ETSI GR mWT 022 V1.1.1 (2021-04)

Analysis of Spectrum, License Schemes and Network Scenarios in the RF bands above 174,8 GHz

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Foreword

This Group Report (GR) has been produced by ETSI Industry Specification Group (ISG) millimetre Wave Transmission (mWT).

Modal verbs terminology

In the present document "**should**", "**should not**", "**may**", "**need not**", "**will**", "**will not**", "**can**" and "**cannot**" are to be interpreted as described in clause 3.2 of the ETSI Drafting Rules (Verbal forms for the expression of provisions).

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Executive summary

The present document provides information about RF frequency range above 174,8 GHz, which have not been specifically addressed by an FS related deliverable by ETSI, nor any frequency plan is available by CEPT/ITU-R.

The analyses include an overview of normative status, regarding current status, foreseen activities for the Radio Conferences (clause 4), existing deliverables from various SDOs (clause 5), propagation characteristics (clause 6). In clause 7, a description of possible applications is provided, in clause 8 an overview of possible future applications is addressed.

Trials and projects are subjects of clauses 9 and 10, while clause 11 deals with licensing, suggesting a flexible regime as appropriate to cover this frequency range. Finally, clause 12 provides some technology related information.

Introduction

Within the scope of telecommunication, frequency bands above 170 GHz are not yet being commercially exploited nor fully covered by standards from all Standards Developing Organizations (SDOs).

The frequency band allocation in Article 5 of the ITU-R Radio Regulations [i.1] is shown in table 1, for the Fixed Service, which is allocated as primary in all the three Regions in RF bands 191,8-200 GHz, 209-217 GHz, 217-226 GHz, 231,5-232 GHz, 232-235 GHz, 238-240 GHz, 240-241 GHz, 252-265 GHz 265-275 GHz.

Table 1: ITU Table of Frequency Allocation (Radio Regulations 2016) - RF sub bands allocated to FS as primary service

Allocation to services		
Band [GHz]	**Region 1 - Region 2 - Region 3**	**Width [GHz]**
191,8-200	FIXED	8,2
209-217	FIXED	8
217-226	FIXED	9
231,5-232	FIXED	0,5
232-235	FIXED	3
238-240	FIXED	2
240-241	FIXED	1
252-265	FIXED	13
265-275	FIXED	10

1 Scope

The present document is intended to provide an analysis of Spectrum, License Schemes and Network Scenarios in the RF bands above 174,8 GHz, including current activities ongoing, foreseen applications and available documents addressing frequency ranges above the current D band, to support possible utilization of these frequencies by FS in next future.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

[i.1] ITU-R Radio Regulations 2016.

NOTE: Available at https://www.itu.int/pub/R-REG-RR-2016.

[i.2] Recommendation ITU-R F.699: "Reference radiation patterns for fixed wireless system antennas for use in coordination studies and interference assessment in the frequency range from 100 MHz to 86 GHz".

NOTE: Available at https://www.itu.int/rec/R-REC-F.699/en.

[i.3] Recommendation ITU-R F.1245: "Mathematical model of average and related radiation patterns for line-of-sight point-to-point fixed wireless system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 GHz to 86 GHz".

NOTE: Available at https://www.itu.int/rec/R-REC-F.1245/en.

[i.4] Recommendation ITU-R F.1336: "Reference radiation patterns of omnidirectional, sectoral and other antennas for the fixed and mobile service for use in sharing studies in the frequency range from 400 MHz to about 70 GHz".

NOTE: Available at https://www.itu.int/rec/R-REC-F.1336/en.

[i.5] Report ITU-R F.2323: "Fixed service use and future trends".

NOTE: Available at https://www.itu.int/pub/R-REP-F.2323-1-2017.

[i.6] Report ITU-R F.2416: "Technical and operational characteristics and applications of the point-to-point fixed service applications operating in the frequency band 275-450 GHz".

NOTE: Available at https://www.itu.int/pub/R-REP-F.2416-2018.

[i.7] Report ITU-R M.2417-0: "Technical and operational characteristics of land-mobile service applications in the frequency range 275-450 GHz".

NOTE: Available at https://www.itu.int/pub/R-REP-M.2417-2017.

[i.8] Recommendation ITU-R P.525-4 (08/2019): "Calculation of free-space attenuation".

NOTE: Available at https://www.itu.int/rec/R-REC-P.525-4-201908-I/en.

[i.9] Recommendation ITU-R P.530-17 (12/2017): "Propagation data and prediction methods required for the design of terrestrial line-of-sight systems".

NOTE: Available at https://www.itu.int/rec/R-REC-P.530-17-201712-I/en.

[i.10] Recommendation ITU-R P.676-12: "Attenuation due to atmospheric gases".

NOTE: Available at https://www.itu.int/rec/R-REC-P.676-12-201908-I/en.

[i.11] Recommendation ITU-R P.837: "Characteristics of precipitation for propagation modelling".

NOTE: Available at https://www.itu.int/rec/R-REC-P.837/en.

[i.12] Recommendation ITU-R P.838-3: "Specific attenuation model for rain for use in prediction methods".

NOTE: Available at https://www.itu.int/rec/R-REC-P.838-3-200503-I/en.

[i.13] Recommendation ITU-R P.840-8 (08/2019): "Attenuation due to clouds and fog".

NOTE: Available at https://www.itu.int/rec/R-REC-P.840-8-201908-I/en.

[i.14] Recommendation ITU-R P.1238-10 (08/2019): "Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 900 MHz to 100 GHz".

NOTE: Available at https://www.itu.int/rec/R-REC-P.1238-10-201908-I/en.

[i.15] Recommendation ITU-R P.1411-10 (08/2019): "Propagation data and prediction methods for the planning of short-range outdoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz".

NOTE: Available at https://www.itu.int/rec/R-REC-P.1411-10-201908-I/en.

[i.16] Report ITU-R P.2406-1: "Studies for short-path propagation data and models for terrestrial radiocommunication systems in the frequency range 6 GHz to 450 GHz".

NOTE: Available at https://www.itu.int/pub/R-REP-P.2406-1-2019.

[i.17] Report ITU-R RA.2189: "Sharing between the radio astronomy service and active services in the frequency range 275-3 000 GHz".

NOTE: Available at https://www.itu.int/pub/R-REP-RA.2189-1-2018.

[i.18] Recommendation ITU-R RA.1860: "Preferred frequency bands for radio astronomical measurements in the range 1-3 THz".

NOTE: Available at https://www.itu.int/rec/R-REC-RA.1860-0-201001-I/en.

[i.19] Report ITU-R RS 2194: "Passive bands of scientific interest to EESS/SRS from 275 to 3 000 GHz".

NOTE: Available at https://www.itu.int/pub/R-REP-RS.2194-2010.

[i.20] Report ITU-R RS.2431: "Technical and operational characteristics of EESS (passive) systems in the frequency range 275-450 GHz".

NOTE: Available at https://www.itu.int/pub/R-REP-RS.2431-2019.

[i.21] Report ITU-R SM.2352-0: "Technology trends of active services in the frequency range 275-3 000 GHz".

NOTE: Available at https://www.itu.int/pub/R-REP-SM.2352-2015.

[i.22] Report ITU-R SM.2450-0: "Sharing and compatibility studies between land-mobile, fixed and passive services in the frequency range 275-450 GHz".

NOTE: Available at https://www.itu.int/pub/R-REP-SM.2450-2019.

[i.23] ETSI White Paper No. 15 (July 2016): "mmWave Semiconductor Industry Technologies: Status and Evolution".

NOTE: Available at http://www.etsi.org/images/files/ETSIWhitePapers/etsi_wp15_mwt_semiconductor_technology.pdf.

[i.24] ETSI TR 103 498: "System Reference document (SRdoc); Short Range Devices (SRD) using Ultra Wide Band (UWB); Transmission characteristics; Technical characteristics for SRD equipment using Ultra Wide Band technology (UWB); Radiodetermination application within the frequency range 120 GHz to 260 GHz".

NOTE: Available at https://www.etsi.org/deliver/etsi_tr/103400_103499/103498/01.01.01_60/tr_103498v010101p.pdf.

[i.25] CEPT Report 70: "In response to the EC Permanent Mandate on the "Annual update of the technical annex of the Commission Decision on the technical harmonisation of radio spectrum for use by short range devices".

NOTE: Available at https://docdb.cept.org/document/9684.

[i.26] Recommendation ERC 70-03: "Relating to the use of Short Range Devices (SRD)".

NOTE: Available at https://docdb.cept.org/download/25c41779-cd6e/Rec7003e.pdf.

[i.27] ERC Report 25: "The European table of frequency allocations and utilisations in the frequency range 8.3 kHz to 3000 GHz".

NOTE: Available at https://docdb.cept.org/download/2ca5fcbd-4090/ERCReport025.pdf.

[i.28] IEEE Std 802.15.3™-2017: "IEEE Standard for High Data Rate Wireless Multi-Media Networks -- Amendment 1: High-Rate Close Proximity Point-to-Point Communications".

NOTE: Available at https://ieeexplore.ieee.org/document/7942281.

[i.29] ETSI GR mWT 018: "Analysis of Spectrum, License Schemes and Network Scenarios in the W-band".

NOTE: Available at https://www.etsi.org/deliver/etsi_gr/mWT/001_099/018/01.01.01_60/gr_mWT018v010101p.pdf.

[i.30] Commission Implementing Decision (EU) 2019/1345 of 2 August 2019 amending Decision 2006/771/EC updating harmonised technical conditions in the area of radio spectrum use for short-range devices.

NOTE: Available at https://eur-lex.europa.eu/eli/dec_impl/2019/1345/oj.

[i.31] APT/AWG/REP-66(Rev.1): "Short range radiocommunication systems and application scenarios operating in the frequency range 275 - 1000 GHz".

NOTE: Available at https://www.apt.int/sites/default/files/APT-AWG-REP-66Rev.1_SRD_System_in_275-1000GHZ.docx.

[i.32] Recommendation ITU-R F.758: "System parameters and considerations in the development of criteria for sharing or compatibility between digital fixed wireless systems in the fixed service and systems in other services and other sources of interference".

NOTE: Available at https://www.itu.int/rec/R-REC-F/recommendation.asp?lang=en&parent=R-REC-F.758.

[i.33] ITU-R Resolution 731 (REV.WRC 19): "Consideration of sharing and adjacent-band compatibility between passive and active services above 71 GHz".

NOTE: Available at https://www.itu.int/net/ITU-R/conferences/docs/ties/res-731-en.pdf.

[i.34] CPM Report to the 2019 World Radiocommunication Conference.

NOTE: Available at https://www.itu.int/md/meetingdoc.asp?lang=en&parent=R16-WRC19-C-0003.

3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

Void

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AI	Agenda Item
APT	Asia Pacific Telecommunity
BBU	Baseband Unit
BER	Bit Error Ratio
BPSK	Binary Phase Shift Keying
BS	Base Station
BW	BandWidth
CPM	Conference Preparatory Meeting
DHBT	Double Heterojunction Bipolar Transistor
ECA	European Common Allocation
EESS	Earth Exploration Satellite Service
EIA	Electronic Industries Alliance
EIRP	Effective Isotropic Radiated Power
FDD	Frequency Division Duplex
FS	Fixed Service
FWS	Fixed Wireless System
HBT	Heterojunction Bipolar Transistor
HEMT	Hi Electron Mobility Transistor
IMT	International Mobile Telecommunications
ISS	Inter-Satellite Service
JAXA	Japan Aerospace Exploration Agency
LMS	Land Mobile Systems
LO	Local Oscillator
LOS	Line Of Sight
LPR	Level Probing Radars
LTE	Long Term Evolution
MAC	Media Access Control
nLOS	near Line Of Sight
NLOS	Non Line Of Sight
PHY	Physical Layer
QAM	Quadrature Amplitude Modulation
RA	Radio Astronomy
RAS	Radio Astronomy Service
RF	Radio Frequency
RR	Radio Regulations
RRH	Remote Radio Head
SDO	Standards Developing Organization
SOI	Silicon On Insulator
SRD	Short Range Device
TDD	Time Division Duplex

TWTA	Traveling-Wave Tube Amplifier
UWB	Ultra Wide Band
WLAN	Wireless LAN
WRC	World Radio Conference

4 RF bands related studies

4.1 Highlights

In the search for more spectrum, all wireless applications are already using higher frequencies than the traditional microwave bands, and the use of will increase. The frequency bands above 174,8 GHz are under consideration for large volume applications supporting services that require high speed and huge bandwidths.

4.2 Frequency allocation

4.2.0 Generalities

RF bands allocation to various services, including Fixed Service (FS), by the ITU-R Radio Regulations 2016 [i.1], in the bands above 174,8 GHz, are shown in table 2, followed by related footnotes.

It should be considered that the overall range contains some fragmentation, such as the extension of continuous sub-bands allocated to FS presents a spread from 0,5 GHz to 13 GHz, depending on frequency intervals. Such fragmentation, which is aligned with ITU-R Radio Regulations [i.1] should be, kept into account, when considering possibility to use wide continuous RF bands to provide very high transmission capacities in future.

4.2.1 ITU-R Radio Regulations

ITU-R Radio Regulations [i.1] is the highest level document containing provisions which are applied worldwide. They are revised by the WRC conferences, which are held every 4 years. Between most important provisions for the radiocommunication services, they contain, in Article 5, the allocation of frequency ranges to the various services, indicating their priority (name in uppercase letters indicate that the service is primary in that band, lowercase letters means secondary service in that band). Frequency intervals can be allocated to one or more services, with same for different status.

Table 2 shows the frequency ranges where FS is allocated as primary, together with the other services which are also allowed to use same frequency intervals, with their state. Just below the table, footnotes are reported, as indicated in the table, where additional info can be found.

Table 2: ITU Table of Frequency Allocation (Radio Regulations 2016 [i.1])

Allocation to services	
Band [GHz]	**Region 1 - Region 2 - Region 3**
174.8-182	**EARTH EXPLORATION-SATELLITE (passive)** **INTER-SATELLITE 5.562H** **SPACE RESEARCH (passive)**
182-185	**EARTH EXPLORATION-SATELLITE (passive)** **RADIO ASTRONOMY** **SPACE RESEARCH (passive)** **5.340**
185-190	**EARTH EXPLORATION-SATELLITE (passive)** **INTER-SATELLITE 5.562H** **SPACE RESEARCH (passive)**
190-191.8	**EARTH EXPLORATION-SATELLITE (passive)** **SPACE RESEARCH (passive)** **5.340**
191.8-200	**FIXED** **INTER-SATELLITE** **MOBILE 5.558**

Allocation to services	
Band [GHz]	**Region 1 - Region 2 - Region 3**
	MOBILE-SATELLITE **RADIONAVIGATION** **RADIONAVIGATION-SATELLITE** **5.149 5.341 5.554**
200-209	**EARTH EXPLORATION-SATELLITE (passive)** **RADIO ASTRONOMY** **SPACE RESEARCH (passive)** **5.340 5.341 5.563A**
209-217	**FIXED** **FIXED-SATELLITE (Earth-to-space)** **MOBILE** **RADIO ASTRONOMY** **5.149 5.341**
217-226	**FIXED** **FIXED-SATELLITE (Earth-to-space)** **MOBILE** **RADIO ASTRONOMY** **SPACE RESEARCH (passive) 5.562B** **5.149 5.341**
226-231.5	**EARTH EXPLORATION-SATELLITE (passive)** **RADIO ASTRONOMY** **SPACE RESEARCH (passive)** **5.340**
231.5-232	**FIXED** **MOBILE** **Radiolocation**
232-235	**FIXED** **FIXED-SATELLITE (space-to-Earth)** **MOBILE** **Radiolocation**
235-238	**EARTH EXPLORATION-SATELLITE (passive)** **FIXED-SATELLITE (space-to-Earth)** **SPACE RESEARCH (passive)** **5.563A 5.563B**
238-240	**FIXED** **FIXED-SATELLITE (space-to-Earth)** **MOBILE** **RADIOLOCATION** **RADIONAVIGATION** **RADIONAVIGATION-SATELLITE**
240-241	**FIXED** **MOBILE** **RADIOLOCATION**
241-248	**RADIO ASTRONOMY** **RADIOLOCATION** **Amateur** **Amateur-satellite** **5.138 5.149**
248-250	**AMATEUR** **AMATEUR-SATELLITE** **Radio astronomy** **5.149**
250-252	**EARTH EXPLORATION-SATELLITE (passive)** **RADIO ASTRONOMY** **SPACE RESEARCH (passive)** **5.340 5.563A**
252-265	**FIXED** **MOBILE** **MOBILE-SATELLITE (Earth-to-space)** **RADIO ASTRONOMY** **RADIONAVIGATION** **RADIONAVIGATION-SATELLITE**
265-275	**FIXED** **FIXED-SATELLITE (Earth-to-space)** **MOBILE**

Allocation to services	
Band [GHz]	**Region 1 - Region 2 - Region 3**
	RADIO ASTRONOMY
275-3000	**(Not allocated) 5.565**

Footnotes related to table 2

5.138 *The following bands: 6 765-6 795 kHz (centre frequency 6 780 kHz), 433.05-434.79 MHz (centre frequency 433.92 MHz) in Region 1 except in the countries mentioned in No. 5.280, 61-61.5 GHz (centre frequency 61.25 GHz), 122-123 GHz (centre frequency 122.5 GHz), and 244-246 GHz (centre frequency 245 GHz)are designated for industrial, scientific and medical (ISM) applications. The use of these frequency bands for ISM applications shall be subject to special authorization by the administration concerned, in agreement with other administrations whose radiocommunication services might be affected. In applying this provision, administrations shall have due regard to the latest relevant Recommendation ITU-Rs.*

5.149 *In making assignments to stations of other services to which the bands: 13 360-13 410 kHz, 25 550-25 670 kHz, 37.5-38.25 MHz, 73-74.6 MHz in Regions 1 and 3, 150.05-153 MHz in Region 1, 322-328.6 MHz, 406.1-410 MHz, 608-614 MHz in Regions 1 and 3, 1 330-1 400 MHz, 1 610.6-1 613.8 MHz, 1 660-1 670 MHz, 1 718.8-1 722.2 MHz, 2 655-2 690 MHz, 3 260-3 267 MHz, 3 332-3 339 MHz, 3 345.8-3 352.5 MHz, 4 825-4 835 MHz, 4 950-4 990 MHz, 4 990-5 000 MHz, 6 650-6 675.2 MHz, 10.6-10.68 GHz, 14.47-14.5 GHz, 22.01-22.21 GHz, 22.21-22.5 GHz, 22.81-22.86 GHz, 23.07-23.12 GHz, 31.2-31.3 GHz, 31.5-31.8 GHz in Regions 1 and 3, 36.43-36.5 GHz, 42.5-43.5 GHz, 48.94-49.04 GHz, 76-86 GHz, 92-94 GHz, 94.1-100 GHz, 102-109.5 GHz, 111.8-114.25 GHz, 128.33-128.59 GHz, 129.23-129.49 GHz, 130-134 GHz, 136-148.5 GHz, 151.5-158.5 GHz, 168.59-168.93 GHz, 171.11-171.45 GHz, 172.31-172.65 GHz, 173.52-173.85 GHz, 195.75-196.15 GHz, 209-226 GHz, 241-250 GHz, 252-275 GHz are allocated, administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 4.5 and 4.6 and Article 29). (WRC-07)*

5.340 *All emissions are prohibited in the following bands: 1 400-1 427 MHz, 2 690-2 700 MHz, except those provided for by No. 5.422, 10.68-10.7 GHz, except those provided for by No. 5.483, 15.35-15.4 GHz, except those provided for by No. 5.511, 23.6-24 GHz, 31.3-31.5 GHz, 31.5-31.8 GHz, in Region 2, 48.94-49.04 GHz, from airborne stations 50.2-50.4 GHz2, 52.6-54.25 GHz, 86-92 GHz, 100-102 GHz, 109.5-111.8 GHz, 114.25-116 GHz, 148.5-151.5 GHz, 164-167 GHz, 182-185 GHz, 190-191.8 GHz, 200-209 GHz, 226-231.5 GHz, 250-252 GHz. (WRC-03)*

5.341 *In the bands 1 400-1 727 MHz, 101-120 GHz and 197-220 GHz, passive research is being conducted by some countries in a programme for the search for intentional emissions of extraterrestrial origin.*

5.554 *In the bands 43.5-47 GHz, 66-71 GHz, 95-100 GHz, 123-130 GHz, 191.8-200 GHz and 252-265 GHz, satellite links connecting land stations at specified fixed points are also authorized when used in conjunction with the mobile-satellite service or the radionavigation-satellite service. (WRC-2000)*

5.558 *In the bands 55.78-58.2 GHz, 59-64 GHz, 66-71 GHz, 122.25-123 GHz, 130-134 GHz, 167-174.8 GHz and 191.8-200 GHz, stations in the aeronautical mobile service may be operated subject to not causing harmful interference to the inter-satellite service (see No. 5.43). (WRC-2000)*

5.562B *In the bands 105-109.5 GHz, 111.8-114.25 GHz, 155.5-158.5 GHz and 217-226 GHz, the use of this allocation is limited to space-based radio astronomy only. (WRC-2000)*

5.563A *In the bands 200-209 GHz, 235-238 GHz, 250-252 GHz and 265-275 GHz, ground-based passive atmospheric sensing is carried out to monitor atmospheric constituents. (WRC-2000)*

5.563B *The band 237.9-238 GHz is also allocated to the Earth exploration-satellite service (active) and the space research service (active) for spaceborne cloud radars only. (WRC-2000)*
5.564A For the operation of fixed and land mobile service applications in frequency bands in the range 275-450 GHz:
The frequency bands 275-296 GHz, 306-313 GHz, 318-333 GHz and 356-450 GHz are identified for use by administrations for the implementation of land mobile and fixed service applications, where no specific conditions are necessary to protect Earth exploration-satellite service (passive) applications.
The frequency bands 296-306 GHz, 313-318 GHz and 333-356 GHz may only be used by fixed and land mobile service applications when specific conditions to ensure the protection of Earth exploration-satellite service (passive) applications are determined in accordance with Resolution 731 (Rev.WRC-19).
In those portions of the frequency range 275-450 GHz where radio astronomy applications are used, specific conditions (e.g. minimum separation distances and/or avoidance angles) may be necessary to ensure protection of radio astronomy sites from land mobile and/or fixed service applications, on a case-by-case basis in accordance with Resolution 731 (Rev.WRC-19).
The use of the above-mentioned frequency bands by land mobile and fixed service applications does not preclude use by, and does not establish priority over, any other applications of radio services in the range of 275-450 GHz. (WRC-19)

5.565 *The following frequency bands in the range 275-1 000 GHz are identified for use by administrations for passive service applications:*
– radio astronomy service: 275-323 GHz, 327-371 GHz, 388-424 GHz, 426-442 GHz, 453-510 GHz, 623-711 GHz, 795-909 GHz and 926-945 GHz;
– Earth exploration-satellite service (passive) and space research service (passive): 275-286 GHz, 296-306 GHz, 313-356 GHz, 361-365 GHz, 369-392 GHz, 397-399 GHz, 409-411 GHz, 416-434 GHz, 439-467 GHz, 477-502 GHz, 523-527 GHz, 538-581 GHz, 611-630 GHz, 634-654 GHz, 657-692 GHz, 713-718 GHz, 729-733 GHz, 750-754 GHz, 771-776 GHz, 823-846 GHz, 850-854 GHz, 857-862 GHz, 866-882 GHz, 905-928 GHz, 951-956 GHz, 968-973 GHz and 985-990 GHz.
The use of the range 275-1 000 GHz by the passive services does not preclude use of this range by active services. Administrations wishing to make frequencies in the 275-1 000 GHz range available for active service applications are urged to take all practicable steps to protect these passive services from harmful interference until the date when the Table of Frequency Allocations is established in the above-mentioned 275-1 000 GHz frequency range.
All frequencies in the range 1 000-3 000 GHz may be used by both active and passive services. (WRC-12)

4.2.2 CEPT

ERC Report 25 [i.27] contains the European table of frequency allocations and applications, in the frequency range 8,3 KHz to 3 000 GHz (ECA table). It is derived from the ITU-R Radio Regulations [i.1].

Currently, no allocation to any service is foreseen for frequencies higher than 275 GHz, although a note that the use for active and passive services is possible.

4.2.3 Radio-frequency channel arrangements

At the moment, while channels plans are available from CEPT for W and D- bands, based on 250 MHz-wide basic RF channels, no channel plan is currently available for RF ranges above 174,8 GHz.

IEEE Std 802.15.3d™-2017 [i.28] includes a channel plan for RF range 252,72 to 321,84 GHz, where basic slots are integer multiple of 2 160 MHz, between 2,16 GHz and 69,12 GHz.

4.3 Activities for Recommendation ITU-R WRC 19

4.3.1 ITU-R

Frequencies higher than 174,8 GHz have been considered during period 2016-2019 by ITU-R, for possible amendments of the RR, under WRC-19 Agenda item 1.15.

This agenda item was aimed to identify spectrum for Land Mobile Service (LMS) and Fixed Service (FS) applications in the 275-450 GHz frequency range while maintaining protection of the existing Earth Exploration Satellite Service (EESS) (passive) and Radio Astronomy Service (RAS) applications.

Compatibility studies concluded that atmospheric attenuation at 275-450 GHz is not sufficient to provide compatibility between FS and RAS operations in the absence of other considerations. Separation distances and/or avoidance angles between RAS stations and FS stations should be considered depending on the deployment environment of FS stations. It was assumed that for the RAS studies, FS also covered the case for LMS.

Methods to satisfy the agenda item

After analyses of studies summarized in Report ITU-R SM.2450 [i.22], seven different proposals (so called "methods") have been proposed in the CPM Report [i.34] to be discussed as bases for ITU-R Radio Regulations [i.1] modifications, by WRC-19, including no change, definition of frequency ranges not requiring specific constraints to protect EESS (passive), regulatory solutions to protect passive services.

4.3.2 CEPT position

CEPT supported the inclusion of a new footnote to Article 5 of the ITU-R Radio Regulations [i.1] identifying the following frequency bands for fixed and mobile service applications in the range 275-450 GHz while maintaining the protection of the passive services identified in note 5.565:

- 275-296 GHz
- 306-313 GHz
- 318-333 GHz
- 356-450 GHz

With a total bandwidth of 137 GHz proposed to be identified above 275 GHz, CEPT stresses that this is exceeding the assessed spectrum requirements of 50 GHz for the land mobile and fixed services, each (with possibility of overlap).

In particular, the band 356-450 MHz provides a large contiguous bandwidth of 94 GHz and, with the 23 GHz already allocated to land mobile and fixed services in the lower adjacent band 252-275 GHz, the identification of the band 275-296 GHz also allows for providing a large contiguous bandwidth of 44 GHz.

4.3.3 WRC-19 Results

Following main results of the WRC-19 are of interest of frequency ranges addressed by the present document:

- Frequency bands as indicated by CEPT were agreed to be inserted in a new note 5.564A in Article 5, related to the operation of fixed and land mobile service applications in frequency bands in the range 275-450 GHz.
- Resolution 731 [i.33], referred in the text of new footnote, has been modified and invites ITU-R to undertake some specific actions, including:
  - to continue its studies to determine if and under what conditions sharing is possible between active and passive services in the bands above 71 GHz, such as, but not limited to, 100-102 GHz, 116-122,25 GHz, 148,5-151,5 GHz, 174,8-191,8 GHz, 226-231,5 GHz and 235-238 GHz;
  - to conduct studies to determine the specific conditions to be applied to the land mobile and fixed service applications to ensure the protection of Earth exploration-satellite service (passive) applications in the frequency bands 296-306 GHz, 313-318 GHz and 333-356 GHz;
  - to complete the necessary studies when the technical characteristics of the active services in these bands are known;
  - to develop Recommendations specifying sharing criteria for those bands where sharing is feasible.

4.4 Activities for WRC-23/WRC-27

WRC-23: no specific AI, related to the allocation of frequencies above 174,8 GHz by FS, is foreseen in the agenda for the next Conference (WRC-23).

Agenda Item 1.14, under the responsibility of ITU-R WP 7C, is the framework requiring studies in this frequency range is related to, for a possible new primary frequency allocations to EESS (passive) in the frequency range 231,5-252 GHz. In order to undertake these studies, request for receiving equipment/system characteristics and protection criteria for the various services have been requested by ITU-R WP 7C to the groups inside ITU-R, which are responsible for the related Services, including WP5C for the FS, which at the moment has not developed yet specific documents that describe the fixed service technical and operational characteristics for the frequency band 231,5-252 GHz.

WRC-27: no specific AI, related to the allocation of frequencies above 174,8 GHz by FS, is foreseen in the provisional agenda for the second next Conference (WRC-27). Only requests for studies in this frequency range is related to provisional AI 2.1, for a possible new additional spectrum allocations to the radiolocation service on a co-primary basis in the frequency band 231,5-275 GHz and identification for radiolocation applications in frequency bands in the range 275-700 GHz for millimetre and sub-millimetre wave imaging systems.

5 Propagation characteristics of the RF bands above 174,8 GHz

Propagation of radiowaves is subject to an attenuation which mainly comes from rain and atmospheric gases. Specific attenuation from gases exhibits a global trend to increase with frequency, in addition to absorption peaks in relation with specific frequencies, due to specific gases (see figure 1).

A detail of the attenuation produced by specific components of atmosphere, evaluated at sea level, is reported in figure 2, up to 10 THz.

Attenuation by rain shows a significant increase for frequencies up to about 100 GHz, while for higher frequencies, there is a trend to a low decrease. Higher rain rated produce higher attenuation.

Specific rain attenuation is shown in figure 3, for frequencies up to 300 GHz.

Specific combined attenuation due to atmospheric gases and rain with increasing frequency, shown in Report ITU-R F.2416 [i.6], calculated according to Recommendation ITU-R P.530-17 [i.9], is shown in figure 4, for frequencies up to 450 GHz.

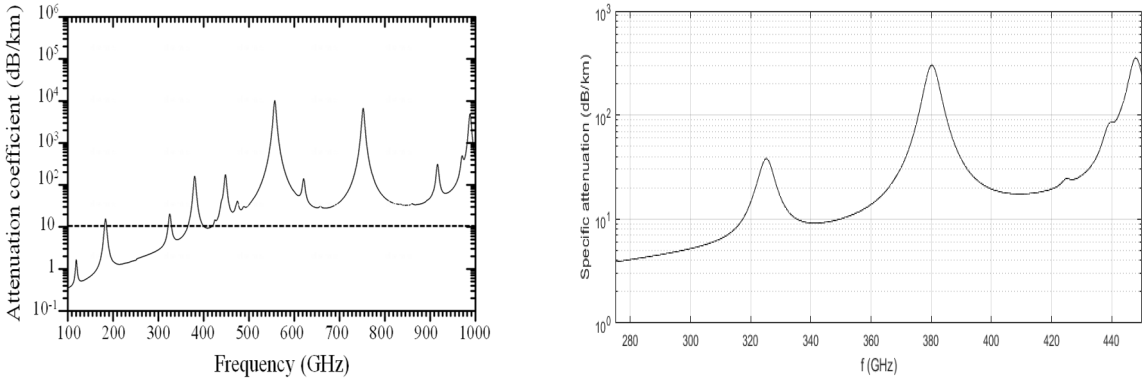

Figure 1: Attenuation from atmospheric gases
(Source: Report ITU-R F.2416 [i.6] and Recommendation ITU-R P.676-12 [i.10])

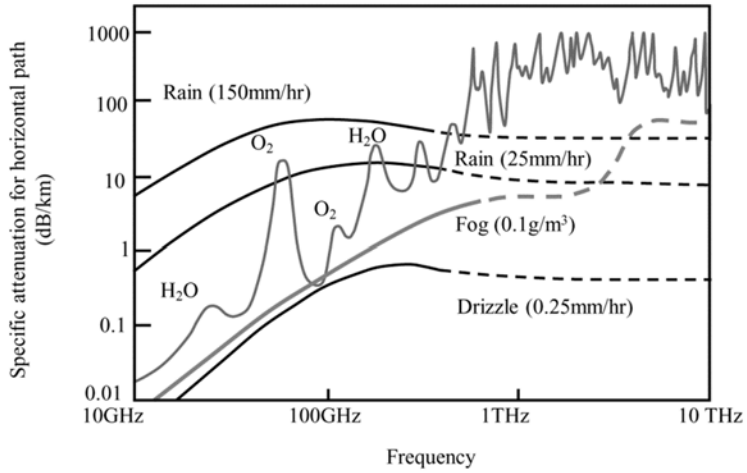

Figure 2: Attenuation by specific components (Source: Report ITU-R F. 2323 [i.5])

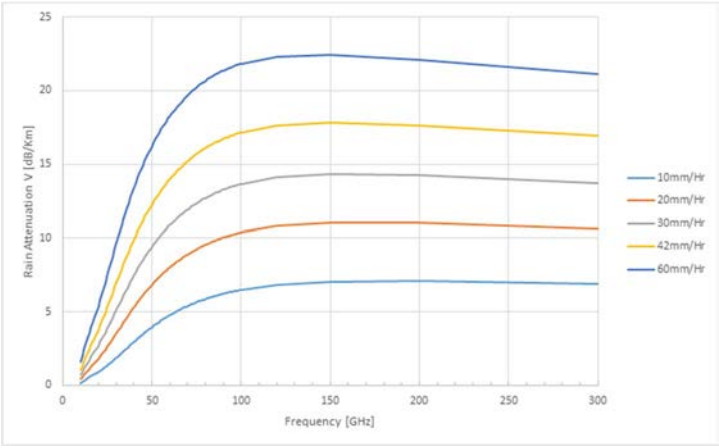

Figure 3: Specific rain attenuation (Source: Recommendation ITU-R P.838 [i.12])

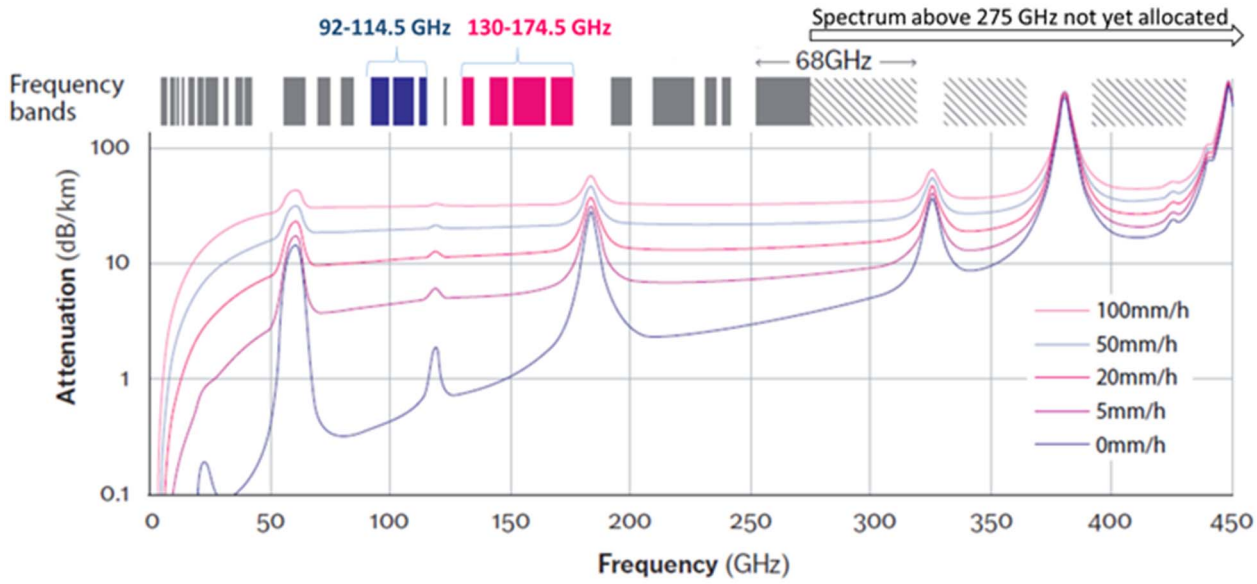

Figure 4: Combined rain and gas attenuation (Source: Report ITU-R F.2416 [i.6])

6 Applications/possible interest for industry

6.1 Highlights

An overview of applications currently considered for the various services in specific Recommendations or Reports is given in this clause. More specific aspects, in any, are covered by other clauses of the present document whose reference is indicated in the text.

6.2 Fixed Service applications

The possible preferred use of Fixed Service in frequency bands above 174,8 GHz is assumed to be the provision of high capacity fronthaul and backhaul functionalities to IMT and future networks, as described in Report ITU-R F. 2416 [i.6]. A possible transport capacity target of 100 Gbit/s is mentioned.

Typical requirements for backhaul/fronthaul are provided in Report ITU-R SM. 2352 [i.21]. In cases, where several tens of Gbit/s are required, the THz frequency range are considered as a possible attractive solution.

Reports ITU-R SM. 2450 [i.22] and ITU-R F.2416 [i.6] provide insight on fronthaul and backhaul, indicating the frequency ranges 275-325 GHz and 380-445 GHz as suitable for the scope, and provide the expected technical and operational characteristics for sharing and compatibility studies where fixed service is involved (see clause 8.2 for more information).

In the documents, additional aspects are considered, including propagation characteristics and technology.

In relation with networks, an estimation of foreseen link density in the order of 10 BS/km^2 is contained, based on actual networks deployment and expectation in Japan.

Report ITU-R SM. 2450 [i.22] states that a bandwidth of around 25 GHz may satisfy the initial typical deployment scenarios while a bandwidth of about 50 GHz will sufficiently support the evolution of IMT traffic of fronthaul and backhaul. The Report also considers frequency band 330-370 GHz as theoretically possible.

Guidance on the future development of the Fixed Service (FS) taking into account evolution of current use and technology development, application trends for fixed wireless systems and future requirements for fixed wireless systems are provided in Report ITU-R F.2323 [i.5] (Use and future trends). Although developed mainly considering frequency ranges currently utilized, mostly below 100 GHz, the same document addresses several info also of possible interest for higher frequencies in next future. Among them, attention is given to FWS use in telecommunication networks, regulatory regimes, technology and antennas.

Suitability of FWS for transport (trunking), Mobile backhaul, Fixed wireless access (examples are provided), Temporary FS (disaster recovery, electronic newsgathering), low latency applications (trading) is considered.

Information and considerations regarding regulatory regimes and licensing for various regions/countries are also given, together with clauses related to propagation, spectrum and capacity, technology. A summary of existing ITU-R sharing and compatibility studies between FS and other services is included.

Frequencies above the D-band are just referenced in relation to antennas and propagation deliverables (Recommendation ITU-R P.837 [i.11] and Recommendation ITU-R P.838 [i.12]).

IEEE std 802.15.3d 2017 [i.28], developed in the context of High Data Rate Wireless Multi-Media Networks, contains technical specifications at a physical layer (PHY) in frequency range between 252 GHz and 325 GHz for switched point-to-point link.

6.3 Passive service applications

Several frequency bands in the 275-450 GHz range are identified for use by passive services for scientific investigation and environmental sensing and monitoring by both the EESS and the RAS, as provided in ITU-R Radio Regulations [i.1] No. 5.565.

Report ITU-R RS.2194 [i.19] addresses the bands of interest to EESS/SRS (passive) from 275 to 3 000 GHz. Same document presents sharing studies between passive spaceborne instruments and active services, which are limited to ISS, since the strong atmospheric absorption in that region of the spectrum effectively shields passive spaceborne instruments from terrestrial-based active services.

In this frequency range there are currently nine current or planned EESS (passive) sensors, which perform global measurements. Additionally, there are at least thirteen distinct RAS sites using these frequencies throughout the world at present, although a few more may be planned in the future.

6.4 Earth exploration-satellite service

Report ITU-R RS.2431 [i.20] provides technical and operational characteristics of EESS (passive) systems in the frequency range 275-450 GHz. In this frequency range, there are several different systems using various portions of this band for scientific measurements, and additional systems are planned.

Indications related to these systems are provided in Annex 1.

Measurements of the sensitivity of millimetre and sub-millimetre frequencies to atmospheric temperature and water vapour variations are given, showing examples of seasonal variations.

Remote sensors can use a limited number of channels. Channels are in general occupying a wide band (in the order of few GHz to about 10 GHz).

6.5 Land mobile service applications

The LMS applications typically operate over short distances mostly in indoors environment and/or with shielded conditions as well as device blocking operations.

Report ITU-R M.2417 [i.7] provides the technical and operational characteristics and spectrum needs of LMS applications operating in the frequency band 275-450 GHz.

Several LMS applications are identified to date, such as:

- Close Proximity Mobile System (CPMS) applications, including KIOSK downloading mobile system (enjoy movies, news, magazines, and music by smart phones and tablet terminals), inter-chip communications (e.g. inside racks of servers/routers in data center of big networks).
- Intra device communications (connection of two or more Printed Circuit Boards (PCBs) or even chips on the same PCB inside a device).
- Wireless links for data centers.

The request in spectrum is in the order of 50 GHz, the operating lengths are less than 1 meter, apart for wireless links in data centers, where length is limited to about 100 m.

Report ITU-R SM. 2450 [i.22] contains results of sharing and compatibility studies between land-mobile, fixed and passive services in the frequency range 275-450 GHz, based on the technical information available on LMS and FS characteristics in Reports ITU-R M.2417-0 [i.7] and ITU-R F.2416 [i.6].

Most of the studies concluded that in the bands 275-296 GHz, 306-313 GHz, 320-330 GHz, and 356-450 GHz only, no specific conditions to protect EESS are necessary, for systems operating within the parameters given in the referenced ITU-R Reports.

Compatibility studies concluded that atmospheric attenuation independent of free-space losses at 275-450 GHz is not sufficient to provide compatibility between FS and RAS operations in the absence of other considerations. Separation distances and/or avoidance angles between RAS stations and FS stations should be considered depending on the deployment environment of FS stations.

6.6 Radio Astronomy service applications

Radio Astronomy sites on the Earth surface consist of radiotelescopes, generally located at sites with low influence from human activities (high and/or isolated locations).

Preferred frequency bands for radio astronomical measurements, including radio frequency lines corresponding to several substances, can be found in specific Recommendation ITU-Rs (see bibliography).

Compatibility studies between RAS and FS, reported in Report ITU-R SM.2450 [i.22], concluded that atmospheric attenuation independent of free-space losses at 275-450 GHz could not be sufficient to provide compatibility between FS and RAS operations in the absence of other considerations. Separation distances and/or avoidance angles between RAS stations and FS stations should be considered depending on the deployment environment of FS stations.

ITU-R Report RA.2189 [i.17] contains measurements of atmospheric attenuation in the frequency range 275-3 000 GHz, including thresholds levels for harmful interference, for two radiotelescopes, located in Atacama desert (Chile) and Sierra Nigra (Mexico).

Interference calculations are carried on for FS, satellites and aeronautical. In case of FS, transmitted power levels in the range from 10 to 30 dBm are assumed (30 cm antenna).

Report RA.2189 [i.17] concludes that sharing with radio astronomy is possible if atmospheric characteristics, as well as transmitter antenna directivity, are taken into account. In particular, direct illumination of radio astronomy sites by transmitters close to sea level, if geometrically possible, would likely involve high atmospheric absorption effects, and the implication is that the impact from FS is expected to be less heavy than for other services.

6.7 Space Research service applications

The use of radio telescopes from space platforms, conducted under the space research service (passive), provides access to the overall radio spectrum; spectral lines and continuum radio astronomical observations conducted in the frequency range between 1 000 and 3 000 GHz are detailed in Recommendation ITU-R RA.1860 [i.18].

6.8 Short Range Devices (SRDs)

Short Range Devices (SRDs) are not belonging to a specific service, in the sense specified by the ITU-R Radio Regulations [i.1]; as such, their use should not produce harmful interference to any existing service, nor can they ask for protection from them.

However, due to widespread use of these devices, activities have been undertaken, and still living, by SDOs, to establish and maintain proper technical characteristics.

ETSI TR 103 498 [i.24] refers to UWB radiodetermination applications within the frequency range 120 GHz to 260 GHz for future systems, to be used for following purposes:

- Object detection and classification/characterization; quality assessment and contour detection are examples of this category of use.

- Motion, speed and presence detection; microwave barrier sensing, object detection and surveillance, contactless flow measurements, gesture control and recognition are considered.
- Distance measurement, such as level probing or high precision measurements for rails or pneumatic/hydraulic cylinders.
- Displacement measurement: thickness of plastic during production and building deformation are shown.

It should be noted that several systems of this type require a large BW (at least 20 GHz or 15 % of the start frequency).

7 Existing deliverables

7.1 Highlights

The possible use and increased interest towards management of high data rate, in addition of the evolution of technology, are shifting the interest of telecommunication to consider extension of upper limit of frequencies ranges well above the current ones.

Characteristics and possible use of wireless communication systems above 100 Gbit/s have been discussed within international standardization organizations, and some documents have been finalized or are under development/revision.

7.2 Spectrum monitoring (ITU-R SG1)

In relation with wireless communications, due to high capacity transmission capability and large propagation loss, use of THz technologies can be considered effective for devices operating in the last mile of the networks.

Report ITU-R SM.2450 [i.22] contains results of sharing and compatibility studies between land-mobile, fixed and passive services in the frequency range 275-450 GHz, in addition to information about threshold levels for radio astronomy.

Report ITU-R SM.2352-0 [i.21] addresses technology trends of active services in the frequency range 275-3 000 GHz, providing technical information to assist in sharing and compatibility studies among active services.

An overview of possible areas of applications above 275 GHz is also offered by Report ITU-R SM.2352-0 [i.21]:

- Astronomy (infrared and terahertz radio telescope to study interstellar cloud in the galaxy)
- Molecular detection (solid-state laser to detect small molecular vibration better than infrared ray)
- Security inspection
- Biomedicine (diagnosis, surgical operation, medical research)
- Radar, (target recognition, precision guidance)
- Wireless communication field

Concerning possible use cases for wireless telecommunications, indication of possible technical requirements of THz communication systems are provided, for various specific cases:

- Super-proximity communication between chips and between circuit boards (few cm, a few tens of Gbit/s, LOS, NLoS, BER ~ 10^{-9})
- Content synchronization with the cloud through near field communication (up to few cm, a few tens of Gbit/s, LoS, BER ~ 10^{-12})
- Wireless communication between servers inside a data center (up to few m, up to a few hundreds of Gbit/s, LoS/NLoS, BER ~ 10^{-12})

- THz wireless local area network, in office, airport, commercial points (THz WLAN) (up to few tens of m, up to a few tens of Mbit/s, BER $\leq 10^{-6}$)
- Wireless Backhauling/Fronthauling - (up to 1 km, up to 100 Gbit/s, outdoor, BER ~ 10^{-12})

7.3 Propagation aspects (ITU-R SG3)

Guidance on outdoor short-range propagation over the frequency range 300 MHz to 100 GHz is given by Recommendation ITU-R P.1411-1 [i.15]. Information is given on basic transmission loss models for Line-of-Sight (LoS) and Non-Line-of-Sight (NLoS) environments, building entry loss, multipath models for both environments of street canyon and over roof-tops, number of signal components, polarization characteristics and fading characteristics. This Recommendation can also be used in compatibility studies.

Prediction methods to be taken into account in the design of digital fixed line-of-sight links, both in clear-air and rainfall conditions, are provided by Recommendation ITU-R P.530-17 [i.9], together a step-by-step procedures including the use of mitigation techniques to minimize propagation impairments. The final outage predicted is the base for other Recommendations addressing error performance and availability. It was developed and revised for frequency ranges lower than 275 GHz; some rain related predictions are considered valid at least up to 100 GHz, while a formula for rain specific attenuation R (dB/km) and values for the coefficients is given, in the range from 1 to 1 000 GHz, in Recommendation ITU-R P.838 [i.12].

Methods to compute attenuation generated by clouds and fog are detailed in Recommendation ITU-R P.840-8 [i.13], valid up to about 200 GHz, while Recommendation ITU-R P.676-12 [i.10], valid up to 1 000 GHz, describes the attenuation due to atmospheric gases.

Studies of short-path propagation data and models for terrestrial radiocommunication systems in the frequency range 6 GHz to 450 GHz are addressed by Report ITU-R P.2406-1 [i.16]. This Report provides experimental and theoretical results related to propagation models and characteristics in frequency range 6 GHz to 450 GHz, for indoor and outdoor environments, in Line-of-Sight and Non-Line-of-Sight.

Recommendation ITU-R P.1238-10 [i.14] provides guidance on indoor propagation over the frequency range from 300 MHz to 450 GHz. Information is given on basic transmission loss models; delay spread models; effects of polarization and antenna radiation pattern, effects of transmitter and receiver locations, effects of building materials furnishing and furniture, effects of movement of objects in the room, statistical model in static usage.

In summary, due to very limited or unclear interest of a possible use of the high frequencies considered in present document, at the moment the applicability of propagation related deliverables, produced by ITU-R SG3, is often limited to lower frequencies; as an example, some basic documents, such as Recommendations ITU-R P.530 [i.9] and P.1411 [i.15], are limited to about 100 GHz.

7.4 Terrestrial (ITU-R SG5)

7.4.1 Generalities

Since the interest of a possible use of the high frequencies considered in present document is just at the beginning, for FS, and very limited interest is emerging in the field of LMS, few documents are available at the moment relating to frequencies above 100 GHz.

7.4.2 Equipment

Reports ITU-R F.2416 [i.6] and ITU-R M.2417-0 [i.7] have been published by the ITU-R, summarizing the technical and operational parameters as well as the spectrum needs for the relevant applications in Fixed Service and Land Mobile service respectively.

Report ITU-R F.2323 [i.5] is also available, addressing FS use and trends, but is at the moment just mainly referring to frequencies below 100 GHz.

Report ITU-R M.2417 [i.7] provides the technical and operational characteristics and spectrum needs of land mobile applications operating in the frequency band 275-450 GHz.

7.4.3 Antennas

Following standards are available concerning antennas:

- Recommendation ITU-R F.699 [i.2] - Antenna Reference patterns coordination studies from 100 MHz to about 70-86 GHz.
- Recommendation ITU-R F.1245 [i.3] - Average radiation patterns for P-P antennas for certain studies from 1 GHz to 86 GHz.
- Recommendation ITU-R F.1336 [i.4] - Radiation patterns of omnidirectional, sectoral from 400 MHz to about 70 GHz.

At the moment, the applicability of these recommendations is limited to frequencies below 100 GHz; measurements up to 120 GHz are available, addressing elements for consideration on future revisions of Recommendation ITU-R F.699 [i.2] and Recommendation ITU-R F.1245 [i.3].

Some measurements of antennas up to 300 GHz are available in Report ITU-R F.2416 [i.6], Report ITU-R SM.2450 [i.22] and APT/AWG/REP-66 [i.31].

7.5 Satellite, broadcast (ITU-R SG4, ITU-R SG6)

No documents from these Study Groups, addressing satellites and broadcast, refer to frequencies above 275 GHz.

7.6 Passive, science, space (ITU-R SG7)

Report ITU-R RS.2194-0 [i.19] specifies the bands of interest to EESS/SRS (passive) from 275 to 3 000 GHz. Same document presents sharing studies between passive spaceborne instruments and active services.

Report ITU-R RS.2431-0 [i.20] provides technical and operational characteristics of EESS (passive) systems in the frequency range 275-450 GHz.

Report ITU-R RA.2189 [i.17] contains measurements of atmospheric attenuation in the frequency range 275-3 000 GHz.

7.7 ETSI

ETSI TR 103 498 (SRDoc) [i.24]: The document covers the request for harmonised spectrum for sensor or radiodetermination applications using UWB technology within the frequency range 120 GHz to 260 GHz.

7.8 CEPT

ERC Report 25 [i.27] contains the European table of frequency allocations and applications, in the frequency range 8,3 KHz to 3 000 GHz (ECA table).

Use of high RF frequencies for non-specific short range devices is foreseen in ERC Recommendation 70-03 [i.26], but upper limit is 246 GHz. EIRP limit of 100 mW is specified for equipment operating in frequency ranges 122 to 122,25 GHz, 122,25 to 123 GHz, 244 to 246 GHz.

Such conditions are also incorporated in Commission implementing Decision (EU) 2019/1345 of 2 August 2019 amending Decision 2006/771/EC [i.30].

7.9 IEEE

IEEE Std 802.15.3d™-2017 [i.28] (Amendment to IEEE Std 802.15.3™-2016 as amended by IEEE Std 802.15.3e™-2017) An alternative Physical layer (PHY) at the lower THz frequency range between 252 GHz and 325 GHz.

7.10 Short Range Device (SRD) - APT

APT/AWG/REP-66 (short range radiocommunication systems and application scenarios operating in the frequency range 275-1 000 GHz) [i.31] provides overview of short range radiocommunication systems, application scenario and typical use cases operating in the frequency range 275-1 000 GHz and intends to provide technical information for future relevant study in this band. Several general concepts and definitions are included, in addition of some measurements on antennas. Proximity systems, such as kiosk/tollgate downloading, chip-to-chip communications, super high-video, wireless data center are considered. Clauses on antenna characteristics are included. Very high capacities (> 10 Gbit/s) are considered feasible.

7.11 Coexistence studies

High volume applications using frequencies higher than 275 GHz have not been developed yet for services addressing data traffic, such as the Fixed and Mobile service, while their use in scientific fields is felt important. As a consequence, only limited sharing/compatibility studies are available.

Sharing studies between passive spaceborne instruments and active services from 275 to 3 000 GHz are contained in Report ITU-R RS.2194 [i.19], which are limited to ISS, since the strong atmospheric absorption shields passive spaceborne instruments from terrestrial-based active services.

Report ITU-R SM.2450-0 [i.22] addresses results of sharing and compatibility studies between land-mobile, fixed and passive services in the frequency range 275-450 GHz; same document contains compatibility studies between RAS and FS.

Concerning SRD, the impact of Level Probing Radars (LPR) using UWB on radio communication services, including FS, is available in CEPT, as well as info about compatibility between SRD and EESS (see bibliography).

The results of studies show that, in general, no major problems are expected and compatibility is possible, taking into account the high atmospheric attenuation and the foreseen high directivity of the antennas.

8 Future Applications in mm-wave Radio

8.1 Use Cases and Possible Applications

This clause provides an overview of possible applications foreseen in this frequency range which, for FS, the provision of high capacity fronthaul and backhaul functionalities to IMT and future networks is considered as a possible attractive solution in Report ITU-R F. 2416 [i.6]. A possible target of 100 Gbit/s is mentioned.

Typical requirements for backhaul/fronthaul are provided In Report ITU-R SM. 2352-0 [i.21] (see table 3). In cases, where several tens of Gbit/s are required, the THz frequency range are considered.

Results of some tests showing such possibilities have been published (see clause 10).

Table 3: Backhaul/fronthaul typical requirements

Communication distance	500 m to 1 km
Data speed	Up to 100 Gbit/s
Propagation environment	Outdoor
Required BER	Not provided

Report ITU-R SM. 2450-0 [i.22] provides definitions of fronthaul as a link connection between the base station's Baseband Unit (BBU) and the Remote Radio Head (RRH), while the backhaul is a link between the base station and the higher level network elements. Figure 5, taken from same document, shows an example of backhaul and fronthaul in the network architecture of mobile systems.

Same information is also provided in Report ITU-R F.2416 [i.6].

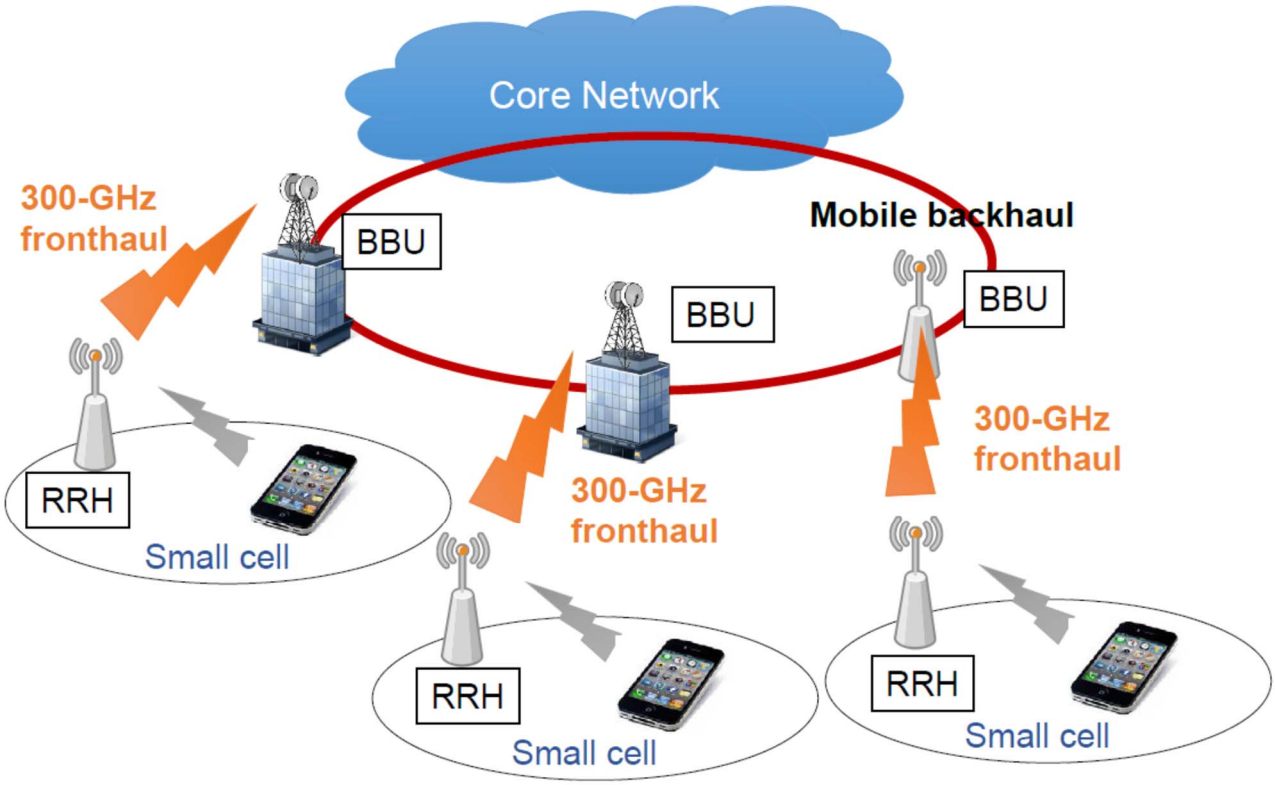

Figure 5: Example of fronthauling and backhauling in mobile network architecture (Source: Report ITU-R SM. 2450-0 [i.22])

Report ITU-R F.2323 [i.5] includes consideration for FWS use in telecommunication networks, providing information about regulatory and licensing regimes in various Regions/Countries, propagation, spectrum and capacity, technology.

A summary of existing ITU-R sharing and compatibility studies between FS and other services is included.

Frequencies above the D-band are just referenced in relation to antennas and propagation deliverables (Recommendation ITU-R P.837 [i.11] and Recommendation ITU-R P.838 [i.12]).

IEEE std 802.15.3d-2017 [i.28], developed in the context of High Data Rate Wireless Multi-Media Networks, contains a technical details at a Physical layer (PHY) application at the lower THz frequency range between 252 GHz and 325 GHz for switched point-to-point link. In addition to center frequencies of channels and MAC/layer management, some relevant Tx and Rx characteristics are given, including requirements for Rx sensitivity, frequency stability, error performance (BER $\leq 10^{-12}$, FER10^{-7}).

8.2 Requirements

Frequency ranges 275-325 GHz and 380-445 GHz are considered suitable for fronthaul and backhaul, in Report ITU-R F.2416 [i.6], and the expected technical and operational characteristics for sharing and compatibility studies where fixed service is involved are provided (see table 4).

In relation with networks, an estimation of foreseen link density in the order of 10 BS/km^2 is contained, based on actual networks deployment and expectation in Japan.

The Report states that a bandwidth of around 25 GHz may satisfy the initial typical deployment scenarios while a bandwidth of about 50 GHz will sufficiently support the evolution of IMT traffic of fronthaul and backhaul. The Report also indicates the frequency band 330-370 GHz may also be considered in the future, if and when parameters are available for that range.

Table 4: Technical and operational characteristics of the fixed service planned applications

Frequency band (GHz)	275-325	380-445
Duplex Method	FDD/TDD	FDD/TDD: Other duplex in schemes are possible
Modulation	BPSK/QPSK/8PSK/8APSK/16QAM/32QAM/64QAM BPSK-OFDM/QPSK-OFDM/16QAM-OFDM/32QAM-OFDM/64QAM-OFDM	BPSK/QPSK/8PSK/8APSK/16QAM/32QAM, 8PSK, 8APSK BPSK-OFDM/QPSK-OFDM/16QAM-OFDM/32QAM-OFDM
Channel bandwidth (GHz)	2…..25 (FDD) 2…..50 (TDD)	2…..32.5 (FDD) 2…..65 (TDD)
Spectrum mask	See Report F.2416 [i.6] Annex 2	See Report F.2416 [i.6] Annex 2
Tx output power range (dBm)	0 ... 20	-10 ... 10
Tx output power density range (dBm/GHz)	-17 ... 17	-28 ... 7
Feeder/multiplexer loss range (dB)	0 … 3	0 … 3
Antenna gain range (dBi)	24 … 50	24 … 50
e.i.r.p. range (dBm)	44 … 70	37 … 60
e.i.r.p. density range (dBm/GHz)	30 … 67	19 … 57
Antenna pattern	Recommendation ITU-R F.699 [i.2] (Single entry) Recommendation ITU-R F.1245 [i.3] (Aggregate)	Recommendation ITU-R F.699 [i.2] (Single entry) Recommendation ITU-R F.1245 [i.3] (Aggregate)
Antenna type	Parabolic Reflector	Parabolic Reflector
Antenna height (m)	6-25	10-25
Antenna elevation (degree)	±20 (typical)	±20 (typical)
Receiver noise figure typical (dB)	15	15
Receiver noise power density typical (dBm/GHz)	-69	-69
Normalized Rx input level for 1×10^{-6} BER (dBm/GHz)	-61 … -54	-61 … -54
Link length (m)	100 … 300	100 … 300
Deployment Density	See Report ITU-R F.2416 [i.6], § 8.1	See Report ITU-R F.2416 [i.6], § 8.1
I/N protection criteria	Recommendation ITU-R F.758 [i.32]	Recommendation ITU-R F.758 [i.32]

NOTE: Due to limited number of applications available, as well as the commercial availability of devices, further studies are still required to check the effectiveness of propagation related data and models at these frequencies, especially in outdoor environments where FS could be used for application similar to the ones already used for transport, such as backhaul. For the same reason, the possible link lengths that can be guaranteed in outdoor use, to comply with the requested performance objectives, should also be consolidated, in relation with the different atmospheric and climatic conditions that can be met in various regions of the world.

8.3 Duplexing considerations

In principle, equipment developed for FS use in these frequency bands can be developed to accommodate FDD or TDD use.

Other possible duplexing available from the equipment could be the fFDD (flexible FDD- see note), which is already foreseen in the D-band and , depending on technological development, FD (Full Duplex), consisting in the simultaneous use of the same RF channel for both directions of a link, in each terminal.

The symmetry between the "go" and the "return" channels of frequency plans mostly adopted at lower frequencies when FDD is adopted is not felt efficient to manage high capacity fronthaul and backhaul use cases, due to their expected inherent asymmetry (evaluated as 4:1 for uplink/downlink in today' s networks).

In order to achieve a high spectral efficiency, possibility to consider the adoption of duplexing schemes tailored to accommodate for asymmetry in the two directions of connections should be investigated in the development of channel plans, as well as in regulatory framework.

NOTE: The small wavelength allows to reduce the size of mechanics, including antennas, such that in the same device there is possibility to allocate separate antennas for Tx and Rx, with sufficient decoupling to guarantee operations as expected. Such a way, independent Tx and Rx chains can be implemented in same equipment, each of them is freely programmable in frequency, so that any duplex spacing can be realized.

8.4 Preferred licensing regimes for bands above 174,8 GHz

The high specific attenuation characterizing frequencies above the D-band (see clause 6) allows adoption of short links, with length in the order of few hundreds of meters, to be used for high capacity applications, as the ones requested by fronthaul/backhaul; same characteristic implies a very fast reduction of possible interference towards other links/applications with the increase of distance from interferer to victim, similar to 60 GHz.

In addition, advancements in adaptive antenna array technology and beamforming techniques could help in further reducing harmful interference.

The area around a new link to be developed, where interference analyses is necessary, is therefore significantly smaller than the one necessary to be examined in lower frequency ranges; due to this, the adoption of a licensing approach based on link-by-link license controlled by an administration can be felt as redundant, taking also account of time and procedures needed.

The adoption of licensing regimes allowing flexibility of use, such as the block based approach or the light licensing regimes, also taking into account the technical capabilities of equipment, are felt appropriate to cover the foreseen use cases within evolving networks, with higher flexibility in service provision and time, while still guaranteeing the expected high level of performance.

9 Projects

ThoR (TeraHertz end-to-end wireless systems supporting ultra high data Rate applications).

THz end-to-end wireless systems supporting ultra-high data Rate applications.

The project is funded by the European Union and the National Institute of Information and Communications Technology (NICT), Japan.

It will study the capability of 300 GHz backhaul/fronthaul links, including use of Photonics-based LO, Electronic THz amplifier and up-converter, High Power THz TWTA, Electronic THz receiver.

10 First Prototypes and Early Deployment

The possibility of transmission of high capacity over frequencies above 174,8 GHz has been tested experimentally, and some documents have been published or ongoing, as reported in Report ITU-R SM.2352 [i.21]:

- Among them, indoor transmission experiments of data rates up to 30 Gbit/s has been described, together with a long-range outdoor transmission, with a distance of 1 km, and data rates up to 24 Gbit/s. For outdoor, a demonstrator has been realized, BPSK to 8PSK have been used, resulting in a BER from about 10E-5 to about 10E-3 respectively.
  16 QAM was not possible, even in indoor (see bibliography).

- 237,5 GHz for transmitting data over 20 m at a data rate of 100 Gbit/s has also described (see bibliography). Data and BER for lengths from 0 to 40 m are shown. For the antenna, a horn followed by an aspherical plano-convex lens has been used.

Other references to published studies and trials can be found in documents referred to in bibliography.

11 Technology aspects

11.1 Highlights

The present clause examines technological aspects. Text is derived from ETSI GR mWT 018 [i.29].

11.2 Active devices

This clause describes main features of active devices for high frequencies, which are summarized in table 5.

Table 5: Overview of semiconductor technologies beyond 100 GHz and their key parameters

Technology	Feature size (nm)	fMAX (GHz)	Vbr (V)	Nfmin (dB) at 50GHz**	Production or research?
GaAs pHEMT	100	185	7	0.5	P
GaAs mHEMT	70	450	3	0.5	R*
GaAs mHEMT	35	900	2	1	R
InP HEMT	130	380	1	<1	R
InP HEMT	30	1200	1	<1	R
GaN HEMT	60	250	20	1	R
GaN HEMT	40	400	42	1.2	R
SOI CMOS	45	280	1	2-3	P
SiGe-HBT	55	400	1.55	1.5	P
SiGe-HBT	130	400	1.4	2	P
InP DHBT	250	650	4	3	R*
InP DHBT	130	1100	3		R

* Ready to be commercialized in 1-2 years
** Nfmin is proportional to the frequency

The main high frequency transistor technology classes are HBT, HEMT, and MOSFET, where MOSFET is typically implemented in SOI CMOS for high frequency operation. A key property is the feature size, since a transistor with smaller feature size supports higher frequencies. As a rule of thumb circuits are designed to operate below fMAX/3, where fMAX is the frequency at which the transistor's power gain is equal to one.

It is possible to bring the operation frequency much closer to fMAX but, depending on the technology, doing so may result in lower power efficiency and higher design complexity. Other important material properties are the minimum noise figure (NFmin) and the breakdown voltage (Vbr), which determine receiver sensitivity and maximum transmitted power.

The maximum transmitted power and minimum receive noise figure limit the system gain. Research has been published on power amplifiers in GaAs, InP and SiGe technologies delivering more than 10 dBm of output power beyond 130 GHz. GaAs pHEMT provides high breakdown voltage and a low noise figure and, in a few years, is also expected to be able to support the D-band. InGaAs mHEMT and InP pHEMT & DHBT technologies support very high frequencies. These technologies are widely used in aerospace applications but have limited commercial availability, however because of their excellent performance they have been valuable in D-band research and predevelopment activities.

Silicon technologies such as SOI CMOS and SiGe-HBT are today feasible up to W-band (92 to 114,5 GHz) although the maximum output power is limited due to the low breakdown voltage of silicon and the noise figure is worse compared to GaAs and InP technologies. The newer generations of SiGe/BiCMOS technologies have fMAX in the region of 300-400 GHz, further increase in fMAX above 400 GHz is under investigation, however as figure 6 shows, nMOS (SOI CMOS) seems to have an optimum of fMAX at 28 nm so may not catch-up with SiGe (BiCMOS).

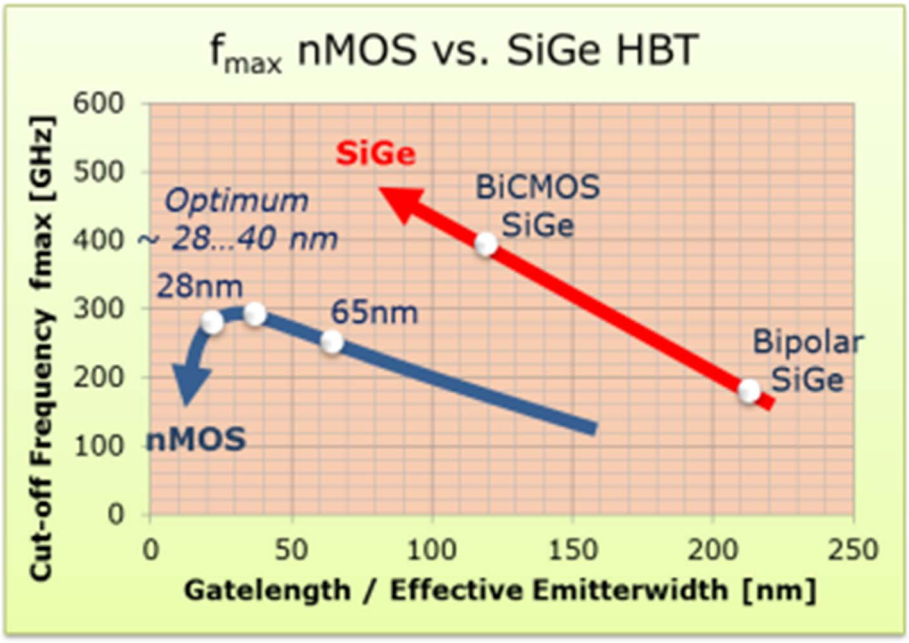

Figure 6: Overview of fMAX for SiGe (BiCMOS/HBT) and nMOS technologies

Silicon technologies are promising for short-range, low-cost applications due to the excellent properties for high integration however performance limitations are expected in the frequency bands above 140 GHz.

Figure 7 shows examples of the performance demonstrated in D-band of power amplifiers and low noise amplifiers manufactured on III-V and Si technologies.

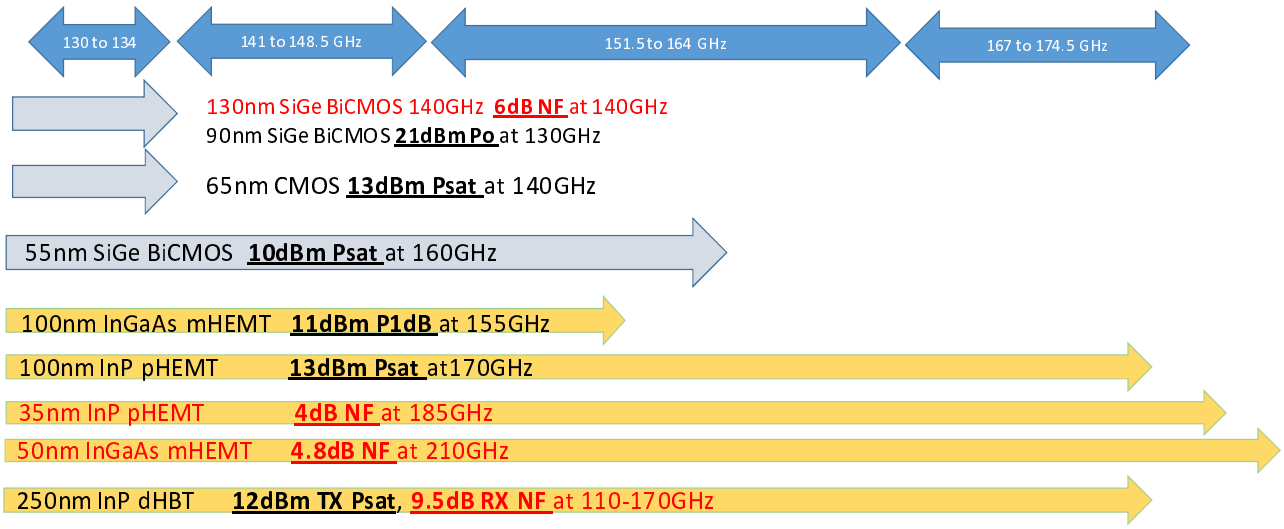

Figure 7: Performance for LNAs (red) and PAs (black) described in the literature

Packaging and interconnect above 100 GHz are challenging due to the short wavelengths. Parasitic effects are more pronounced and the tolerance requirement is high in design, manufacturing and assembly, especially when considering wide bandwidths. Crosstalk and unwanted resonances are additional issues since the typical MMIC size is of the order of the wavelength. This makes traditional interconnects, such as wire bonding and flip chip, difficult to use with high yield.

12 Waveguides

Table 6 provides main specifications of waveguides covering frequency ranges addressed by present document.

Table 6: Designation of waveguides

Designation (EIA)	Designation (IEC)	Frequency band	Cutoff frequency	Inner dimension (mm)
WR5	R1800	140-220 GHz	115,71 GHz	1,2954 x 0,6477
WR4	R2200	172-260 GHz	137,24 GHz	1,0922 x 0,5461
WR3	R2600	220-330 GHz	173,57 GHz	0,8636 x 0,4318

13 Antennas

No specific technical description of antenna requirements is currently available in standardization related deliverables.

Only few measurements are available for frequencies above 174,8 GHz (Report ITU-R F.2416 [i.6]), while some basic description of radiating systems used in trials can be found in published reports.

Wherever indicated (such as Report ITU-R SM.2450 [i.22]), opinions are contained about the expectation of narrow beams and high directivity, which is available also from small size antennas, due to high operating frequency.

14 Summary and Conclusions

Frequencies above 174,8 GHz are characterized by the availability of wide contiguous bands intervals and high specific attenuation with length, in the order of few dB/km, comparable to the 60 GHz range.

At the moment, they are mainly addressed by space services for observations of spectral lines, while their use for short range applications, such as position detection or transmission of high data between devices close to each other is under use or study for short time adoption.

The use of these frequencies for most other services, including FS, is felt as possible in a later time.

Concerning the FS, the possibility of transmission of very high capacity, in the order of few tens of Gbit/s up to about 100 Gbit/s, for indoor use or over outdoor short links, appears to be the most promising applications, covering the needs of fronthaul and backhaul.

Due to specific propagation condition, a kind of licensing regime more flexible than the link-by-link is felt necessary to support the use of these portions of the RF spectrum.

Annex A:
Earth Exploration Satellite Service applications specs

Report ITU-R RS.2431 [i.20] provides technical and operational characteristics of EESS (passive) systems in the frequency range 275-450 GHz.

Categorization of sensors, together with some very basic objectives and information is reported in table A.1.

Table A.1: Instruments with radiometric channels between 275 and 450 GHz

Instrument	Short description and main objective	Mission/Sponsor
Remote Sensor-1 (ICI)	Ice Cloud Imager (ICI): Conical scanning radiometer. Main objective: cloud ice retrieval, with emphasis on cirrus clouds, and water vapour profile measurement capability Submillimetre wave sensor with channels from 183 to 664 GHz	Instrument selected for MetOp Second Generation -B (EUMETSAT) Under development Operational system for 2 020-2 040
Remote Sensor-2 (TWICE)	Tropospheric Water and Cloud ICE (TWICE): Conical scanning radiometer. Main objective: Water vapour and ice clouds in upper troposphere, and study of circulation models for climate modelling	On-going development for CubeSat deployment NASA
Remote Sensor-3 (SMM)	Passive submillimetre wave (SMM) ice cloud radiometer. Main objective: measurement of ice clouds, namely cloud ice mass, particle size, and mean cloud altitude.	Completed feasibility study Preparation for mission proposal was supported by JAXA
Remote Sensor-4 (STEAMR)	STEAMR Millimetre wave multi-beam Limb sounder Main objective: 3D limb sounding with embedded cloud imaging capability	One of the payloads of PREMIER for an Earth Explorer Core Mission
Remote Sensor-5 (GEM)	Geosynchronous Microwave (GEM) sensor Main objective: Temperature and moisture profiling from the lower stratosphere down to ~2-5 km altitude.	Sensor on GOES-class satellites
Remote Sensor-6 (GOMAS)	Geostationary Observatory for Microwave Atmospheric Sounding (GOMAS). Main objective: Temperature and moisture profiles, cloud ice/liquid water gross profile.	Earth Explorer Opportunity Mission
Remote Sensor-7 (CAMLS)	Compact Adaptable Microwave Limb Sounder (CAMLS) Main objective: understanding the composition and structure of UT/LS.	On-going development for next generation of microwave Limb Sounders NASA
Remote Sensor-8 (GMS)	Geostationary Microwave Sounder (GMS)	Chinese FY-4 microwave satellite
Remote Sensor-9 (MASTER)	MASTER- Millimetre wave multi-beam Limb sounder Main objective: 3D limb sounding	Earth Explorer Core Mission

Annex B:
Licensing and regulation

B.1 Licensing regimes description

B.1.1 Highlights

In relation with use of frequencies, several regimes exist with different characteristics and objectives; they can be categorized as belonging to one of following categories:

- Link-by link licensing.
- Frequency block assignment.
- Light licensing.
- Licence exemption.

B.1.2 Link by link licensing

This regime consists in the provision of a specified RF channel for each proposed microwave link, after interference analysis and spectrum fee calculation. This process is fully under control by the administrations. The link is therefore not expected to be under threat of harmful interference from other entities in the same geographic area.

B.1.3 Frequency block assignment

This regime consists in the assignment of a frequency range to a licensee (e.g. network operator) , for nationwide or more limited geographic area. Other frequency blocks can be assigned to other licensees.

Licensees are responsible for planning and interference analysis of their own network. Potential interference towards adjacent blocks can be controlled on the base of existing standards or following the indications provided by administrations (e.g. by means of guard bands).

Concerning the use of frequency inside blocks, the administrations can allow licensee to set up the size and center frequency of channels to be used, according to their preference, or require that channels inside the blocks should be in any case aligned with the ones foreseen by the "official" national channel plan.

In some schemes, the licensee has no obligation to inform the administration on the use inside the block, while in others the link data need to be reported periodically the to the administration to be recorded into the national data base and used to calculate the related fees.

B.1.4 Light-licensed FWS

Light licensing regime is a national regulation intended to accommodate the minimal regulatory constraints and costs with the same assurance of a protected spectrum.

In this regime, the position and characteristics of the stations are recorded on a database on a first-come first-served basis, with responsibility for subsequent users to ensure the compatibility with previously notified stations.

The use of light licensing has been authorized by some administrations, particularly in the context of high frequency applications, such the E-band, where, due to the space transmission loss, higher than in the bands below 60 GHz, and the high directivity of antennas, decrease the probability that links interfere with one another.

For this reason, it is felt that frequency planning under total administration control may not be necessary in these bands.

B.1.5 License-exempt FWS

License-exempt can be adopted in some RF bands, where equipment functionalities intended to mitigate interferences and allow fair use of spectrum by users are described by specific documents developed by SDOs.

Among license-exempt, examples of most commonly used bands are 2,4 GHz, 5 GHz, and 60 GHz. The specific attenuation at 60 GHz, much larger than at other frequencies because of oxygen absorption, facilitates the frequency-reuse, increasing the density of cells.

The deployment of license exempt bands allows fast provision of applications, but the possibility of suffering harmful interference from other links cannot be excluded.

Annex C: Bibliography

- Report ITU-R F.2107: "Characteristics and applications of fixed wireless systems operating in frequency ranges between 57 GHz and 134 GHz".
- ETSI EN 302 217-3: "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 3: Equipment operating in frequency bands where both frequency coordinated or uncoordinated deployment might be applied; Harmonized EN covering the essential requirements of Article 3.2 of the R&TTE Directive".
- ETSI EN 302 217-4-2 (V1.4.1): "Fixed Radio Systems; Characteristics and requirements for point-to-point equipment and antennas; Part 4-2: Antennas; Harmonized EN covering the essential requirements of Article 3.2 of the R&TTE Directive".
- Recommendation ITU-R RA.769-2: "Protection criteria used for radio astronomical measurements".
- Recommendation ITU-R RA.314: "Preferred frequency bands for radio astronomical measurements".
- Recommendation ITU-R RA.1860: "Preferred frequency bands for radio astronomical measurements in the range 1-3 THz".
- ETSI EN 305 550 (V2.1.0): "Short Range Devices (SRD); Radio equipment to be used in the 40 GHz to 246 GHz frequency range".
- ECC report 139: "Impact of Level Probing Radars (LPR), using Ultra-Wideband Technology on Radiocommunications Services".
- ECC Report 190: "Compatibility between Short-Range Devices (SRD) and EESS (passive) in the 122 to 122.25 GHz band".
- IEEE 802.15-14-0017-00-0thz™: "High Data Rate Wireless Communication using a 240 GHz Carrier", J. Antes et al, Los Angeles, January 2014.

NOTE: Available at https://mentor.ieee.org/802.15/dcn/14/15-14-0017-00-0thz-high-data-rate-wireless-communication-using-a-240-ghz-carrier.pdf.

- S. König et al., Wireless sub-THz communication system with high data rate, Nature Photonics 7, 977–981 (2013).

NOTE: Available at http://www.nature.com/nphoton/journal/vaop/ncurrent/abs/nphoton.2013.275.html.

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