health effects (essentially relating to temperature increase). 'Basic Restrictions' (Table 26 and Table 27) are derived from these, relating to 'occupational' and 'general public' exposure cases. These basic restrictions are then used to set 'Reference Levels' (Table 27) which are specified in terms intended to be straightforward to measure or predict (i.e. as electric field strengths). It is assumed that in the case of occupational exposure, workers will be able to minimise risk in an informed manner, so the limits can be set higher than for the 'General Public' case, where individuals may be unaware of exposure.

[105] See the Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz). Directive 2014/53/EU of the European Parliament and of the Council of 16 April 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment and repealing Directive 1999/5/EC is also relevant.

[106] See Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz), recital 15: "Member States may, in accordance with the Treaty, provide for a higher level of protection than that set out in this recommendation."

[107] Exposure to high frequency electromagnetic fields, biological effects and health consequences (100 kHz-300 GHz) - Review of the Scientific Evidence and Health Consequences. Munich: International Commission on Non-Ionizing Radiation Protection; 2009.

[108] ICNIRP statement on the "Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)", Health Phys 97(3):257-258, 2009

[109] "ICNIRP guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz)", Health Physics 74(4), pp494-522, 1998. Available at https://www.icnirp.org/cms/upload/publications/ICNIRPemfgdl.pdf

The rate at which the energy of a radio frequency (RF) electromagnetic field is absorbed by the human body is measured by the *specific absorption rate* (*SAR*). Below 10 GHz (i.e. in Table 26), the basic restrictions on SAR are intended to prevent whole-body heat stress and excessive localised tissue heating. Above 10 GHz (Table 27), the basic restrictions on power density are intended to prevent heating of tissue at or near the body surface. As we explain in Section 6.4.2, it is expected that the boundary will move downward from 10 GHz to 6 GHz in the next version of the ICNIRP Guidelines.

The objective of the ICNIRP is to minimise exposure of the body; however, it is impractical to measure this in practice. For this reason, practical measurements are generally done using power density expressed in Volts per metre (V/m), or field strength expressed in Watts per square metre (W/m^2) – if these levels are fulfilled, requirements in terms of SAR are deemed to have been met. Current ICNIRP guidelines in terms of SAR appear in Table 26, while corresponding reference levels for power density and field strength appear in Table 27.

Table 26: Current ICNIRP basic restrictions (general public)

		SAR$_L$ (W/kg)		Power density, S_L (W/m^2)
Frequency (f)	Whole body SAR	Head & trunk	Limbs	
10 MHz-10 GHz	0.08	2	4	
10 – 300 GHz				10

NB: the SAR values are to be averaged over 6 minutes.

Table 27: Current ICNIRP reference levels (general public).

Frequency (f)	Electric field (V/m)	Power density (W/m^2)	Averaging	Peak
400-2000 MHz	1.375 f$^{0.5}$	f/200	Averaged over 6-minutes	1000 x power density or 31 x field strength
2-10 GHz	61	10	Averaged over 6 minutes	
10 – 300 GHz	61	10		

Regarding the aggregate exposure to multiple fields, the SAR and densities should be assumed to be additive, thus:

$$\sum_{i=100\text{ kHz}}^{10\text{ GHz}} \frac{SAR_i}{SAR_L} + \sum_{i>10\text{ GHz}}^{300\text{ GHz}} \frac{S_i}{S_L} \leq 1$$

6.4.2. Draft new ICNIRP limits

As noted, the new ICNIRP Guidelines have been released in draft form, but have not yet been finalised. The information in this section corresponds to the published draft.

A significant change to the ICNIRP guidelines is that the limit below which exposure is defined in relation to absorption rate rather than power density is reduced from 10 GHz to 6 GHz. This change has no immediate impact on 5G deployments inasmuch as no currently proposed 5G bands lie in the range 6-10 GHz.

As with the current Guidelines, irrespective of this definition, practical measurements can be expected to generally be made using field strength or power density – if these are in bounds, SAR levels are presumed to be met.

Permissible SAR levels are as shown in Table 28.

Table 28: Draft new Basic Restrictions (general public) for exposure ≥6 minutes.

	SAR (W/kg)			Power density (W/m²)
Frequency (f)	**Whole body SAR**	**Head trunk**	**& Limbs**	
10 MHz-6 GHz	0.08	2	4	
6 – 300 GHz				20

NB: As before, the SAR values for head, trunk and limbs are to be averaged over 6 minutes, but those for the whole body are averaged over 30 minutes

A new *Basic Restriction* is being introduced to ensure that the cumulative energy permitted by the 6-minute-average limit is not absorbed by tissue too rapidly. This is specified as a 'Specific Energy Absorption' (SA) in Joules/kg (see Table 29).

Table 29: Draft new Basic Restrictions (general public) for exposure <6 minutes.

Frequency (f)	SAR (W/kg)	SA (J/kg)
400 MHz-6 GHz	$50 + 35.4\ (t-1)^{0.5}$	
6 – 300 GHz		$0.5 + 0.354\ (t-1)^{0.5}$

NB: t is the time interval in seconds. For t<1, t is set to 1.

Reference levels are now given for three cases: whole body exposure, local exposure (<6 minutes), and local exposure (> 6 minutes). These Public Exposure values appear in Table 30, Table 31 and Table 32, respectively.

Table 30: Draft new Reference levels (general public) Whole-body exposure.

Frequency (f)	Electric field (V/m)	Power density (W/m²)	Averaging
400-2000 MHz	$1.375\ f^{0.5}$	f/200	Averaged over 30 minutes
2-300 GHz		10	Averaged over 30 minutes

Table 31: Draft new Reference levels (general public) Local exposure (≥ 6 minutes).

Frequency (f)	Energy density (J/m²)	Averaging
400 MHz-6 GHz	$0.8f^{0.51}[0.5+0.354(t-1)^{0.5}]$	Averaged over 6 minutes
6-300 GHz	$55\ f^{0.177}$	Averaged over 6 minutes

Table 32: Draft new Reference levels (general public) Local exposure (< 6 minutes).

Frequency (f)	Energy density (J/m²)	Averaging
400 MHz-6 GHz	$0.8f^{0.51}[0.5+0.354(t-1)^{0.5}]$	Averaged over 6 minutes
6-300 GHz	$2.75f^{-0.177}[0.5+0.354(t-1)^{0.5}]$	Averaged over 6 minutes

For multiple fields, it is still assumed that power is additive (i.e. fields are additive)

6.4.3. Lack of harmonisation of EMF limits among the EU Member States

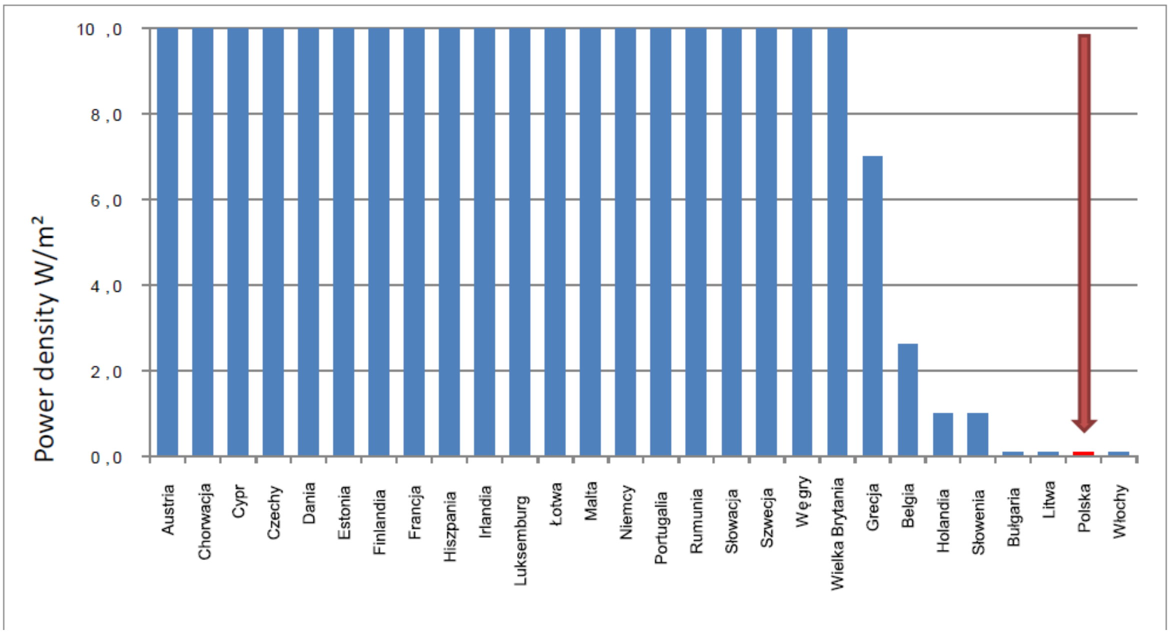
In previous work for the European Commission,[110] we raised the concern that a number of Member States including Italy and Belgium implement EMF maximum authorised exposure limits that are far more restrictive than those advocated at European level.[111] In this study, we find that similar concerns apply to additional Member States, including Latvia and

[110] See J. Scott Marcus, Ulrich Stumpf, Peter Kroon, Stefano Lucidi, Lorenz Nett, Veronica Bocarova, Philippe Defraigne, Peter Dunn, Christian Hocepied, Hervé Jacquemin, and Robert Queck (2017), "Substantive issues for review in the areas of market entry, management of scarce resources and general end-user issues", Final Report, study for the European Commission.

[111] See for instance http://www.elektrosmoginfo.de/ under "Grenzwerte". Some values are more stringent than those in Annex II of the Council Recommendation of 12 July 1999 (ibid.).

Poland. Indeed, it is the Polish Ministry of Digital Affairs that compiled the comparative figures on EMF limits in EU Member States that appear in Figure 34. Municipalities sometimes also play a role, for instance by imposing stricter EMF rules on locations that the municipality itself rents to network operators. The scientific basis for these tighter restrictions is often unclear. We speculate that there is a temptation for national and municipal authorities to adopt a particularly strict precautionary approach; whether doing so is societally optimal, however, is debatable for reasons noted in Section 6.3. The relative balance of risks and costs needs to be carefully weighed.

Figure 34: Permissible EMF levels in selected EU countries at frequencies above 2 GHz



Source: Aleksander Sołtysik, Polish Ministry of Digital Affairs (2017), "Agreement on 5G and acceptable Electromagnetic Field levels for cost-effective 5G implementation".[112]

These restrictions clearly have an impact on the deployment of mobile infrastructure. A study in France found that lowering EMF limits would significantly delay the deployment of LTE.[113] A 2013 study by the GSMA identified restrictive EMF limits in Belgium, Bulgaria, and Italy, as well as potentially time-consuming procedures in multiple Member States.[114]

These differences are particularly significant in the context of the expected high density of 5G access points. The concern that lack of harmonised rules for EMF might hamper the deployment of small cells was already noted in our 2012 study of mobile traffic off-load for the Commission.[115] The same concern is also noted in a recent ITU document,[116] and in a joint proposal of the GSMA and the Small Cell Forum that seeks to standardise conditions

[112] Presented at an RSPG workshop on 5G. They quote their data source as being the Commission Report on the application of Council Recommendation 1999/519/EC.

[113] In July 2013, for example, a report commissioned by the French Ministries of Ecology and of the Digital Economy showed that lowering exposure to EMF from mobile base stations (2G and 3G) to a maximum level of 0.6V/m would significantly reduce mobile network coverage, especially inside buildings. See GSMA (2014), "Arbitrary Radio Frequency exposure limits: Impact on 4G network deployment Case Studies Brussels, Italy, Li thuania, Paris and Poland".

[114] GSMA (2013), "Base station planning permission in Europe 2013", Figure 1, page 7, at http://www.gsma.com/gsmaeurope/gsma-europe-report-on-base-station-planning-permission-ineurope/, viewed 31 August 2016.

[115] Marcus J. S. and J. Burns (2013),"Impact of traffic off-loading and related technological trends on the demand for wireless broadband spectrum", study for the European Commission, page 128.

[116] ITU-T (2018), "The impact of RF-EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and 5G mobile network deployment", Series K Supplement 14 (05/2018).

for deployment such as the exclusion zone and the minimum height above the walkway at which equipment must be placed (see Section 6.6.3).[117]

All of this implies that there may be work to be done in terms of European policy. The recommendations that we provide in this report seek to specifically address these concerns by ensuring that suitable standards emerge. At the same time, our recommendations encourage the Commission to put in place a new review process in order to ensure that the implementation in the EU of portions of standards relevant to EMF and health reflect excellence, balance and objectivity.

6.5. Known EMF health effects of mm-waves

Health effects of mobile services in general have been researched for many years, but many questions are open. Health effects of EMF in the mm wave range (which is our focus in this study) have been less studied than EMF in the traditional mobile services frequency range; nonetheless, some things are known with moderate confidence. As previously noted, current literature seems to indicate that current scientific evidence has not conclusively demonstrated that wireless and mobile communications cause harmful health effects in humans when operated within established limits; however, risks cannot be excluded.

6.5.1. EMF effects and wireless services

A quite huge literature exists on the overall health effects of EMF associated with mobile services. The authors of this study are not health sciences professionals, and we will not attempt a full assessment here.

Some experts make a broad claim that research "has convincingly confirmed serious health risks from RF-EMF fields from wireless technology."[118]

Others disagree. In reviewing their just-completed study, the National Toxicology Program (NTP) of the United States provided a quick summary of the overall state of affairs. "*While current scientific evidence has not conclusively linked cell phones with any health problems, NTP and other scientific organizations recognize that additional data are needed*." They also note that "*Current exposure guidelines are based largely on protection from acute injury from thermal effects. Little is known about potential health effects of long-term exposure to radiofrequency radiation. Data from human studies are inconsistent. Additional studies are being conducted.*"[119]

In its 2011 assessment, the *International Agency for Research on Cancer* (*IARC*) of the World Health Organisation (WHO) concluded that then current evidence was "*limited among users of wireless telephones for glioma and acoustic neuroma, and inadequate to draw conclusions for other types of cancers. The evidence from the occupational and environmental exposures mentioned above was similarly judged inadequate*." Based on this, they classified radiofrequency EMF as "*possibly carcinogenic to humans (Group 2B)*[120] *based on an increased risk for glioma, a malignant type of brain cancer, associated with wireless phone use*". The chairman of the group noted that "there could be some risk, and therefore we need to keep a close watch for a link between cell phones and cancer risk."[121]

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[117] Small Cell Forum (2018), "Simplifying Small Cell Installation : Harmonized Principles For RF Compliance", SCF012.

[118] Rainer Nyberg and Lennart Hardell on behalf of 180 oncologists (2017), "Scientists warn of potential serious health effects of 5G".

[119] NTP (2017), "Cell Phone Radiofrequency Radiation Studies", November 2017.

[120] This classification is typically "used for agents for which there is limited evidence of carcinogenicity in humans and less than sufficient evidence of carcinogenicity in experimental animals."

[121] WHO IARC (2011), "IARC Classifies Radiofrequency Electromagnetic Fields As Possibly Carcinogenic To Humans", Press Release 208, 31 May 2011.

Subsequent assessments by other expert groups do not appear to support the finding in regard to glioma, which had been tentative in 2011.[122] The 2015 assessment by the SCENIHR found that *"Overall, the epidemiological studies on mobile phone RF EMF exposure do not show an increased risk of brain tumours. Furthermore, they do not indicate an increased risk for other cancers of the head and neck region. Some studies raised questions regarding an increased risk of glioma and acoustic neuroma in heavy users of mobile phones.*

The results of cohort and incidence time trend studies do not support an increased risk for glioma [emphasis added] while the possibility of an association with acoustic neuroma remains open."[123]

We place particular weight on the SCENIHR assessment inasmuch as the experts are vetted by the Commission and make a public declaration of interests, and can therefore be assumed to have provided an objective analysis.

Even the best studies leave many questions unanswered. A study using rats and mice that was just concluded by this same National Toxicology Program (NTP)[124] is considered by many to be the best conducted to date.[125] Per the press release for the study, "*High exposure to radiofrequency radiation (RFR) in rodents resulted in tumors in tissues surrounding nerves in the hearts of male rats, but not female rats or any mice … The incidence of tumors, called malignant schwannomas, that were observed in the heart increased in male rats as they were exposed to increasing levels of [EMF] beyond the allowable cell phone emissions. Researchers also noted increases in an unusual pattern of cardiomyopathy, or damage to heart tissue, in exposed male and female rats. Overall, there was little indication of health problems in mice related to [EMF*]."[126]

To us as non-specialists, the absence of health problems seems puzzling. Perhaps a clue is visible in press coverage, where John Bucher, a senior scientist at the National Toxicology Program, was quoted during a telephone news briefing as noting *"that the heart tumors in rats — called malignant schwannomas — are similar to acoustic neuromas, a benign tumor in people involving the nerve that connects the ear to the brain, which some studies have linked to cellphone use*."[127]

Moreover, irradiated rats actually lived longer than the control group. "*A seemingly paradoxical finding that has also puzzled the researchers is that the rats exposed to the cellphone radiation actually lived longer than the controls. One possible explanation, Dr. Bucher said, is that the radiation may ease inflammation, and lessen the severity of a chronic kidney disorder that is common in aging rats and can kill them*."[128]

In evaluating the study, the NTP's expert review panel appears to have felt that it was a bit too timid in some key areas. Their conclusions recommend upgrading the assessment of some findings to reflect greater certainty of the findings in rats than is visible in the

[122] See for instance US National Institutes of Health (NIH) National Cancer Institute (2018), "Cell phones and Cancer Risk", at https://www.cancer.gov/about-cancer/causes-prevention/risk/radiation/cell-phones-fact-sheet#q6.

[123] Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) (2015), "Opinion on Potential health effects of exposure to electromagnetic fields (EMF)"

[124] NTP (2018), "NTP Technical Report on the toxicology and carcinogenesis studies in hsd:sprague dawley sd rats exposed to whole-body radio frequency radiation at a frequency (900 mhz) and modulations (gsm and cdma) used by cell phones", NTP TR 595.

[125] See Rainer Nyberg and Lennart Hardell on behalf of 180 oncologists (2017), "Scientists warn of potential serious health effects of 5G".

[126] US National Institutes of Health (2018), "High Exposure to Radiofrequency Radiation Linked to Tumor Activity in Male Rats".

[127] New York Times (2018), "Cellphones Are Still Safe for Humans, Researchers Say", 2 February 2018.

[128] New York Times (2018), "Cellphones Are Still Safe for Humans, Researchers Say", 2 February 2018.

current text.[129] Dr. Bucher cautions *"that the findings tell us that we should take a closer look, but they should not be directly extrapolated to human cell phone usage*."[130]

Most recently, the final report on this experiment (reflecting the consensus of the agency and the expert review panel) indeed expresses greater caution,[131] but still falls well short of definitively answering the question of the impact of mobile phones on human health. "The experiment, by the National Toxicology Program, found positive but relatively modest evidence that radio waves from some types of cellphones could raise the risk that male rats develop brain cancer. 'We believe that the link between radio-frequency radiation and tumors in male rats is real,' John Bucher, a senior scientist at the National Toxicology Program, said in a statement. But he cautioned that the exposure levels and durations were far greater than what people typically encounter, and thus cannot 'be compared directly to the exposure that humans experience.'"[132]

Meanwhile, a number of individuals have claimed over a period of many years to be suffering from headaches, sleep, attention and memory problems, and social isolation, which they attribute to exposure to electromagnetic waves. Their condition is referred to as *Electromagnetic hypersensitivity (EHS)*. EHS is not a recognised medical diagnosis today.

The French ANSES has nonetheless conducted assessments of EHS in 2003, 2005, 2009, 2013, and, 2016. The most recent, based on the work of 40 experts who were mobilised over a period of four years, was published in March 2018.[133] This most recent study concludes that pain and suffering that these individuals claim "correspond[s] to a lived reality, leading them to adapt their daily lives to cope." The perceived symptoms "require and justify appropriate management by health and social actors." At the same time, they find that "current scientific knowledge does not show a causal link between the symptoms experienced by people reporting EHS and their exposure to electromagnetic waves."

6.5.2. Overview of the state of knowledge of EMF effects in the mm wave bands in general

In the remainder of this section, we provide an overview of the state of knowledge on EMF effects in the mm wave bands in general. Much of the information presented comes from a 2013 survey article by Le Dréan and numerous colleagues for the French National Research Agency (ANR), and the French Agency for Food, Environmental and Occupational Health & Safety (ANSES).[134] The article impresses us as being comprehensive, and as striving to present a fair picture of uncertainties and limitations. Inasmuch as it was written for French government agencies, we have no reason to believe that it is subject to systematic bias from commercial parties, which is always a potential concern with research on EMF.[135]

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[129] US National Institutes of Health (2018), "NTP cell phone studies — experts recommend elevated conclusions", April 2018.

[130] US National Institutes of Health (2018), "NTP cell phone studies — experts recommend elevated conclusions", April 2018.

[131] US National Institutes of Health (2018), Cell Phone Radio Frequency Radiation Studies, at https://www.niehs.nih.gov/health/materials/cell_phone_radiofrequency_radiation_studies_508.pdf viewed 30 January 2019.

[132] New York Times (2018), "Major Study Finds 'Some Evidence' of Link Between Cellphone Radiation and Brain Cancer", 1 November 2018.

[133] ANSES (2018), Hypersensibilité électromagnétique ou intolérance environnementale idiopathique attribuée aux champs Electromagnétiques. See also ANSES (2018), Hypersensitivity to electromagnetic waves: amplify the research effort and adapt the care of the people concerned, https://www.anses.fr/fr/content/hypersensibilit%C3%A9-aux-ondes-%C3%A9lectromagn%C3%A9tiques-amplifier-l%E2%80%99effort-de-recherche-et-adapter-la viewed 18 March 2019.

[134] Yves Le Dréan, Yonis Soubere Mahamoud, Yann Le Page, Denis Habauzit, Catherine Le Quément, Maxim Zhadobov, and Ronan Sauleau (2013), Electromagnetic fields: from dosimetry to human health : State of knowledge on biological effects at 40–60 GHz

[135] Prof. Nyberg, an author of the open letter "Scientists warn of potential serious health effects of 5G", recommended it to us.

The mm-wave spectrum has been used for a variety of health treatments in Eastern Europe for many years.[136] Applications are varied, including cancer treatments and pain relief (analgesia). Much of what is known about health effects in the mm wave bands comes to us due to research conducted along these lines. "*Although the biological effects of low-intensity [mm-waves] have been studied for decades, particularly in Eastern European countries, very little reliable and reproducible data are available*."[137]

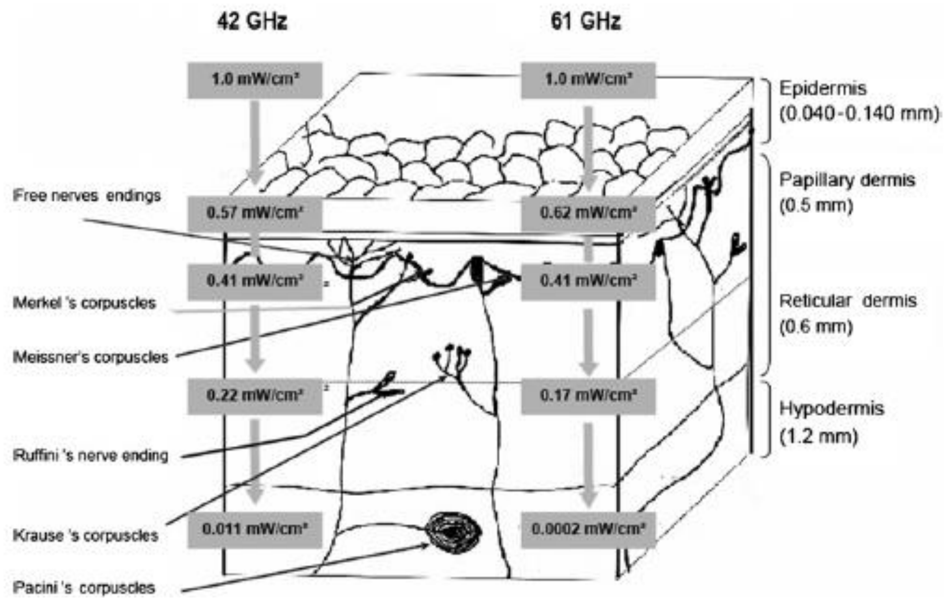
That radiation produces thermal effects (heating, of the skin in this case) complicates research. Study of effects at absorption levels high enough to cause heating needs to disentangle thermal from non-thermal effects. "*Unlike toxicologists who can demonstrate the deleterious effects of chemicals by using high levels of exposure, experimenters cannot use high exposure levels without trigger hyperthermia. This point is particularly important when using mm-waves, because the energy is very locally absorbed by the body surface, which generates significantly higher specific absorption rates (SAR) compared to those obtained at lower microwave frequencies for identical power density values*."[138]

There are however large gaps and huge uncertainties in our knowledge for a variety of reasons. "Often, the models and the exposure parameters are quite different, and it is not easy to harmonise and to reconcile such disparate experiments and results. Among the described biological effects, those showing hypoalgesic [pain relief] effects are probably the more reliable, as positive data, using blind tests with animals or human volunteers, have been published by different laboratories."

6.5.3.Skin penetration

The ability of mm-waves to penetrate the skin is extremely limited. Penetration "is of the order of a few tenths of millimetres to several millimetres, depending on frequency and tissues, indicating that the skin or near-surface zones of the tissues are the main targets for MMW radiations".[139] This rapid absorption is clearly depicted in Figure 35 which shows remaining power for every mW/cm^2 that is incident at the surface of the skin at 42 GHz and 61 MHz.

Figure 35: Schematic representation of the skin's structure and penetration depth of mm waves



Source: Le Dréan et al. (2013), op. cit.

136 Le Dréan et al. (2013), op. cit.

137 Le Dréan et al. (2013), op. cit.

138 Le Dréan et al. (2013), op. cit.

139 Le Dréan et al. (2013), op. cit.

6.5.4. Ionising effects

Danger from ionising effects can be ruled out with a high degree of certainty. Millimetre waves "are non-ionising radiations as the photon energy (10−4 to 10−3 eV) remains several orders of magnitude below the level required to ionise biological molecules (typically > 10 eV). This is important because non-ionising and ionising radiations generate fundamentally different effects in living organisms."[140]

6.5.5. Thermal effects

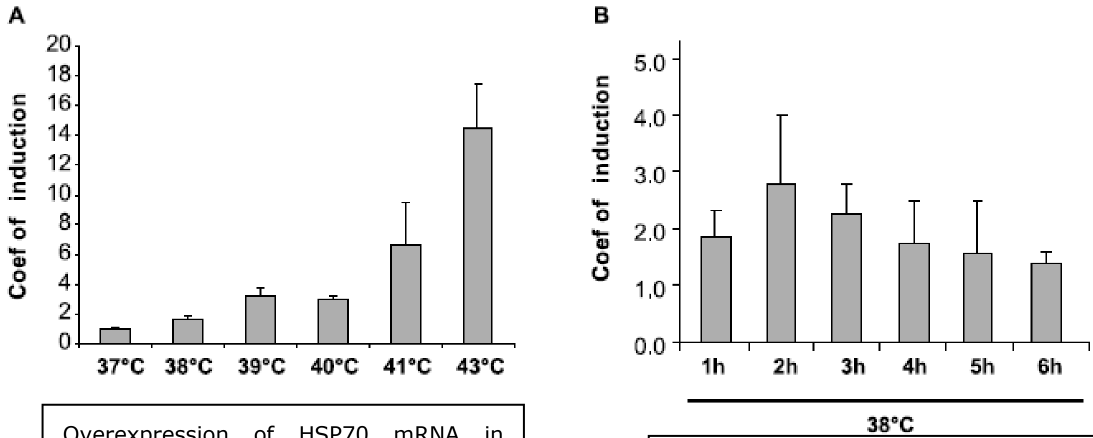
The thermal (skin heating) properties of mm waves are fairly well understood. *Mobile applications are expected to operate well below the power levels where these are believed to be a significant concern*; nonetheless, it is possible that some thought is warranted as regards sustained exposure over longer periods of time.

"Thermal effects appear after exposure to incident power density (IPD) above 5–10 mW/cm2. High-intensity mm-waves act on human skin and cornea in a dose-dependent manner: heating sensation may occur at low-power densities, then followed by pain at higher exposures, and even by physical damage at very high powers. The active denial systems rely on this thermal effect. People exposed to high-power 94-GHz radiations undergo a sudden increase in their superficial temperature, resulting in a quick burning sensation and in an escape reaction from the mm-wave beam. It was demonstrated on human volunteers that the pain sensation was correlated with an increase in surface temperature."[141]

How do these thermal effects interact with the human body? Temperatures above 45◦ C can be lethal to most mammalian cells. Temperatures ranging between 40◦ C and 44◦ C are not in general, "but such exposures activate an adaptive mechanism called heat-shock response (HSR)." HSR causes increased of expression of the heat shock protein 70 (HSP70), which "*is therefore used as a convenient biomarker to monitor the impact of environmental factors on cells. Because acute HSR is not observed below 39◦C, the scientific community often considers that moderate elevation of temperature (ΔT < 2◦ C) has no significant consequence for the cell*."

Even though temperature elevation of up to 2◦ C is thought not to be harmful, prolonged exposure increases production of HSP70, which is to say that it has effect on the human body. Again, this implies challenges for research inasmuch as it means that it is difficult to disentangle thermal from non-thermal effects. The level of HSP70 produced at different temperatures and at 38◦ (i.e. one degree temperature elevation) over different period is shown in Figure 36.

Figure 36: Representative heat-shock response in human epidermal cells.[142]



Overexpression of HSP70 mRNA in response to acute heat shock (45 min at temperature indicated).

Levels of HSP70 mRNA after moderate heat shock (38 ◦C for the duration indicated).

140 Le

141 Le Dréan et al. (2013), op. cit.

142 For a keratinocyte cell line (HaCaT).

Source: Le Dréan et al. (2013), op. cit.

6.5.6. Non-thermal effects: Impact on protein and DNA

For all of the reasons previously noted, there is considerable debate as to whether non-thermal effects exist at all for mm waves.

The natural tendency to date has been to assume that mm-wave EMF effects must be limited due to limited penetration;[143] however, the therapeutic use in Eastern Europe calls this assumption into question. Notably, the effectiveness as a pain killer cannot be readily explained in the absence of subtle effects that generate indirect benefits elsewhere in the human body, not just in the skin. These would presumably work through the nervous system or the circulatory system (e.g. with release of opioids or other substances into the bloodstream). It appears that the pain killing effect "*is mediated by the central nervous system, particularly by the hypothalamic area*."[144]

One potential non-thermal effect that has been studied relates to the impact on protein and on genetic material, i.e. DNA. Research to date strongly suggests that no effect on protein is to be expected at levels of exposure that are anticipated; however, more subtle effects might be relevant, particularly where exposure is prolonged. Research to date likewise indicates that no effect on DNA is to be expected at levels of exposure that are anticipated.[145] This finding as regards DNA may possibly be somewhat at odds, however, with the recent NTP study (see section 6.5.1).

6.5.7. Non-thermal effects: Impact on cell reproduction

Given that mm-waves have been effective against cancer, one might expect that the impacts on cell reproduction would have been well studied. In reality, "*it is very difficult to draw clear conclusions from those studies, first because of contradictory observations, and second because of the heterogeneity of models and exposure parameters*."[146] It is clear that there are effects, possible mechanisms have been postulated, but the actual mechanisms are not yet truly known or understood.[147]

6.6. Modelling

To understand the practical implications of EMF limits on network roll-out, some engineering modelling has been undertaken. We provide a brief summary here, and then plunge into the details in the sections that follow.

The focus of our modelling has been on 5G in the mm-wave bands from terrestrial sources, not from satellites. We have modelled incident radiation at the surface of the skin. We have not commented on resultant health effects.

We developed two kinds of models:

- A static model that explores exposure under worst case scenarios; and
- A dynamic simulation model that uses a ray-tracing approach with pseudo-random variations (i.e. Monte Carlo techniques) to explore the impact of mm-wave small cells on overall EMF levels in more realistic scenarios that can include beam-forming, moving pedestrians, and obstacles.

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[143] Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) (2015), "Opinion on Potential health effects of exposure to electromagnetic fields (EMF)", page 5. "Millimetre wave and THz applications … do not [currently] significantly affect the average exposure of the general public. These applications will operate with low power and, due to the small penetration depth of the radiation, expose only superficial tissues."

[144] Le Dréan et al. (2013), op. cit.

[145] Our results clearly demonstrate that low-power MMWs (0.14 mW/cm2) within the 59–61.2 GHz frequency range does not trigger ER stress.

[146] Le Dréan et al. (2013), op. cit.

[147] Le Dréan et al. (2013), op. cit.

The static model finds that relevant ICNIRP limits from a base station (gNodeB) to an arbitrary person in the vicinity are likely to be exceeded only if a person were less than 0.7 metres away from the base station. Base stations are expected, however, to be mounted well above street level – the ITU-R normal modelling assumption is that they are mounted 6m above the level of the street. For a human being who is not more than 2 metres tall, it can thus be expected that ICNIRP field strength limits are far from being exceeded, even in the worst case. Even if a standard an order of magnitude more restrictive than ICNIRP were to be adopted, it would be likely to be exceeded only if a person were less than 2.3 metres away from the base station, which again is implausible for base stations located 6m above the level of the street.

The dynamic model was used to simulate the impact on pedestrians walking through a city square with a plausible mix of 5G in the 800 MHz, 3.5 GHz and 26 GHz bands, together with traditional broadcasting in the 500 MHz band. EMF proves unsurprisingly to be far more variable at 26 GHz than in the other bands due to the short-range and narrow beams. A key finding is that, even in the worst case, the EMF values lie below the ICNIRP limit by a factor of more than 100 (i.e. by more than 20dB).

The detailed discussion that follows is highly technical. The reader may wish to review the *List of abbreviations* that appears at the beginning of this report.

6.6.1. Overall approach to modelling

As previously noted, our focus here is on modelling incident radiation at the surface of the skin, not on assessing health effects; however, an understanding of what is known about health effects is essential in understanding what the modelling might need to consider. Our work has been informed by this understanding, and also by the results of our numerous interviews (see also Section 6.7).

In this study, our focus is on mm-wave; however, consideration of 5G deployment in the traditional bands is necessary as well. Exposure is not solely a matter of 5G in the mm-wave bands; rather, use of the mm-wave bands serves as a short range high capacity complement to use in lower frequency, more traditional bands. As previously noted in Section 6.3, some reflection on the interaction with older 2G/3G/4G technologies would likewise appear to be unavoidable.

The relationship to public Wi-Fi is relevant but challenging, and has not been taken into account here.

Our emphasis in this analysis is on terrestrial 5G services. Signals from a satellite to an end-user are unlikely to be an issue in light of the power levels to be used and the attenuation to be expected at the distances involved.

As for 5G signals from an end-user to a satellite, it is perhaps too early to speculate on likely EMF effects. In any event, if power levels are similar to those used for terrestrial 5G mobile services, then EMF exposure is likely to be of the same order of magnitude.

6.6.2. mm-wave base station characteristics

3GPP documents do not define a maximum EIRP for Type 2-O base stations[148]. For the User Equipment (UE), the minimum peak EIRP is 22.4dBm with an upper limit of 43dBm (TR 38.815). .

ITU-R Document 5-1/36 gives characteristics for sharing studies. For 'outdoor urban hotspots' a density of 30 BSs/km2 is to be assumed, with a height of the base station antenna of 6m and a downtilt of 10 degrees. These are modelling assumptions, not necessarily what will be deployed in all cases in the field. The antenna has 8x8 elements (64), with an element gain of 5dBi. Conducted power per element (before ohmic losses) is

[148] Base stations operating above 24 GHz (i.e. in Frequency Range 2, or FR2) are 'Type 2'. The only class of base station defined is '-O', where the power is defined in terms of Over-the-Air (OTA) performance

10 dBm/200 MHz, and ohmic loss is 3dB. For 64 elements, the total conducted power is 10dBm + 18dB – 3dB = 25dBm.

The maximum antenna gain that can be synthesised is 23dBi, so the maximum EIRP is 48dBm (18dBW = 63W).

CEPT Report 68 stipulates technical conditions for use of the 26 GHz band based on 'Total Radiated Power (TRP) rather than EIRP. This is necessary to accommodate the use of active antenna systems within 5G, where antennas no longer have a fixed pattern or gain, and can only be tested in 'Over The Air' (OTA) conditions.

6.6.3. Static EMF model

For the practical case of most concern, i.e. protection of the general public from fields due to base stations, the '< 6 minute' limits in the new draft ICNIRP Guidelines (see Section 6.4.2) are relevant. Given the likely dynamics of service users, antenna beamforming and third party 'victims', substantial exposure is unlikely to persist for more than 6 minutes. As noted in Section 6.5.3, mm-waves penetrate the human body to a depth of only a millimetre or so, which is to say that that the human body is effectively opaque to mm-waves. Normal MIMO routing can therefore be expected to choose a path that does not attempt to go through the body.

That said, it is possible to conceive of plausible scenarios where exposure lasts for more than 6 minutes?? apply – for example, a bystander who is sitting on a bench close to a gNodeB that is serving a stationary mobile user, but not fully blocking the signal from the gNodeB to the user.

Assume that a user has established a link to a gNodeB that is operating at full power. The ICNIRP reference level power flux density (PFD) limit of 10 W/m^2 is met at a distance of 0.72m from the gNodeB. The usual ITU modelling assumption is that base stations are located 6m above the walkway, in which case this clearly would represent no constraint on deployment.

Small cells operating in the mm-wave bands may sometimes, however, be located closer to human beings than 6m. The standard proposed by the Small Cell Forum (SCF)[149] would mandate that cells operating at more than 2 W but less than 10 W should be operated with suitable exclusion zones and at a height of at least 2.2m above the walkway. Cells operating at more than 10W but less than 100W should be operated with suitable exclusion zones and at a height of at least 2.5m above the walkway.

The SCF's proposal that deployment standards for small cells, taking transmission power into account, should be imposed at EU level impresses us as sensible. Our modelling indicates that a spacing from the gNodeB to human bodies of at least 29cm is needed to ensure that the ICNIRP limit is not exceeded by a 10W transmitter, and a spacing from the gNodeB to human bodies of at least 280 cm is needed to ensure that the ICNIRP limit is not exceeded by a 100W transmitter. A standard that mandates a minimum height of transmitters above the walkway, taking into account not only the mean height of a person but also the distribution of heights, could go a long way toward safeguarding human health without needlessly impacting deployment flexibility.

The standards that are discussed in this report, including this suggested standard in particular, have important implications for human health. The organisations that produce these standards tend to be staffed by technical experts, some of whom have ties to industry, rather than by independent health scientists and health professionals. In light of the sensitivity of these matters, and the need to ensure public confidence in the correctness, balance, and objectivity of the decisions reached, the recommendations that we provide in this report make suggestions regarding periodic independent review of relevant portions of key standards with EMF implications.

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[149] Small Cell Forum (2018), "Simplifying Small Cell Installation : Harmonized Principles For RF Compliance", SCF012.

Despite the lower EIRP, it is the radiation from user equipment that is more likely to infringe ICNIRP limits in practice. Even here, beamforming will be employed with the effect that most radiated power in mm-wave bands will tend to be directed away from the body due to normal MIMO routing, as previously noted.

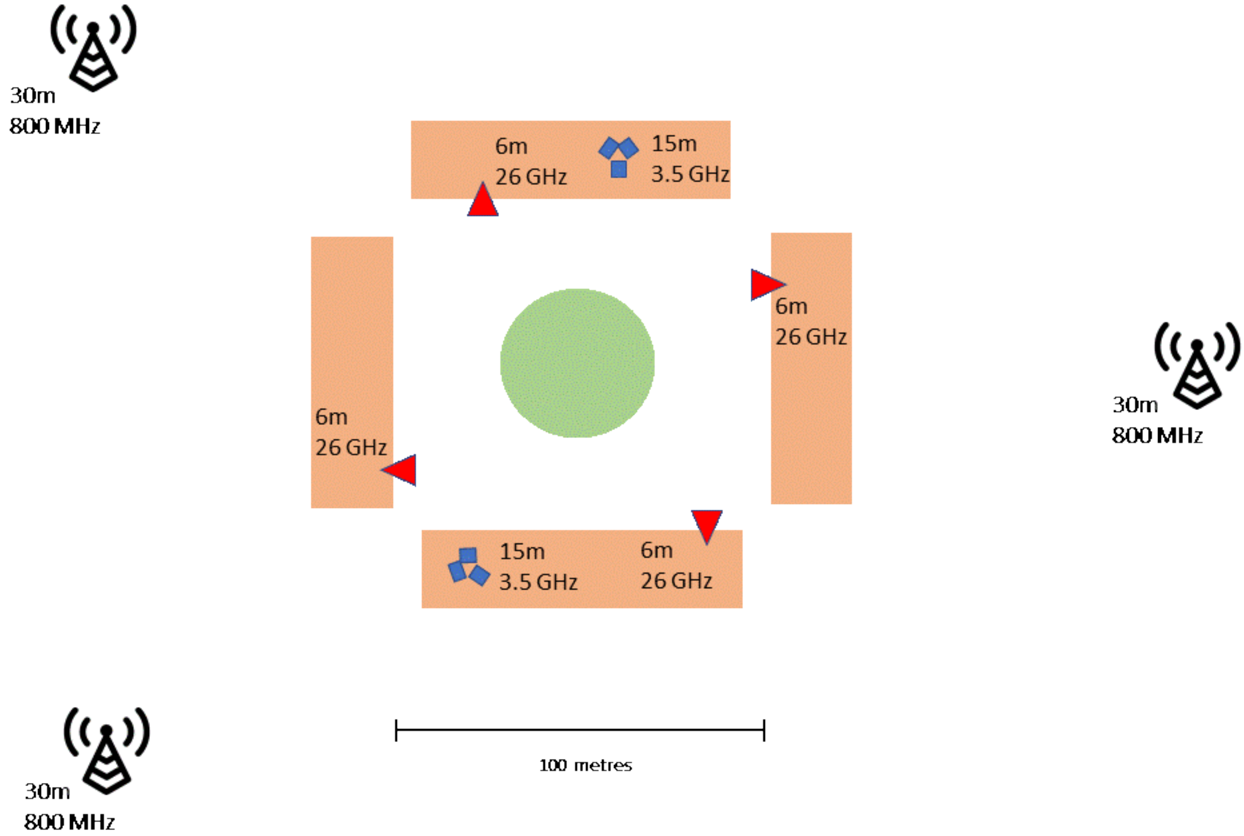
6.6.4. Probabilistic EMF model

Given the short range and dynamic beam steering associated with millimetre wave, static modelling is inadequate. We have therefore developed a simple probabilistic model with which to explore the impact of mm-wave small cells on overall EMF levels.

This model makes use of a simple, ray-tracing approach and can include arbitrary buildings, vehicles, and obstacles such as street furniture and trees. Reflection and scattering are modelled, and active (beamforming) antennas are included in the functionality. 5G base stations are modelled in a representative environment, and the statistics of EMF field strength are evaluated on dynamically-modelled 'users' who can be configured to follow uniform or random-walk trajectories.

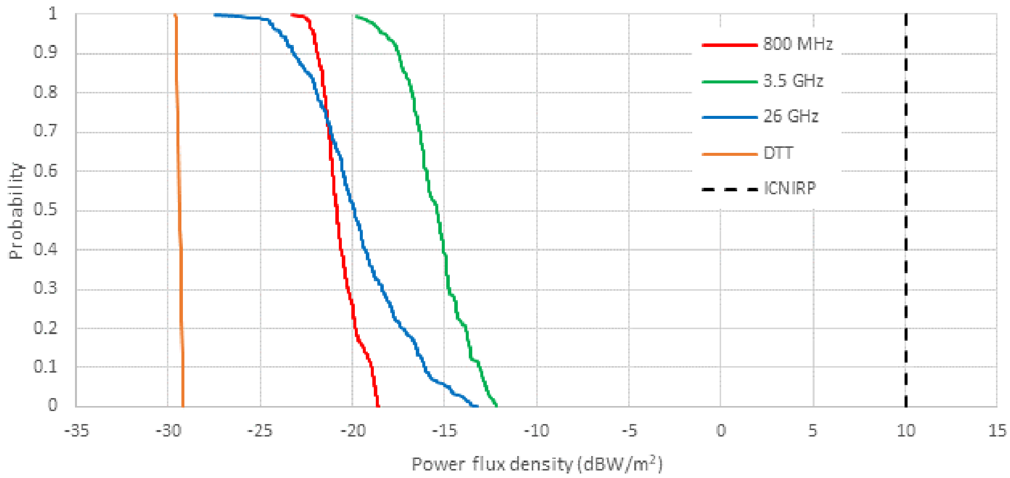
In the scenario reported here, a city square is modelled with cellular service provided from 3 macrocell sites at 30m above ground, two microcell sites at 15m and four mm-wave sites at 6m. In addition, a high-power (200kW ERP) DTT transmitter operating at around 500 MHz and radiating six multiplexes is included in the modelling.

Figure 37: Scenario for probabilistic model



The output of the model is in terms of cumulative distributions of exposure (i.e. the probability that a certain power flux density (PFD) value will not be exceeded at a randomly-chosen location within the area modelled), by band, as shown in Figure 38.

Figure 38: Predicted power flux density figures for sample deployment



The results show the greater variability of the EMF at 26 GHz, due to the short-range and narrow beams. The 3.5 GHz microcells are assumed to be located on the roofs of nearby buildings, and to operate with traditional (rather than beam-forming) antenna systems. This is also the case for the microcell 800 MHz sites, whose greater range gives rise to a smaller variability in EMF.

It should be noted that even in the worst case, the EMF values lie more than 20dB below the ICNIRP limit. The relative values of EMF from different networks at different frequencies will depend on the exact local conditions and the topology of the networks. For example, in the area immediately around an 800 MHz cell in the modelled scenario, that single source would be expected to dominate the overall EMF value rather than the 3.5 GHz network.

While this particular simulation therefore represents only a single, unique scenario, it confirms the results of static deterministic simulations (see Section 6.6.3), and results from other sources. In a measurement study[150] relating to the deployment of small cells in the town of Annecy, the ANFR found that maximum EMF values increased from 0.2V/m to 0.3V/m, a change from 0.3% to 0.5% of the ICNIRP limit.

6.7. Summary of interview findings

We have held interviews with nearly 30 stakeholders, but only 17 had comments on EMF. Twelve of these were governmental entities – spectrum management authorities, ministries, or NRAs. For the governmental authorities, responses were often limited because the SMAs and other authorities that we interviewed often did not have responsibility, or did not have full responsibility, for EMF. Commercial stakeholders often responded to the effect that this was a scientific matter, and that they would adhere to whatever limits were set.

Authorities in many of the EU Member States (Croatia, Hungary, Malta, the Netherlands, Slovenia, Spain) reported that they adhere to ICNRP limits and to the 1999 Council Recommendation,[151] with no other EMF restrictions in place. A few, however, reported either more restrictive regimes at national level, or else local divergence.[152]

[150] See: https://www.anfr.fr/fileadmin/mediatheque/documents/Actualites/2017-04-26_-_Rapport_résultats_Annecy.pdf

[151] European Council (1999), Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz), (1999/519/EC).

[152] The restrictive standards in Italy and Belgium were already visible in the literature, including in J. Scott Marcus, Ulrich Stumpf et al. (2017), "Substantive issues for review in the areas of market entry, management of scarce resources and general end-user issues", Final Report, study for the European Commission, at https://ec.europa.eu/digital-single-market/en/news/substantive-issues-review-areas-market-entry-management-scarce-resources-and-general-end-user-0.

- AGCOM (Italy) explained that Italy has one of the most stringent regulations regarding EMF emissions, which does not facilitate authorisation at municipal level. Some MNOs have already come forward to complain to AGCOM that this will be an issue for 5G deployment, where dense coverage will be needed in order obtain a good quality of service; however, it is the Ministry of Health that is responsible for these limits in Italy, not AGCOM.
- The BIPT (Belgium) notes that the city of Brussels has developed particularly restrictive legislation at local level to prevent health hazards from EMF. This has already been a problem for 4G deployment, and might well be a serious issue for dense 5G deployments.
- The ANFR (France) is informed when a base station is to be deployed, and they must determine whether EMF levels are atypically high. The ARCEP specifies a general limit in the licence, the COMSIS office of ANFR also specifies a limit taking into account other users of spectrum.
- The RRT (Lithuania) reports that its EMF requirements are the most stringent in Europe, and are set at just one tenth of ICINRP norms.

Enquiries by the project team have not, as yet, identified any scientifically-rigorous justification for these lower levels; we will continue to investigate the historical background to the chosen levels.

In several of the EU Member States, the NRA must approve base station deployments, and should or must take EMF issues into account when doing so. This is the case for instance for the ANFR (France), BNetzA (Germany), and EETT (Greece).

The BIPT (Belgium) has identified a need for the Commission to establish harmonised EMF standards in preparation for 5G deployment, and comments from some of the other public agencies seemed to assume that the European Commission would be providing studies and/or guidance.

Among the market players, Arqiva noted that no major health issues have been observed in the US or Asia, where dense networks of small cells are already deployed. They also noted that equipment will typically be deployed at a height of 6 metres, and is therefore unlikely to cause EMF problems.

Intelsat suggested that 200m is a reasonable assumption for cell radius for mm wave; however, if there is strong enough concern over health effects, it might force deployments to go to lower power than now anticipated, and therefore to a cell radius less than 200m.

Qualcomm opined that EMF limits in some EU Member States are by a factor of ten more restrictive than ICNIRP limits, and these restrictive EMF limits are likely to inhibit 5G deployment if they remain in force. As shown in Figure 35 (Section 6.4.3) the differences in EMF limits can vary significantly between EU Member States. Restrictive EMF limits are in place in Greece, the Netherlands, parts of Belgium, Slovenia, Poland, Italy, Lithuania, and Bulgaria. Qualcomm also observe that the restrictive EMF limits in Italy do not facilitate base station deployment. They expressed a desire that the EMF values should be finalised this year and suggested that the EU adopt ICNIRP limits. Qualcomm further noted that different values could apply for testing and for commercial operation of 5G networks.

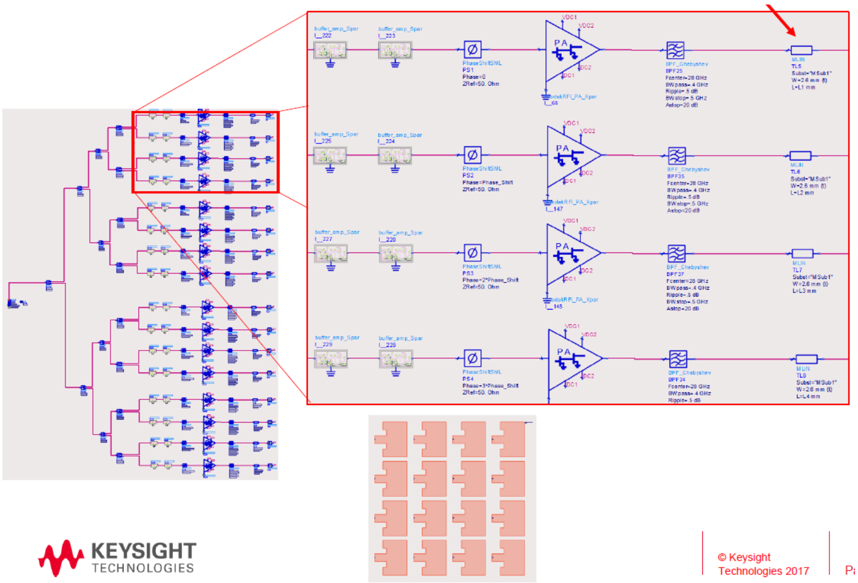
Several of the comments dealt with the question of how best to measure the risk of mm-wave EMF exposure (e.g. EIRP versus SAR) – the traditional measures applied to lower frequencies are not necessarily the right way to look at mm-wave exposure. (This question was touched on in the discussion of the ICNIRP Guidelines in Section 6.4, and also plays a key role in the measurement issues addressed in Section 6.8.).

6.8. Challenges in the measurement of EMF

With previous technologies operating in the spectrum bands traditionally used for mobile services, measurement of EMF in the laboratory and in the field was relatively straightforward. The shift to 5G operating in mm-wave bands appears to require a very different approach to the measurement of EMF. At present, it is not clear how this should be done. Further research is needed.

The 3GPP specifications for base stations operating above 24 GHz assume that no antenna connectors will be available and that power must therefore be defined in terms of Over-the-Air (OTA) performance. This follows from the architecture necessary to implement active antennas at this frequency, in which each antenna element has an associated active device. These devices are distributed throughout the antenna and coupled closely to the individual element.

Figure 39: Phased array architecture



Source: Keysight Technologies

There is currently a very active debate regarding the development of methods for the OTA testing of mm-wave base stations and terminals, and in particular, how to create a repeatable and realistic simulation of a spatially-diverse channel in a test environment. Measurement is possible only where a user terminal is present.

Standards bodies including 3GPP are studying these issues, but no solution has emerged to date. The recommendations that we make in this report reflect our concern that the standards bodies might not settle on a solution to this problem as quickly as Europe needs or desires it.

Somewhat similar challenges will apply to the verification of EMF levels in the field. The nature of mm-wave 5G networks implies that results obtained by site measurement will have only a location specific value unless the base station can be measured in a statistically-meaningful and repeatable manner.

These industry activities relating to OTA testing may be of high relevance for national authorities that may need to monitor compliance with EMF limits.

7. Findings and recommendations

This Chapter summarises the findings of the study. More detail of the findings and supporting analysis is presented in each chapter.

7.1. Identification of potential 5G services in mm-waves bands and analysis of the potential demand

- Services expected to use mm-wave bands are the following:
  - Enhanced Mobile Broadband (eMBB) services for high capacity (Fixed Wireless Access (FWA), high-definition video communications, virtual, augmented and mixed realities),
  - Services for vertical sectors including automotive (V2X: Vehicle-to-everything, autonomous cars), other transportation (trains and buses), manufacturing / industrial automation, energy grid communications, smart cities, and medical applications;
  - Public safety and
  - Fronthauling / backhauling.
- The first services that are likely to be deployed in mm-wave bands will be eMBB and new use cases of backhauling (different from incumbent fixed links), but no killer application has been identified so far.
- Use of the mm-wave bands will be progressive in Europe with expected initial adoption by 5G operators in congested hot-spots, roads and major transport paths. Deployment of small cells using the 26 GHz band is expected to start in 2022-2023, but with limited initial volumes.
- Based on our evaluation, a maximum of 10% of the 5G cell sites would support mm-waves in 2025.
- The framework for using existing spectrum for 5G is considering 2020 for availability in EU-28 countries. For EU-28, the expected availability of at least 1 GHz in the 26 GHz band in 2020 will provide sufficient initial capacity for the progressive 5G deployment.

7.2. Analysis of potential co-existence scenarios and assessment of the prospects for the evolution of the business environment

- Of the potential coexistence issues, only that with 26 GHz fixed links appears to require significant study.
- The decision to protect the EESS (passive) service below 24 GHz with a stringent out-of-band emission limit at 26 GHz has enforced a 'maximum compliance' approach, with implications for the practical availability of the lower part of the 26 GHz band. This may have an impact more in terms of the administrative process for spectrum assignment (i.e. block sizes available for operators) than on constraining capacity, given the relatively long period foreseen to build demand at mm-wave.
- Co-ordination with receiving (EESS, SRS) and transmitting (FSS) Earth stations is not expected to be a significant constraint on 5G deployment, due to the small number[153] of sites involved and their rural location. CEPT Report 68 also notes the "*need to maintain the possibility for additional earth stations to be deployed in the EU Members States…*".The necessary technical tools for coordination with these services already exist.

[153] There are five major Ka-band receive Earth stations operating in the EESS and SRS within Europe (see Section 3.6.2).

- Studies in PT1 and elsewhere indicate that no significant co-existence issues are envisaged with respect to the 40.5 – 43.5 GHz band identified in the RSPG 'second opinion' as a priority band for second-stage deployment.
- The 66-71 GHz band, identified as the other 'second-stage' 5G band, is attractive partly by virtue of its adjacency to the existing 57 – 66 GHz licence exempt band. The potential for adjacent band interference between the two allocations is under study, but is unlikely to be more problematic than that between different users within the same band.

7.3. Allocation and authorisation

Below is a summary of the findings on allocation and authorisation.

- There is recognition among SMAs that the 26 GHz band is a priority band for 5G and that it should be made available when demand occurs.
- Member States indicated that they will make at least 1 GHz of the 26 GHz band available before the end of 2020 in line with the Code and this is likely to be the frequency range 26.5-27.5 GHz as recommended by RSPG.
- The sub-band below 26.5 GHz is more problematic to make available in the near term in Member States due to both the presence of incumbent services and the requirement to protect space sensors of the EESS.
- In line with good practice, the least onerous and most flexible access mechanism should be adopted as a default for authorisation of mm-wave spectrum. However, most SMAs have yet to publish proposals on this.
- For the 26 GHz band, there are authorisation challenges resulting from protection of incumbent and out of band services, including the EESS. This tends to point toward use of an IA or light licensing approach for this band.
- Subject to study of local circumstances, different authorisation approaches may be possible for indoor vs outdoor services. Consideration should be given to GA for indoor if protection requirements can be met (subject to retaining a common band plan).
- Consideration should be given to authorisation mechanisms to enable regional and local operators as well as industry vertical to access mm-wave spectrum on a location basis. Use of a GA or light licensing approach could enable access for these players.
- While there may be legitimate reasons for differences in authorisation approaches between Member States based on local conditions, there is a need for consistency and coordination between Member States to avoid fragmentation and reducing investment incentives, in particular for services with a pan-European dimension (for example services that are used either side of a country border such as for railways).
- Authorisation in the 26 GHz band could be based on the use of a mechanism based on advanced database techniques (e.g. LSA) to provide the required flexibility and adaptability over time as demand for both 5G and incumbent services develop.
- The position on authorisation of other mm-wave bands is less clear but there appears to be a consensus emerging on use of GA for the 66-71 GHz band.

7.4. Hybrid services

- Developments on satellite hybrid solutions are taking place (with a global emphasis as well as Europe)[154]. However, there seems to be a lack of awareness among many of what is happening (albeit at an early stage) and these developments are lagging behind terrestrial ecosystem developments.
- Further analysis is required of the potential satellite use cases that hybrid solutions potentially enable in the European context, given the high penetration of terrestrial solutions.
- No interest was expressed by any of the stakeholders approached in broadcast / terrestrial 5G convergence.

7.5. EMF

- As regards wireless services in general and mobile services in particular, there have been long-standing public concerns over possible health effects due to exposure to the electromagnetic fields (EMF).
- Various global and regional bodies have studied EMF effects, including the World Health Organisation.
  - A quite huge literature exists on the analysis of overall health effects of EMF associated with mobile services. A number of rigorous studies have been conducted, including epidemiological cohort and incidence time trend studies and animal studies. In this chapter, we review a number of the most recent and most highly respected results (see especially Section 6.5.1).
  - There are diverging views on the interpretation of the results of this research.
  - Existing literature seems to indicate that current scientific evidence has not conclusively demonstrated that wireless and mobile communications cause harmful health effects in humans when operated within established limits; however, risks cannot be excluded.
  - Health effects associated with mm-waves are distinct from those in the traditional mobile bands because mm-waves have little ability to penetrate the skin. Even though mm-waves have not been used for mobile services, there is a body of research on potential health effects due to the use of mm-waves in Eastern Europe for medical purposes; however, very little reliable and reproducible data is available. Among these, the most reliable research results are associated with pain relief (analgesia). (Le Dréan et al. (2013))
  - Other than heating effects (which are not significant at the power levels to be expected for 5G), no harmful mm-wave health effects have been demonstrated in humans to date. (Le Dréan et al. (2013)) Many assume that health effects would be limited to the skin and eyes, due to the limited penetration; however, the use in Eastern Europe of mm-waves for pain relief raises the possibility that there might also be effects that are transmitted in other ways. (Le Dréan et al. (2013))
- In Europe, EMF guidelines for non-ionising EMF are primarily based on the guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The current ICNIRP guidelines are reflected in a 1999 Council Recommendation[155] on the permissible level of emissions for equipment to be deployed. Article 58 of the newly enacted European Electronic Communications Code (EECC) effectively requires Member States to notify the Commission of draft measures where the Member State intends to

[154] For example, the Sat5G project, which is addressing 6 pillars of work including SDN/NFV for satellites, network management and network orchestration, multilink and heterogeneous transport, harmonisation of satcom and the 5G user plane. Also, Satis5 – a demonstrator for satellite – terrestrial integration in the 5G context

[155] European Council (1999), Council Recommendation of 12 July 1999 on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz), (1999/519/EC).

deviate from the Council Recommendation, and empowers the Commission or other Member States to question the draft measure.

- Some Member States, and some regions or municipalities within Member States, impose EMF limits one or even two orders of magnitude more restrictive than the Council Recommendation of 1999. At these levels, 5G deployment would likely be seriously impeded.
- The move to 5G will be accompanied by a move to large numbers of small cells, some of them operating in the mm-wave bands. Exposure of the population to EMF is less than linear in the number of base stations; nonetheless, the shift is sure to change exposure. Transmit power in the mm-wave bands will be much lower than is typical in the macro cellular network today, but the presence of large numbers of base stations in conjunction with beam-forming means that exposure at any given instant in time could vary greatly depending on where an individual is relative to the base stations, and which locations they are sending to at that moment.
- Our modelling results suggest that any increase in exposure of the population to EMF caused by the shift to 5G and small cells is likely to remain very modest. This is broadly in line with measurements conducted in a measurement study relating to the deployment of small cells in the town of Annecy by the French ANFR,[156] which found an increase in EMF associated with the move to small cells of only 0.1 V/m (to a maximum of 0.5% of the ICNIRP limit). The ANFR study represents only a single small city under a 4G small cell deployment scenario that may or may not prove to be fully representative of 5G deployments, but it nonetheless represents an important datum to the extent that it embodies experience in a real world setting.
- The characteristics of 5G raise new issues for the measurement of EMF. Simply measuring the power delivered to the antenna is of limited value in a setting where beam-forming plays a key role; moreover, 3GPP specifications for base stations operating above 24 GHz assume that no antenna connectors will be available and that power must therefore be defined in terms of Over-the-Air (OTA) performance (see Section 6.8). Measurement is therefore possible only where a user terminal is present. Standards bodies including 3GPP are currently studying these issues. The recommendations that we make in this report reflect the contingency that the standards bodies might not settle on a solution to this problem as quickly as Europe needs or desires it.
- In order to ensure that EMF limits are respected it is likely that national authorities will find it necessary to place greater reliance on field tests than in the past. Exchange of best practice among national authorities will probably be needed (as suggested by COCOM),[157] possibly accompanied by action on the part of the Commission..

7.6. Recommendations

1. In light of the low risk of harmful interference, the primary focus of the European Commission in monitoring Member State developments as regards allocation and authorisation of mm-wave bands for 5G should be on ensuring that the objectives set in the European Electronic Communications Code as regards the timely availability for use of the 5G pioneer bands are achieved.

2. The European Commission should monitor the implementation of vertical services within the European Union using mm-wave spectrum and work with relevant Spectrum Management Authorities and/or NRAs to ensure that there are no barriers or

[156] See https://www.anfr.fr/fileadmin/mediatheque/documents/Actualites/2017-04-26_-_Rapport_résultats_Annecy.pdf.

[157] COCOM Working Group on 5G (2018), "Report on the exchange of Best Practices concerning national broadband strategies and 5G "path-to-deployment", COCOM18-06REV-2.

authorisation conditions which could slow down the implementation of vertical services using mm-wave bands.

3. Authorisation of mm-wave spectrum for 5G at Member State level should take into account (1) spectrum availability in the band in question, (2) specific competitive circumstances, and (3) the risk of harmful interference, which is likely to be far less for mm-wave than for frequencies below 6 GHz. An overall goal is that licensing regimes be no more onerous or restrictive than is strictly necessary, and that they promote opportunities for the sharing of spectrum. This implies that Member States should consider light licensing regimes in the 26 GHz band if scarcity is present; otherwise, General Authorisation should be preferred. Furthermore, any progressive authorisation of the 26 GHz band should facilitate contiguity of spectrum holdings upon market demand. The Commission should monitor the development by ETSI of ENs for 5G mm-wave bands[158], which will improve the coexistence and authorisation environment for 5G and future incumbent service deployment in these bands.

4. The 26 GHz band should be harmonised for 5G ensuring that sharing with incumbent services and services requiring protection in adjacent bands is possible. The European Commission should monitor availability and authorisation of services in the 26 GHz band (both the minimum of 1 GHz required by the EECC to be made available by end 2020 subject to market demand and the expansion up to full band use for 5G) in Member States to assess progress with implementation.

5. The Commission should exercise its coordinating powers as regards the next ITU WRC in 2019 to seek to ensure that the bands recommended by the RSPG for 5G deployment, including mm-wave bands, become or remain available for 5G.

6. The European Commission and the European Space Agency should continue to cooperate on R&D pilots and test beds related to 5G satellite hybrid networks.

7. The European Commission should monitor standards developments in 3GPP and elsewhere that seek to provide a means of measuring EMF in laboratory conditions, and in field conditions (see Section 6.8). If these efforts fail to deliver practical solutions in a reasonable period of time, the Commission may need to initiate corrective actions.

8. Once standards for measurement of EMF are stable (see again Section 6.8), Member State authorities should establish procedures for verifying that EMF limits for 5G (including mm-wave 5G deployments) fulfil European requirements as specified in the Council Recommendation of 1999 (or any successor). Some degree of field testing might well be necessary in the future.

9. Once standards for measurement of EMF are stable (see again Section 6.8), it may be appropriate for the Commission (in consultation with suitable bodies such as the RSPG) to provide default procedures for verifying the EMF limits for 5G (including mm-wave 5G deployments. We assume for now that use of these default procedures on the part of the Member States would be voluntary, but would spare participating Member State authorities the need to each develop their own methodologies.

10. In line with ITU recommendations,[159] the ICNIRP limits, and taking into account the technical views of Associations such as the Small Cell Forum,[160] the Commission may consider issuing guidance so as to ensure that deployments of small cells operating in

[158] See https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=54728 and https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=54786

[159] ITU-T (2018), "The impact of RF-EMF exposure limits stricter than the ICNIRP or IEEE guidelines on 4G and 5G mobile network deployment", Series K Supplement 14 (05/2018).

[160] Small Cell Forum (2018),"Simplifying Small Cell Installation: Harmonized Principles For RF Compliance", SCF012.

the mm-wave bands maintain an appropriate distance from human beings, taking into account the EIRP or PFD at which the equipment operates. This could, if needed, be mandated in the Implementing Decisions that the Commission will be making. Determining the exact parameters to be specified is beyond the scope of this report, but Section 6.6.3 identifies necessary framing conditions on distance from the base station to the human body. The Commission may wish to entrust the determination of detailed parameters and the formulation of suitable technical standards to a standards body, for which CEN / CENELEC seems to be a good candidate. CEN and CENELEC are European Standards Organisations (ESOs), which is to say that the Commission is empowered to issue mandates to them to study relevant standardisation issues.

11. In light of the sensitivity of these matters, and the need to ensure public confidence in the correctness, balance and objectivity of the decisions reached, the Commission may wish to put in place a process for the periodic review of relevant portions of standards with EMF implications, specifically beginning with and including those mentioned in these recommendations. An obvious candidate to conduct these reviews is the Scientific Committee on Health, Environmental and Emerging Risks (SCHEER) replacing the former Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) that has already demonstrated competence in dealing with EMF issues. The SCHEER is an advisory committee that was specifically created to provide the Commission with "opinions on questions concerning emerging or newly identified health and environmental risks and on broad, complex or multidisciplinary issues requiring a comprehensive assessment of risks to consumer safety or public health", including "physical hazards such as noise and electromagnetic fields".[161] Its procedures are designed to ensure "excellence, independence and impartiality, and transparency".[162] Alternatively, the Scientific Advice Mechanism (SAM) could be charged with this task.[163]

[161] C(2015) 5383 final. Commission Decision of 7 August 2015 on establishing Scientific Committees in the field of public health, consumer safety and the environment.

https://ec.europa.eu/health/sites/health/files/scientific_committees/docs/call_2015_5383_decision_with_annexes_en.pdf

[162] Ibid.

[163] Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) (2015), "Opinion on Potential health effects of exposure to electromagnetic fields (EMF)".

8. Annex

8.1. Spectrum needs for different frequency ranges between 24.25 GHz and 86 GHz

	Examples	Associated conditions (details in Annex A of [ITU17-WP5D])	Spectrum needs in total (GHz)	Spectrum needs (GHz) per range
Application-based approach	1	Overcrowded, Dense urban and Urban areas	18.7	3.3 (24.25-33.4 GHz range) 6.1 (37-52.6 GHz range) 9.3 (66-86 GHz range)
		Dense urban and Urban areas	11.4	2.0 (24.25-33.4 GHz range) 3.7 (37-52.6 GHz range) 5.7 (66-86 GHz range)
	2	Highly crowded area	3.7	0.67 (24.25-33.4 GHz range) 1.2 (37-52.6 GHz range) 1.9 (66-86 GHz range)
		Crowded area	1.8	0.33 (24.25-33.4 GHz range) 0.61 (37-52.6 GHz range) 0.93 (66-86 GHz range)
Technical performance-based approach (Type 1)	1	User experienced data rate of 1 Gbit/s with *N* simultaneously served users/devices at the cell-edge, e.g., Indoor	3.33 (*N*=1), 6.67 (*N*=2), 13.33 (*N*=4)	Not available
		User experienced data rate of 100 Mbits/s with *N* simultaneously served users/devices at the cell-edge, for wide area coverage	0.67 (*N*=1), 1.32 (*N*=2), 2.64 (*N*=4)	Not available
	2	eMBB Dense Urban	0.83-4.17	Not available
		eMBB Indoor Hotspot	3-15	Not available
	3	With a file transfer of 10 Mbits by a single user at cell-edge in 1 msec	33.33 GHz (one direction)	Not available
		With a file transfer of 1 Mbit by a single user at cell-edge in 1 msec	3.33 GHz (one direction)	
		With a file transfer of 0.1 Mbits by a single user at cell-edge in 1 msec	333 MHz (one direction)	
Technical performance-based approach (Type 2)	–	Dense urban micro	14.8-19.7	5.8-7.7 (24.25-43.5 GHz range)
		Indoor hotspot		9-12 (24.25-43.5GHz and 45.5-86 GHz range)
Information from some countries based on their national considerations	–	–	7-16	2-6 (24.25-43.5 GHz range) 5-10 (43.5-86 GHz range)

Source: ITU-R Working Party 5D, LIAISON STATEMENT TO TASK GROUP 5/1, "SPECTRUM NEEDS AND CHARACTERISTICS FOR THE TERRESTRIAL COMPONENT OF IMT IN THE FREQUENCY RANGE BETWEEN 24.25 GHz AND 86 GHz", February 2017

Countries considered in the last row of the above table[164] are the following: United States, South Korea, Brazil, Egypt, Bahrain and the Russian Federation.

[164] https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Documents/5D_TEMP_249(Rev1).pdf

8.2. One5G project - Outdoor hotspots and smart offices with AR/VR and media applications

Network and UE deployment KPIs	Scenario #1: Outdoor hotspot	Scenario #2: Indoor hotspot	Comments
Layout and layers	Two layers: Macro + micro	Single layer: - Indoor floor (Open office) (12BSs per 120m x 50m) Candidate TRP numbers: 3, 6, 12	[38.913], Table 6.1.1-1: Attributes for indoor hotspot [38.802], Table A.2.1-1
ISD (m)	Macro: 200m Micro: 3 micro TRP per macro TRP	20m (Equivalent to 12TRPs per 120m x 50m)	[38.913], Table 6.1.1-1: Attributes for indoor hotspot Indoor scenarios assume a small ISD.
Carrier frequency/ BW	Around 4 GHz: Up to 200MHz (DL+UL) Around 30 GHz: Up to 1GHz (DL+UL) Around 70 GHz: Up to 1GHz (DL+UL) (Only indoor)		[38.913], Table 6.1.1-1: Attributes for indoor hotspot
BS / UE transmit power (dBm)	Macro: 40 dBm Micro: 33dBm UE: 23 dBm	DL: < 6 GHz → 24dBm; >6 GHz → 23 dBm UL: < 6 GHz → 23 dBm; 30 GHz → 23 dBm; 70 GHz → 21 dBm	Outdoor: [38.913] Indoor hotspot: To be defined in the new RAT study item. [RANGAN14] [38.802], Table A.2.1-1: System level evaluation assumptions.
# BS/UE antennas	BS Up to 256 Tx and Rx elements		[38.913]
	UE Around 4GHz: Up to 8 Tx and Rx antenna elements Above 4 GHz: Up to 32 Tx and Rx antenna elements		
Maximum # UEs	Uniform/macro TRP + clustered/micro TRP, 10 users per TRP	10 users per TRP; 100 % Indoor.	[38.913]
Maximum / Average # Active UEs	See "UE distribution and speed"		[38.913]
UE distribution	Uniform with temporal high concentration spots.		[38.803], Table 5.2.1.3-1: Single operator layout for indoor.
UE speed	Up to 30 km/h	3km/h	[38.913], Tables 6.1.1-1 and 6.1.1-2: Attributes respectively for indoor and outdoor hotspots.
Area traffic capacity	Peak value (w 3 Micro TRPs) - 4GHz DL → 0.347 Mbps/m2	30/70 GHz UL→15 Mbps/m² 30/70 GHz DL→30 Mbps/m²	[38.913], 7.14 Area traffic capacity.

Source: Deliverable D2.1 - Scenarios, KPIs, use cases and baseline system evaluation (https://one5g.eu/documents/)

	Peak value (w 3 Micro TRPs) - 4GHz UL → 0.173 Mbps/m2	4 GHz UL →3 Mbps/m^2 4 GHz DL → 6 Mbps/m^2	
Connection Density	200 – 2500/Km2	75/1000 m2	[NGMN15]
Traffic density	DL: 300 Mbps (750 Gbps/km^2) UL: 50 Mbps (125 Gbps/Km^2)	DL:15 Gbps / 1000 m^2 UL: 2 Gbps / 1000 m^2	Outdoor hotspot: [22.261] (Table 7-1-1) Indoor hotspot: [NGMN15]
Mobility interruption time	0ms	0 ms	[38.913], 7.7 Mobility interruption time It means the shortest time duration supported by the system during which a user terminal cannot exchange user plane packets with any base station during transitions.
Experienced data rates (Mbps)	User Experienced Data Rate: DL: 300 Mbps, UL: 50 Mbps	User Experienced Data Rate: DL: 1 Gbps, UL: 500 Mbps	[NGMN15]
		• 10 to 50 Mbps: current-gen 360°video (4K) • 50 to 200 Mbps: next-gen 360°video (8K, 90+ FPS, HDR, stereoscopic) • 200 to 5000 Mbps: 6 DoF video or free-viewpoint.	[QUALC17]

Source: Deliverable D2.1 - Scenarios, KPIs, use cases and baseline system evaluation (https://one5g.eu/documents/

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