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5G SPECTRUM OPTIONS FOR EUROPE

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1. Introduction

The capabilities of next generation of wireless networks will make possible massive new levels of connectivity, tremendous throughput speed and high reliability mobile communications. These capabilities will be met through the development of new air interfaces, new networking technologies as well as the evolution and enhancement of today's technology. 5G is thus more than a gradual evolution of current mobile broadband: it is a trigger for deep social, business, and industrial transformation that will impact numerous vertical markets: automotive, energy, agriculture, city management, government, healthcare, manufacturing, public transportation, etc.

Technology developments to meet these capabilities will be deployed in the existing frequency bands identified for mobile communications but they will also require new spectrum resources to specifically provide high bandwidth resources that can efficiently deliver high throughput services.

The ITU-R considers the spectrum for public wireless networks (3G, 4G and now 5G) under the IMT framework. At the ITU-R World Radiocommunications Conference 2015 an Agenda Item for WRC-19 (AI 1.13) for studying 5G spectrum was agreed. A number of frequency bands between 24.25 GHz and 86 GHz will be studied until WRC-19, where a decision on allocations for the Mobile Service and/or Identifications for IMT will be taken. In the study period between WRC-15 and WRC-19 the new spectrum needs for IMT will be analysed, as well as compatibility with other services.

In parallel, there are local initiatives to specify new frequency bands for commercial use or test systems, such as the recent Rulemaking in the US and the activities towards the Olympic Games in Korea and Japan. These initiatives are addressing higher frequency bands that will satisfy the very high throughput capabilities of 5G networks, but also bands below 6 GHz that could provide a combination of high bitrates and good coverage. Some of the bands under consideration are not on the ITU-R list for WRC-19. In addition, there are test systems planned or already up and running in a number of locations and for various frequency bands in different countries.

These different activities need to be taken into consideration already now in the development of a strategic roadmap for 5G spectrum in Europe, in order to achieve maximum possible harmonization and for Europe to influence and keep pace with international developments.

2. ITU-R activities: Agenda Item 1.13 for WRC-19

Table 1 below contains the frequency bands to be studied under AI 1.13 towards WRC-19. These bands are in the frequency range 24.25 – 86 GHz and have a total bandwidth of about 32 GHz. It is not expected that all of these bands will be identified for or used by 5G. The selection of bands will depend on the results from the study of spectrum needs for IMT and the compatibility with incumbents in different parts of the world.

30 GHz	24.25 – 27.5 GHz, 31.8-33.4* GHz
40 – 55 GHz	37-40.5,40.5-42.5*,42.5-43.5 GHz, 45.5-47 GHz, 47-47.2*, 47.2-50.2 GHz, 50.4-52.6 GHz
66 – 86 GHz	66-71 GHz, 71-76 GHz, 81-86 GHz

Table 1. Frequency bands for AI 1.13. Frequency bands marked with an asterisk do not have a mobile allocation in the Radio Regulations.

3. Local and regional initiatives for 5G spectrum

A number of local initiatives have been taken for 5G spectrum, both for commercial deployments and test beds. In some cases, local spectrum needs have a different timing than that of the ITU-R process, in other cases particular frequency bands not on the ITU-R list for WRC-19 have been identified as providing good 5G opportunities locally. In addition, bands that already have IMT identifications, below 6 GHz, may be used for 5G deployments.

USA

The recent "Spectrum Frontiers" Rulemaking from FCC in the US proposes that the four-millimetre wave bands in Table 2 (New Rules Adopted) should be made available for 5G usage in the US, while it considers additional bands (Future Consideration). A comparison with Table 1 shows that one of those is not on the ITU-R list, 27.5 – 28.35 MHz. The FCC has published a REPORT AND ORDER AND FURTHER NOTICE OF PROPOSED RULEMAKING[1] adopting the rules authorizing mobile operation in the four-millimetre wave bands. In addition, in the US there is the Mobile Now Act[2], a proposal for a bill where a number of bands are proposed for further studies.

US Regulatory Consideration	Bands Considered		
FCC Spectrum Frontiers Rulemaking	New Rules Adopted	Future Consideration	
	27.5-28.35 GHz 37-38.6 GHz 38.6-40 GHz 64-71 GHz	24.25-24.45 GHz 24.75-25.25 GHz	31.8-33 GHz 42-42.5 GHz 47.2-50.2 GHz 50.4-52.6 GHz 71-76 GHz 81-86 GHz Above 95 GHz
Mobile Now Act	3100-3550 MHz 3700-4200 MHz 24.25-24.45 GHz 25.05-25.25 GHz 31.8-33.4 GHz 71-76 GHz 81-86 GHz		

Table 2: US Bands

There are some low (sub-6 GHz) spectrum bands that will become available in the US around the time that 5G standards are expected to be finalized, making these bands good candidates for 5G deployments. The 600 MHz band (575 – 698 MHz), where TV broadcast spectrum is being repurposed for mobile broadband use via the incentive auction process, is one such band. The 600 MHz incentive auction is currently underway and TV stations

[1] https://www.fcc.gov/document/fcc-adopts-rules-facilitate-next-generation-wireless-technologies

[2] Bill S.2555, Making Opportunities for Broadband Investment and Limiting Excessive and Needless Obstacles to Wireless Act or the MOBILE NOW Act, Introduced 2/11/16, https://www.congress.gov/bill/114th-congress/senate-bill/2555?q=%7B%22search%22%3A%5B%22mobile+now%22%5D%7D&resultIndex=1

that participate in the auction will have up until 39 months to transition out of the band, which makes the band available in the 2020 timeframe.

The 3.5 GHz band in the US is another candidate for 5G deployments. The FCC just put the finishing touches on rules, but it has only just begun the process of approving the Spectrum Access System and Environmental Sensing Capabilities that need to be in place before 3.5 GHz mobile operations can commence. This process (which involves the development of additional spectrum access guidelines that industry is working on) can take an additional 2-3 years, which makes this band another candidate for 5G mobile operations.

Korea

Around 28 GHz (26.5-29.5 GHz) has been identified for a 5G trial service at the 2018 winter Olympics. Three operators in Korea have been allocated 1 GHz each in this range for the purposes of the trial.

China

China Academy of Information and Communication Technology has announced the ongoing 5G technology trial in the 3400-3600 MHz band. Operators considering 3400-3600 MHz for 5G.

The Chinese led IMT-2020 Promotion Group (IMT-2020PG) is carrying out a multi-annual trial programme to promote the development of 5G technology and systems in the higher frequency bands with a first technology trial phase progressing until the end of 2018. The trial partners are drawn from the entire supply chain including global chipset vendors, infrastructure/ device vendors, operators and instrumentation suppliers. Phase 2 will move into product R&D trials until 2020.

Japan

Aiming for international harmonization, Japan has been also investigating the promising bands for 5G including 3600-4200 MHz, 4400-4900 MHz and 28GHz, in the Radio-policy 2020 council established recently. The requirement for early access to 5G frequency bands in the US, Korea, China, Japan etc. is driving the focus for the development of the first 5G capable infrastructure and devices.

The following candidate frequencies have been evaluated and selected by the 5GMF (5G Mobile Forum) as the potential frequency bands for 5G deployment in Japan. At this stage the frequency evaluation was performed from a inter system perspective and regulatory or harmonization aspects were not considered. A verification trial is planned for FY2017 connecting radio access, network and applications to ensure a smooth commercialisation of 5G systems by 2020.

WRC 19 – Agenda Item 1.13			5GMF		
BW (GHz)	Frequency Band (GHz)		Frequency Band (GHz)		BW (GHz)
6 – 30 GHz					
			5.925	7.250	1.325
			7.375	8.750	1.375
			10.000	10.500	0.500
			10.550	10.680	0.130
			10.700	11.700	1.000
			14.500	15.350	0.850

			15.400	21.400	6.000
			22.000	23.600	1.600
3.250	**24.250**	**27.500**	**24.750**	**31.00**	6.250
30 – 60 GHz					
			31.00	31.30	0.300
1.60	**31.80**	**33.40**	**31.50**	**42.50**	11.00
3.50	**37.00**	**40.50**			
2.00	**40.50**	**42.50**			
1.00	42.50	43.50			
1.50	**45.50**	**47.00**	**45.30**	**47.00**	1.70
0.20	**47.00**	**47.20**	**47.00**	**50.20**	3.20
3.00	**47.20**	**50.20**			
2.20	**50.40**	**52.60**	**50.40**	**52.60**	2.20
			54.25	57.00	2.75
60 – 100 GHz					
10.00	66.00	76.00	**66.00**	**76.00**	10.00
5.00	81.00	86.00	**81.00**	**86.00**	5.00
			92.00	100.00	8.00

Table 3: Japan Bands (bold marks various zones of overlap)

Europe

In CEPT, ECC PT1 has been assigned as the responsible European group for Agenda Item 1.13 preparation, and work has been initialized to prioritize among the bands on the ITU-R list. To that end, ECC PT1 has sent out a questionnaire[3] to administrations and industry on use and future plans for the frequency bands listed for agenda item 1.13, to be answered before September 1st.

With regards to spectrum below 6 GHz, it is noted that the frequency range 3.4 – 3.8 GHz has been given some attention recently. ECC PT1 has sent a liaison statement[4] to 3GPP and ETSI, inviting them to consider harmonized bands in Europe below 6 GHz of relevance to 5G/IMT-2020, for instance 3400 – 3800 MHz, also referring to the minutes of meeting of the 41st meeting[5] of ECC stating that "existing harmonised bands (for example 3.4-3.8 GHz) may respond to IMT 2020 needs." In addition, in the on-going discussion within the EU the already harmonized mobile bands in the frequency range 3.4 – 3.8 GHz are regarded as suitable for early deployment of 5G in Europe.

Furthermore, in its draft 'Opinion on spectrum related aspects for next-generation wireless systems (5G)', the RSPG "…considers the 3400-3800 MHz band to be the primary band suitable for the introduction of 5G use in Europe even before 2020, noting that this band is already harmonised for mobile networks, and consists of up to

[3] http://www.cept.org/cept/start-page/questionnaire/?sqid=p63a6yg6hnt6edk3ftpr

[4] http://www.cept.org/ecc/groups/ecc/ecc-pt1/client/meeting-documents/ (ECC PT1/2016/ECC PT1#52, 19-21 April, Bucharest, Romania)

[5] http://www.cept.org/ecc/groups/ecc/client/meeting-documents/ (ECC/2016/41st meeting ECC Plenary - 01-04 March - Belgium/Minutes)

400 MHz of continuous spectrum enabling wide channel bandwidth. This band has the possibility to put Europe at the forefront of the 5G deployment."

In a more long-term perspective, extending mobile spectrum up to 4.2 GHz could be an attractive solution. In this context it may be noted that Ofcom of the UK has recently had a public consultation[6] regarding 3.8 – 4.2 GHz, "as a candidate band for enhanced spectrum sharing." Spectrum below 6 GHz could thus provide a good combination of coverage and capacity, although without satisfying all of the diverse 5G requirements, e.g. for extremely high bitrates or low latency.

The European Commission has stated that there will be a 5G spectrum action plan for Europe before the end of 2016. Further, it has been observed that 700 MHz could be an attractive 5G frequency band. RSPG notes in its work programme[7] that "…it is important that Europe develops and proposes its own spectrum strategy to respond to the 5G challenges. Therefore, a coherent spectrum strategy including a roadmap is needed…", that "5G deployment is envisaged from 2020 onwards", that "the RSPG Report on 'Awards and efficient usage of spectrum' highlights how the current harmonised spectrum in Europe could respond to some early and future 5G challenges", and that it is required to "focus on and prioritize those bands having the best potential for European and global harmonization."

In addition, the RSPG Report mentioned above states that "5G is likely to utilise a broad portfolio of spectrum, including lower frequency bands and large contiguous blocks above 6 GHz. As a result, we expect 5G to make use of existing mobile bands and require new ones."

4. Test Beds

As mentioned in the introduction, a number of test beds have been devised in order to demonstrate the capabilities of future wireless systems. Some of these test beds and associated results are described below.

Nokia, Ericsson and Huawei are cooperating in Finnish 5G trialing[8] activities as partners in 5G Test Network Finland (5GTNF), which is a joint offering of several Finnish 5G testbeds. Nokia is further engaged in several 5G technology trialing with mobile operators in Asia, Europe and the Americas.[9]

Huawei has conducted field trials with China Mobile of its 5G radio system in existing cellular frequencies (2.6GHz band) (Sub 6GHz), and has worked with Deutsche Telekom at mmWave frequencies (73GHz); it has developed Sparse Code Multiple Access, Filtered-OFDM, Polar Coding and full duplex communication for the RAT, and is developing massive and multi-user MIMO systems.

At the Mobile World Congress, Ericsson showed a test bed based on 800 MHz bandwidth, 512 BS antennas, 8 UE antennas and massive MIMO beamforming, thus reaching 14+ Gbps for single user MIMO and 25+ Gbps for multiple user MIMO. In a similar set-up Ericsson and DoCoMo reached 20+ Gbps outdoor (multiple user MIMO) and 10 Gbps at 200 m distance outdoor, using massive MIMO beamforming.

Samsung Electronics has been demonstrating developments through a series of technology test beds designed to build understanding of the technical performance and characteristics of 5G mm-wave technology in

[6] http://stakeholders.ofcom.org.uk/consultations/opportunities-for-spectrum-sharing-innovation/

[7] http://rspg-spectrum.eu/work-programme/

[8] 5G Test Network Finland: http://5gtnf.fi/

[9] For more details: http://networks.nokia.com/innovation/5g/press-releases

collaboration with several mobile operators in Asia, US and Europe. Most recently, mobile handover has been demonstrated with giga-bit data throughput in a multi-cell mm-wave network.[10]

Qualcomm announced in June 2016 a 5G New Radio (NR) prototype system and trial platform. The 5G NR prototype system operates in the sub-6 GHz spectrum bands and will make the best use of a wide range of spectrum bands. This add to the existing 5G mmWave prototype system, operating at 28 GHz and capable of robust mobile broadband communications in non-line-of-sight environment, utilizing advanced beamforming and beam-steering techniques.

During Mobile World Congress 2016 Intel announced[11] 5G mobile trial platform offering a high-performance development platform for faster integration and testing of 5G devices and wireless access points. Intel is currently working with global operators on 5G development, prototyping and testing. During Computex 2016 Intel announced[12] a collaboration with Foxconn on development of network infrastructure technologies to help transform communications networks and lay the foundation for 5G collaborating on proof of concepts and pilot programs for technologies like Mobile Edge Computing, Cloud Radio Access Network (CloudRAN) and Network Functions Virtualization (NFV) enabling more intelligent, efficient and flexible networks.

5. Frequency ranges and 5G requirements

As noted in the DIGITALEUROPE Position Paper on 5G spectrum (from September 2015)[13] and in its response to the European Commission's public consultation on 5G spectrum[14], different frequency ranges will be required for different aspects of 5G. Enhanced mobile broadband (eMBB), massive Machine Type Communication (mMTC) and critical Machine Type Communication (cMTC) all have different requirements on coverage, bitrate and delay, which together with the variation in propagation requirements for different frequency ranges imply the need for a wide range of different frequency bands, from the UHF range all the way up to higher bands of the ITU-R list.

600 MHz and 700 MHz have been discussed in the US and Europe respectively. In this frequency range the bandwidths available will be of the magnitude of 10 MHz, or less for some IoT applications, and the coverage will be excellent. Moving up to the 3 and 4 GHz ranges, the available bandwidths could be in the order of 100 MHz, becoming relevant for some eMBB applications, while still providing good coverage in most environments. Moving above 20 GHz, there are possibilities for 1 GHz or more, sufficient for the more extreme requirements on bandwidth and delay, while due to the changing propagation characteristics coverage will become increasingly limited, although changes in propagation characteristics can to some extent but not fully be compensated for by advanced antenna systems.

6. Harmonization options

A key aspect of the frequency allocation for 5G is to achieve global or regional harmonization, so as to enable economy-of-scale advantages. Another important reason is that with the advanced antenna systems of 5G, both

[10] More information can be found at: https://news.samsung.com/global/ (search on "5G")
[11] https://newsroom.intel.com/news-releases/intel-accelerates-path-to-5g/
[12] https://newsroom.intel.com/editorials/intel-computex-2016-5-things-know/
[13] http://www.digitaleurope.org/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&EntryId=1011&PortalId=0&TabId=353
[14] http://www.digitaleurope.org/DesktopModules/Bring2mind/DMX/Download.aspx?Command=Core_Download&entryID=2246&PortalId=0&TabId=353

for base stations and terminals, implementation of a large number of separated bands above 10 GHz may add significant or even insurmountable complexity to the design of equipment. The key challenge for higher frequency ranges is associated with the implementation of the beam steering antenna arrays whose performance depends largely on the size and spacing of physical elements that are specific to the frequencies being deployed. The efficiency of the beam steering capability will reduce towards the operating band edges. This challenge is very important when considering the limited "real estate" for antenna array placement inside a small form factor device.

However, an important observation is that sufficient harmonization does not rely on having exactly the same spectrum available in different regions, which may be difficult to achieve due to different situations with incumbents and local requirements.

In order to maximise the addressable market for any device, implementation consideration is being given to the idea of tuning ranges, i.e. the same equipment could be used in (near) adjacent frequency bands, provided that these are in proximity of each other and that the total bandwidth is not too large. This so-called "band twinning" is exemplified in Figure 1, where it is illustrated how "band twinning" could provide enough spectrum harmonisation for a single device implementation to serve different frequency release situations in different territories or markets.

Regarding the size of the tuning range, some experience can be drawn from the implementation of WiGiG (IEEE802.11ah) technology in the 60GHz range which also uses advanced antenna techniques. Implementation experience suggests that a tuning range in the order of about 10% either side of the design centre frequency would be achievable in the near future.

Section 3 highlights the interest the US and South Korea have in deploying spectrum in parts of the band 26.5-29.5GHz and observes how this is driving the early development of devices and chip-sets. "Band twinning" could allow the European region to benefit from this early device development which underlines the importance of the frequency ranges just below 27.5GHz in achieving early roll out of mm-wave 5G systems.

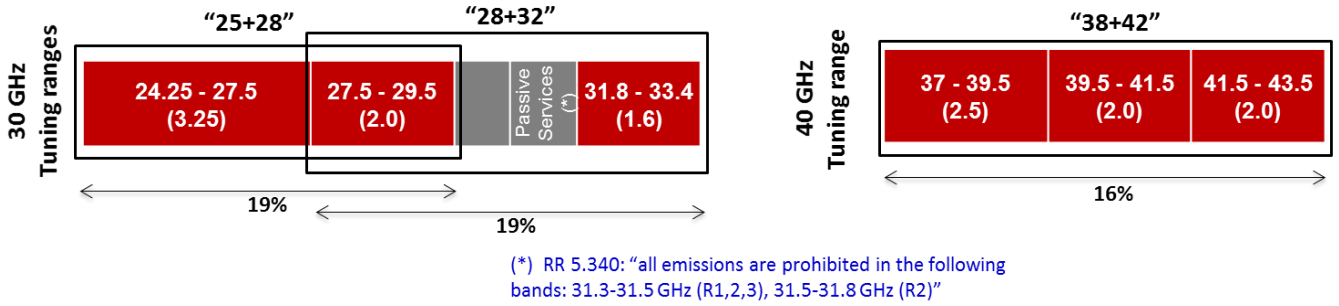

Figure 1: Two examples of "band twinning" in the 30 GHz range and one in the 40 GHz range.

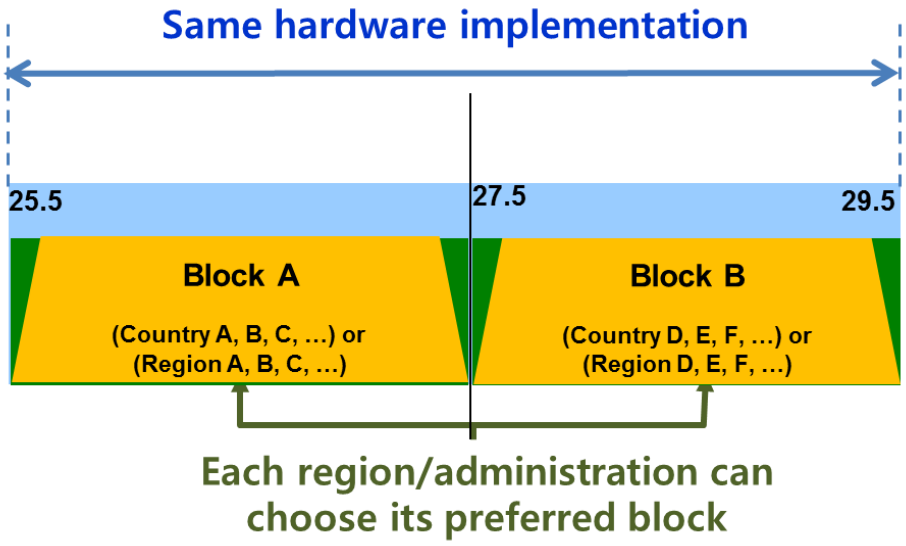

Figure 2: "Band twinning" around a centre frequency at 27.5GHz

Similarly, 37 – 40 GHz is in the list of the "Spectrum Frontiers" rulemaking, see Table 2, and 37.5 – 40 GHz received significant global support in preparation for WRC-15. Noting that the frequency range 40 – 43.5 GHz is not heavily used in some regions, which appears to be the case also in Europe, administrations may thus want to consider further investigation of the feasibility and benefits from the 37 - 43.5 GHz tuning range (which would mean 8% below and above 40.25 centre frequency).

"Band twinning" could be more difficult to achieve between the 28GHz band and the 32GHz band, see Figure 1, due to the existence of the band with sensitive passive services just below 31.8 GHz where "all emissions are prohibited in the following bands: 31.3-31.5 GHz (R1,2,3), 31.5-31.8 GHz (R2)". This need to protect other services in the spectrum between these bands could lead to challenges in the equipment design and implementation.

In addition, the optimum centre design frequency effort would be focussed outside the possible range for operation implying that performance in either band would not be optimum.

These factors may drive towards a need to implement specific devices for the 32GHz band thereby losing the "global terminal" opportunity and delaying the time to market for "second wave" devices in some territories.

7. 5G Spectrum options for Europe

Based on the above, DIGITALEUROPE proposes that for developing commercial services:

- Europe will benefit from recognising and taking advantage of the early developments in other regions in order to be in a leading position for the development of 5G services.
- Activities both within and outside of ITU-R towards obtaining 5G spectrum should be given due consideration to ensure sufficient amounts of spectrum as well as global/regional harmonization.

- Spectrum in different frequency ranges, providing different bandwidths and propagation characteristics, should be considered so as to address different 5G use cases.
- Spectrum in the 3 and 4 GHz ranges should be considered as an opportunity for early 5G deployment with good coverage. In particular, the already harmonized mobile band 3.4 – 3.8 GHz as well as the immediately adjacent and potentially suitable 3.8 – 4.2 GHz band which would together provide a unique opportunity for early and wide-scale 5G deployment could become the core 5G spectrum below 6 GHz for Europe. It is noted however that additional bands, both below and above 6 GHz, will also be necessary to achieve full 5G capabilities.
- 24.25 – 27.5 GHz offers good propagation characteristics and it could be attractive for extreme bandwidth and more targeted capacity deployments. There is the possibility for "band twinning" together with the 28 GHz band, for which there is already momentum in other regions for early deployment of 5G before 2020. Compatibility with existing services in the band will need to be investigated further and with a matter of urgency to avoid delays in the process of harmonizing and authorizing the band for 5G and to enable services to be launched in Europe by 2020.
- 31.8 – 33.4 GHz also offers good propagation characteristics, it has been proposed for IMT by all regional organisations at WRC-15 and thus it has high potential for global harmonization and should be investigated further, keeping in mind that the presence of 800 MHz of passive services below 31.8 GHz and their associated protection requirements (ITU-R RR Footnote 5.340: "all emissions are prohibited in the following bands: 31.3-31.5 GHz (R1,2,3), 31.5-31.8 GHz (R2)") might lead to some additional technical constraints and uncertainty about the final amount of spectrum available for IMT. This might also add complexity to a tuning range solution including the 28 GHz range.
- For more long-term deployment, consideration should be given to the 37 – 43.5 GHz range, where a similar "band twinning" could be achieved. The bands 37 – 38.6 GHz and 38.6 – 40 GHz are included in the R&O concerning 5G from FCC[1], and there is thus already now a certain momentum for these frequency range. For Europe, due to the fixed service use below 40 GHz, it may be the spectrum just above 40 GHz that is suitable.
- Spectrum above 60 GHz should be considered in the ITU-R process, and may provide very good bandwidth for short-range/indoor systems.
- Frequency bands below 1 GHz will provide good coverage for applications with high demands on coverage but lower demands on bandwidth (e.g. IoT applications).

In addition to developing the spectrum for commercial services it will be important to keep in mind spectrum opportunities to demonstrate and allow access to the eMBB capabilities of 5G and the potential benefits for new industry sectors to understand the opportunities that 5G can bring to their industries. In particular, noting the momentum that licensing in the US (and other parts of the world) may bring to the development of equipment in the 28 GHz range and the possibility for "band twinning" with 26 GHz:

- It could be prudent to encourage trial systems in the 26 and 28 GHz bands in Europe noting the emphasis on terrestrial operations in certain parts of these bands.

8. List of Acronyms and Abbreviations

3GPP – 3G Partnership Project

5G NORMA - 5G NOvel Radio Multiservice adaptive network Architecture

5GPPP – 5G Public Private Partnership

5GMF – 5G Mobile Forum

AI – Air Interface

ECP – European Common Proposal

FANTASTIC-5G - Flexible Air iNTerfAce for Scalable service delivery wiThin wIreless Communication networks of the 5th Generation

IMT - International Mobile Telecommunications

ITU-R – International Telecommunications Union Radiocommunication Sector

M2M – Machine-to-Machine

MBB – Mobile Broadband

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

MIMO - Multiple Input Multiple Output

mmMAGIC - Millimetre-Wave Based Mobile Radio Access Network for Fifth Generation Integrated Communications

NGMN – Next Generation Mobile Networks

OFDM - Orthogonal Frequency-Division Multiplexing

QoS - Quality-of-Service

RSPP - Radio Spectrum Policy Programme

UHD – Ultra High Definition

WRC-15 – World Radiocommunications Conference 2015

WRC-19 – World Radiocommunications Conference 2019

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