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Abstract

Timely access to spectrum is one of the keys for the success of the fifth generation (5G) mobile communication system comprising both the right radio frequencies and sufficient bandwidth. The introduction of the pioneer bands became very important in helping to find harmonised spectrum bands in a timely manner that ideally match the identified European market needs and emerging internationally standardised 5G technologies. Although secure access to spectrum by exclusive licenses remains important for future investments in infrastructure, new research results on spectrum sharing may improve the efficiency of the total resources utilisation for some non-critical services.

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Executive Summary

A successful technology revolution of mobile and wireless communications for many different sectors in society and economy needs the careful matching of the market need, internationally standardised technology and harmonised spectrum bands. EURO-5G has played a pivotal role in helping find harmonised spectrum bands in a timely manner that ideally match the identified European market needs and emerging internationally standardised fifth generation (5G) technologies.

Finding spectrum for a new generation of cellular technology is never easy. EURO-5G came up with an innovative process for a research community to contribute to the spectrum debate that we termed "5G pioneer bands".

At the very outset, the Radio Spectrum Policy Group (RSPG) challenged industry to define the problem to be solved for 5G. EURO-5G responded to this rigorous approach with papers to 5G Infrastructure Association (5G IA) Working Group (WG) 5G Spectrum that revealed that one 5G spectrum band was not enough to meet divergent future market needs for both capacity and coverage.

The RSPG and European Commission (EC) were receptive to the *pioneer band approach and three pioneer bands* emerged in the European Union's (EU's) RSPG Opinion:

Low band	700 MHz,
Middle band	3.4 - 3.8 GHz (3.6 GHz band), and
High band	24.25 - 27.5 GHz (26 GHz band).

This has given Europe a better set of spectrum tools to meet the 5G market needs compared to other regions of the world that find their options limited by a focus on only a single 5G spectrum band mainly for enhanced mobile broadband.

Throughout EURO-5G has worked with all of the relevant 5G research projects in establishing the details of what is required not just to get 5G launched but the long-term needs that are to be the subject of World Radiocommunication Conference 2019 (WRC-19).

The next spectrum challenges for Europe are:

- Identifying the next mobile band(s) beyond the three 5G pioneer bands with the focus on WRC-19 and bands above 26 GHz.
- Innovative spectrum sharing/licensing arrangements where careful research is needed to ensure robust approaches to minimising harmful interference.

Both require technical inputs and both raise industrial sensitivities that may, at times, make rapid progress challenging.

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Abbreviations

5G	5th Generation (mobile network)
5G IA	5G Infrastructure Association
5G PPP	5G Public Private Partnership
ASA	Authorised Shared Access
BW	Bandwidth
DL	Downlink
EC	European Commission
eMBB	Enhanced Mobile Broadband
EU	European Union
IMT	International Mobile Telecommunications
KPI	Key Performance Indicator
LAA	Licensed Assisted Access
LSA	Licensed Shared Access
RR	Radio Regulations
RSPG	Radio Spectrum Policy Group
UHD	Ultra-High Density
UP	Uplink
WG	Working Group
WRC	World Radiocommunication Conference

1 Introduction

Access to spectrum is one of the most important keys for a successful 5G. This is underlined at the European [1] as well as at International [2] levels. Suitable globally harmonised frequency bands must be available at the right time as well as the management authorisation aspects in using them. They have to be matched to the market needs as well as the emerging 5G technology standards. One of the profound changes taking place is the bringing into use of new bands in the mmWave region of the radio spectrum. These bands have radically different technical and economic characteristics due to very low achievable range from the bands that have been used to provide nation-wide mobile services. The new higher bands offer opportunities of wider radio channels and massive leaps in capacity and data speeds. But this comes at a price. The cost of covering cities, towns and entire countries with these high capacity systems becomes prohibitive. This is creating a new situation in the 5G era where a single band can no longer solve every problem. This is illustrated in Figure 1 by EURO-5G in the 5G Infrastructure Association (5G IA) response to the Radio Spectrum Policy Group (RSPG) public consultation [3].

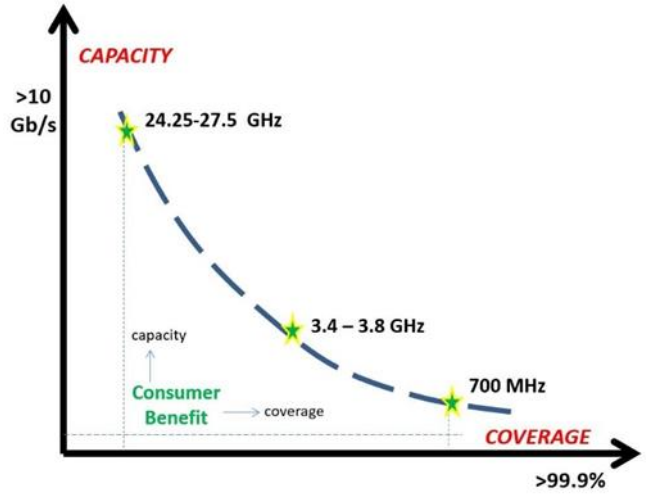

Figure 1: Qualitative illustration of coverage and capacity versus frequency [3]

In general, the low frequency range (e.g., below 1 GHz) has good coverage and limited capacity, the high frequency range at the millimetre wave (e.g., about 20 GHz) offer very high capacity but with limited coverage. The range in between has a varying degree of both. Thanks to the work of EURO-5G these new technical and economic challenges have now been better understood by Europe's regulators in addressing the issue of spectrum bands for 5G.

This deliverable also provides an overview of results from the 5G PPP activities, the working group (WG) 5G spectrum under 5G IA and the projects that contributed to spectrum topics. The WG has addressed early access to frequency bands and some management aspects. The 5G PPP projects that have contributed to spectrum have addressed topics areas as indicted in Table 1.

Project	Contribution to the 5G spectrum topics
5G-Crosshaul	Integrated fronthaul and backhaul wireless options in frequency bands up to 100 GHz, with particular attention to the 50-90 GHz range
5G-XHaul	Focus on the 60 GHz band for backhaul and fronthaul
COHERENT	Management schemes for shared spectrum
EURO-5G	Support actions and lead of working group 5G spectrum
METIS-II	Spectrum requirements and technical aspects of spectrum
mmMAGIC	Spectrum above 6 GHz, including mm-waves, for 5G mobile communications access and self-backhaul
SPEED-5G	Dynamic spectrum access for multiple radio access technologies

Table 1: 5G PPP projects addressing spectrum topics for 5G

This deliverable has 6 main chapters where Chapter 2 presents requirement to spectrum, Chapter 3 deals with frequency bands, Chapter 4 explains “Pioneer Bands”, Chapter 5 provides insight on the EURO-5G innovation of “5G pioneer bands” and beyond, and Chapter 6 introduces some spectrum management aspects such as authorisation to use and also share spectrum that may lead to the need for further activity by EURO-5G.

2 Requirements for spectrum

There are both coverage and capacity requirements when delivering 5G services. The low range of spectrum below 1 GHz, which is already used for mobile services and identified for International Mobile Telecommunications (IMT) in Radio Regulations (RR) [4], or spectrum used for broadcast can provide much better coverage than the higher frequencies. At this frequency range low-capacity services such as many machine type communication types and to some degree broadband services can be provided everywhere. Also the requirement to high reliability is better secured as coverage is high. At higher frequencies the capacity is far better due to wider possible carrier bandwidth and lower range (smaller cells) and at millimetre range spectrum the capacity can be very high, but then with limited coverage.

The most demanding requirements are derived from providing 4k video. It will need 15 - 25 Mbit/s leading to about 60 - 70 Gbit/s per km^2 for a typical city population density [5][6]. In spectrum terms this leads to 600-700 MHz per operator. Table 2 provides requirements to spectrum for the 4k video as Media on Demand and nine other uses cases as estimated by the mmMAGIC project [5]. The study indicates a spectrum demand up to 3.5 GHz for dense urban society with distributed crowds, and very large bandwidths for moving hot spots.

Use case	BW-DL (MHz)	BW-UL (MHz)
Media on Demand	500	10
Cloud services (pico cell environment)	300	50
Dense urban society with distributed crowds	1 175	2 350
Smart office	1 000	270
Moving Hotspots (Not in-vehicle cell/relay)	50 000	25 000
Remote surgery/robotic control	500	10
Remote surgery/robotic control	500	10
Tactile internet	10	10

Table 2: Bandwidth (BW) requirements for downlink (DL) and uplink (UL) use cases studied by mmMAGIC, Table 6-2 in [5]

An analysis by METIS-II suggests about 15 GHz for the case of virtual reality office.

Use case	Radio frequency (GHz)	Bandwidth (GHz)
Broadband access everywhere	Below 6 GHz	0.9
Virtual reality office	Above 6 GHz only	4.9 - 14.6*
Dense urban information society	Above 6 GHz only	2.4 – 7.1*

*) Smallest estimate for three times more efficient spectrum usage

Table 3: Bandwidth requirements for some use cases studied by METIS-II in [7]

One important requirement is the radio channel bandwidth for enhanced mobile broadband (eMBB) services. At the millimetre range frequencies it should be easy to establish wide enough radio channels of several hundred MHz to cost-efficiently offer throughput rates above 10 Gbit/s. At frequencies below 6 GHz, it is more of a challenge. It is important to make available 100 MHz wide channels for services requiring throughput rates in order of Gbit/s that differentiates 5G from 4G.

3 Frequency bands

A number of frequency bands below 6 GHz are allocated to mobile service on a primary basis and are identified for IMT in the RR [4]. The last World Radiocommunication Conference in 2015 (WRC-15) identified some new bands for IMT. Some bands were below 6 GHz, and will clearly become available for 5G (as identified for IMT 2020 in the ITU-R terminology) along with the bands already identified for IMT. Decisions were decision taken in favour of the 700 MHz band, 1427-1518 MHz, and 3.4 - 3.6 GHz, identified for IMT.

A number of new bands above 6 GHz for 5G were discussed at WRC-15. Resolution 238 (WRC-15) [8] lists the bands and decided them to become the candidate bands for 5G, see Table 4.

The decision is to perform sharing and compatibility studies and to identify agreed bands including identification for IMT at WRC-19.

Bands that have allocations to the mobile service on a primary basis	Candidate bands for additional allocations to the mobile service on a primary basis
24.25-27.5 GHz	31.8-33.4 GHz
37-40.5 GHz	40.5-42.5 GHz
42.5-43.5 GHz	47-47.2 GHz
45.5-47 GHz	
47.2-50.2 GHz	
50.4-52.6 GHz	
66-76 GHz	
81-86 GHz	

Table 4: Bands for sharing and compatibility studies prior to WRC-19

For trials and early commercial deployment it is necessary to get access to spectrum early. It is useful to have a limited but sufficient number of bands identified for both spectrum authorities for spectrum assignment and industry in order to gain experience with 5G systems.

Figure 2 illustrates the bands according to WRC-19 together with the pioneer bands (700 MHz band, 3.4 - 3.8 GHz (3.6 GHz band) and 24.25-27.5 GHz (26 GHz band)). The coverage is very important where the low pioneer band provides coverage for wide area and indoor, the middle band is useful for urban areas, and the high band for hot-spots and very broadband services. Europe expects to be deploying trials in each of the three pioneer bands in the 2018 - 2020 timeframe. (See later section for an explanation of the term “pioneer band”.)

For eMBB services it is important that large enough contiguous bandwidth is made available, about 100 MHz for the middle band and 500 MHz and more for the high band.

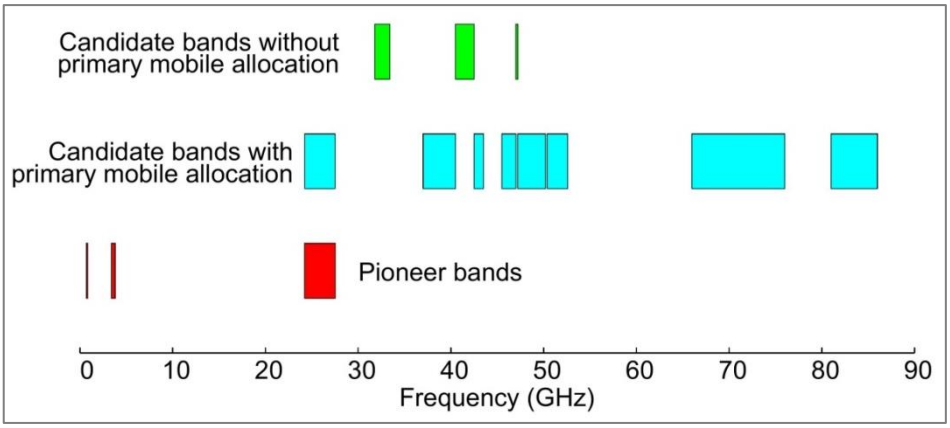

Figure 2: Candidate bands for 5G and pioneer bands

The pioneer bands seem good candidates for global harmonisation, particularly the middle band. The high band could benefit from specific radio technology for the use of adjacent spectrum bands notably in the US and some countries in Asia.

The high band 26 GHz is in study for WRC-19, along with a number of other bands up to 86 GHz. All the candidate millimetre bands are potentially of interest for 5G services. The total bandwidth of candidate bands is 33.3 GHz, and spread out over a fairly wide range. It seems that the most demanding eMBB applications can only be provided at the millimetre range of frequencies.

Wireless technology for backhaul and fronthaul requires access to adequate spectrum. An overview is provided by 5G-Crosshaul in [9] where with all possible bands above 100 GHz are indicated, but within current allocations of the RR. At 60 GHz there is a fairly wide range of 7 - 9 GHz that is treated as unlicensed spectrum for short range devices and is not listed as candidate bands in Table 4. Link lengths up to about 200 m can be served and the band may be used for high capacity backhaul and fronthaul, see 5G-XHaul report in [10]. In hybrid technology with another radio below 6 GHz in parallel it is possible to connect base station in shadow areas for the millimetre links.

The suitability of millimetre waves for coverage, capacity, and mobility, e.g. Doppler effects, is assessed [11] with respect to key performance indicators (KPIs) used within 5G PPP.

4 Why 5G "Pioneer" Bands?

Studies by EURO-5G and WG 5G Spectrum identified that Europe's spectrum management arrangements were severely challenged by the 5G technology and attendant time-scale. The accepted practice was for regulators to release spectrum on a technology neutral basis (as it became available) and for industry to decide which bands to use from its spectrum holding to meet new needs, such as 5G. However, what was different about 5G enhanced mobile broadband (eMBB) was the need for very wide radio channels (at least 100 MHz wide). None of the existing spectrum holdings in the market offered industry the means to accommodate these very wide radio channels. On the other hand, the regulators time-scales for new spectrum were being driven by the impending ITU WRC-19 rather than the specific needs of launching 5G in Europe by 2020. There was no obvious solution to this potential road block. To find the way around this road-block Euro 5G came up with a new concept of "5G Pioneer Bands".

The purpose of the 5G Pioneer Band approach was to change the focus of attention from the ITU agenda of all the possible future mobile bands to "the probability" of the very first bands that might be used for the very first deployment of 5G networks anywhere in Europe in 2020. This first "stake in the ground" could then be used to get the best information of the band that might be available in most countries across Europe to create a viable market size in which to launch 5G. We envisaged that the information would begin more in the nature of an informed "forecast" that would allow researchers to use this band for research and test beds with "the best likelihood" of it being the band eventually used for operational deployments. In this way, the efficiency of the wireless research would be enhanced. This gave us the license, as a research community, to talk about the sensitive subject of specific 5G bands. Normally this is the preserve of regulatory affairs experts in industry. However, our ambition went much further. In identifying this speculative "start-point" early we hoped to create a ripple effect that would lead to an eventual consensus involving both industry and regulators for the use of the band. The aim was to get this consensus to a critical mass by 2020. This was the theory. In practice, we found ourselves pushing at an open door as industry, regulators, and the Commission were already under pressure to find answers. The emergence of our concept of "pioneer bands" was perfectly timed to provide it. The huge burst of effort put in by EURO-5G and WG 5G Spectrum to meet the RSPG/EC time-scale demands has been well rewarded with success [1].

5 Implications of 5G Pioneer Bands

The RSPG approach to finding spectrum for 5G was very insightful. They said to industry at the very outset (RSPG Workshop, London, March 2016) not to approach them demanding a specific band but rather to approach them on the basis of "defining the problem to be solved". The WG-Spectrum's response, informed by EURO-5G inputs, followed this guidance. Only by industry examining in detail the problem to be solved did it become clear that it was impossible for a single spectrum band to meet all of the problems of coverage and capacity of a 5G infrastructure.

For Europe, the following *pioneer bands* have been suggested by the EU's RSPG Opinion [12]:

Low band	700 MHz band,
Middle band	3.4 - 3.8 GHz (3.6 GHz band), and
High band	24.25 - 27.5 GHz (26 GHz band).

Each of the 5G pioneer bands does a job very well and the three together allow the most powerful 5G infrastructure to emerge as shown in figure 3.

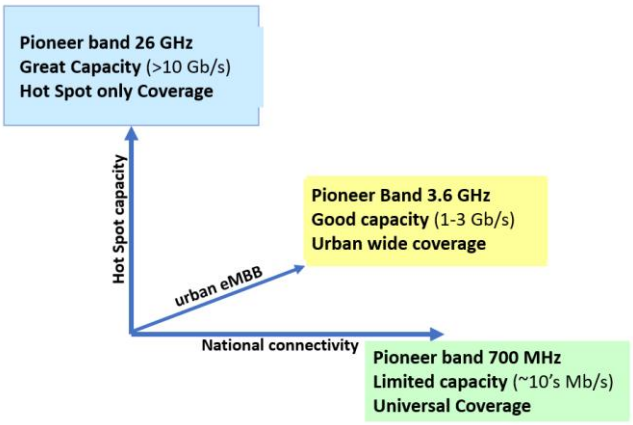

Figure 3 – The choice of 5G pioneer spectrum bands to meet the different problems to be solved.

The identification of these three 5G pioneer bands led Europe widening the 5G infrastructure opportunity compared with other parts of the world that pre-supposed a specific single band (28 GHz) only to discover later that it has limited their 5G opportunity to hot spots (or wireless local loop).

The advantage of identifying the 5G pioneer bands has been to create the best conditions for the launch of 5G in Europe. Keeping the number of bands to a minimum allows R&D efforts to be focussed, early economies of scale to be achieved and will enable 5G roaming services to emerge much earlier. It is important to note that the 5G pioneer band concept does not preclude the identified bands being used for other technologies and neither does it guarantee the bands will be available with the right radio channel widths in every market. That is still down to the industrial consensus and political will from the regulators.

As the 5G market grows more spectrum bands will be needed and this justifies on-going efforts focussed on WRC-19 and beyond.

6 Spectrum management

Mobile network operators need security for long-term investments in building and operating networks. Traditionally, and perhaps still the case, they prefer exclusive licence right to spectrum. Exclusive access rights allow secured high quality service delivery. On the other hand, license exempt use of spectrum or unlicensed, e.g., in 2.4 GHz and 5 GHz ISM bands, allows spectrum sharing where anyone can transmit just respecting some very basic rules, but with possibly higher risk for degraded service. Licence-exempt spectrum also provides the route to consumer mass products that allows small businesses and consumer to buy their own indoor cells at low prices. The result has been tens of millions of WiFi units across Europe using unlicensed spectrum meeting consumer needs as well as relieving the pressure on wide area networks.

Both exclusive licence and license-exempt access are well-established. They have provided a stable and predictable regulatory regime. The case for exclusive access rights to spectrum for cellular services may be less overwhelming in new higher bands that do not lend themselves to providing national coverage. There likely to be significant geographic areas where such spectrum remains unused. This creates opportunities for innovative approaches to spectrum sharing but it is important to underline the need for careful research into robust means to protect the services of “priority users” against harmful interference if high quality 5G public services are to be sustained.

Innovative spectrum sharing schemes are useful as well as supplementary solutions to exclusive rights [7], such as licensed shared access (LSA), authorised shared access (ASA), and licensed assisted access (LAA) for service using co-existence of licensed and unlicensed (or lightly licensed) spectrum.

In summary on spectrum sharing, from the COHERENT project [13]:

- Traditional exclusive rights frequencies and license exempt will continue
- Flexible management and sharing will give more freedom and can lead to beneficial business
- Both LSA and ASA is of interest
- LAA is gaining interest
- Co-primary sharing gives new degrees of freedom to network operators
- At microscale level flexible duplex technologies provide improvement in usage efficiency

Dynamic access to spectrum is still considered, at least as a research item. SPEED-5G has developed a radio resource management (RRM) entity with new algorithms for example license-assisted schemes for small cells and fuzzy multiple attribute decision making (MADM) strategy in multi-radio access technology (RAT) environments [14].

In the first set of H2020 projects SANSA worked on improved sharing of spectrum by satellite and fixed radio links [15].

7 Conclusions

Frequency spectrum is a sensitive subject and EURO-5G sometimes finds itself treading a fine line between the technical needs of the research community and concerns injected by competing industrial interests. At times progress is slow. However, innovative ideas such as the "5G pioneer bands" have allowed EURO-5G to provide a timely input that has facilitated Europe arriving at a spectrum solution for 5G that creates a clear opportunity for European leadership in 5G deployment. It has also given more certainty to the research community on which bands to use in research projects and thus enhancing the efficiency of wireless research and Test Beds.

The next spectrum challenges for Europe are:

- Identifying the next mobile bands beyond the three 5G pioneer bands with the focus on WRC19 and bands above 26 GHz
- Innovative spectrum sharing/licensing arrangements where careful research is needed to ensure robust approaches to minimising harmful interference

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Appendix A Members of WG 5G Spectrum

The table below lists organisations and projects active in the WG 5G Spectrum. Type of connection indicates representation as member of 5G IA, or a project. EC is an observer.

Organisation	Type connection	5G PPP project	Other H2020
5G IA	5G IA		
Airbus	5G IA		
CTTC	5G IA		SANSA
DT	5G IA		
EC	Observer		
Ericsson	5G IA	METIS-II mmMAGIC	
Fairspectrum	5G Project	COHERENT	
Huawei	5G IA	5G-Xhaul	
IHP	5G Project	5G-Xhaul	
Imdea	5G IA	5G-Crosshaul	
Intel	5G IA		
IT Aveiro	5G IA	SPEED-5G	
Leonardo S.p.A	5G IA		
NEC	5G IA		
Nokia	5G IA	METIS-II 5G NORMA FANTASTIC-5G	
NTT Euro-Labs	5G IA		
Orange	5G IA	FANTASTIC-5G	
Poznan University of Technology	5G Project	COHERENT	
Real Wireless	5G project	5G NORMA	
Samsung	5G IA	mmMAGIC	
TAS	5G IA		
Telecom Italia	5G IA	METIS-II	
Telespazio	5G IA		
TNO	5G IA		
UC3M	5G Project	5G-Crosshaul	
University of Bologna	5G IA		
University of Surrey	5G Project	EURO-5G	
VTT	5G Project	COHERENT	