



ECC Report **287**

Guidance on defragmentation of the frequency band 3400-3800 MHz

approved 26 October 2018

0 EXECUTIVE SUMMARY

This ECC Report provides guidance to administrations on defragmentation of the 3400-3800 MHz band to ensure appropriate conditions for 5G introduction in this band in line with the CEPT roadmap. This guidance is based on an analysis of the information on existing MFCN (mobile/fixed communications networks) authorisations, usage, plans, timing, national experiences and possible defragmentation plan with intended timescale for successful 5G introduction in Europe by 2020.

After detailed analysis of the current situation and objectives for the 3400-3800 MHz, and in the light of the CEPT roadmap [1] and European Commission (EC) plans [2] for 5G introduction in this band, this Report gives guidance to make available large contiguous blocks of spectrum to enable high throughput 5G applications, and to facilitate defragmentation of existing licences.

National actions are required to consider how to reorganise the entire band, to make it available for 5G before 2020 to give Europe the advantage of being a leading region for innovative 5G services, and to maximise social/economic benefits. New assignments should be based on technical conditions for the usage of 5G in this band settled in the amended ECC Decision (11)06 in 2018 [3], which have been developed on the basis of technology neutrality principle.

A review of the usage in the band in CEPT in 2016 confirmed its large fragmentation in a number of countries and the need for timely national decisions enabling availability of wider bandwidth for 5G by 2020 on a national basis.

It is up to each national administration to introduce 5G according to national policy objectives. The Radio Spectrum Policy Group (RSPG) of the European Commission (EC) "is of the opinion that the availability of the primary 5G band 3.4-3.8 GHz in Europe will be key for the success of 5G in Europe. Member States should consider appropriate measures to defragment this band in time for authorising sufficiently large blocks of spectrum by 2020" [4]. Furthermore, RSPG suggests that European administrations consider coexistence with FSS earth stations, using the technical toolkit developed by ECC (ECC Report 254 [5]).

In areas intended for 5G, it is recommended that administrations consider relocation of incumbent users to a different geographical location or to a different band above 3800 MHz, with the goal of making the band substantially available by 2020.

It is recognised that it is the role of each national administration to take action for reorganisation of the band taken into account incumbents and national policy targets to introduce 5G while shaping national policy objectives (e.g. to deliver high broadband to all, etc.). In facilitating large contiguous bandwidths for 5G, use cases for other MFCN services with smaller bandwidths may be permitted.

This ECC Report confirms importance of timely availability of the 3400-3800 MHz band to secure successful initial rollout of 5G throughout Europe by year 2020 and for facilitation of larger bandwidths and contiguous spectrum suitable for high throughput 5G applications. In case of fragmented spectrum, this may imply actions to reorganise the band accordingly. This ECC Report provides guidance to help administrations to manage this challenging task and is not exclusive from other tools available at national or European level.

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LIST OF ABBREVIATIONS

Abbreviation	Explanation
ACK	Acknowledgment
AAS	Active Antenna System
BLER	Block Error Rate
BW	Bandwidth
BWA	Broadband Wireless Access
CEPT	European Conference of Postal and Telecommunications Administrations
DL	Downlink
ECC	Electronic Communications Committee
eMBB	Enhanced Mobile Broadband
FDD	Frequency Division Duplex
FSS	Fixed-Satellite Service
FWA	Fixed Wireless Access
LTE	Long Term Evolution
MFCN	Mobile/Fixed Communications Network
MIMO	Multiple Input Multiple Output
NACK	Negative Acknowledgement
NLoS	Non-Line of Sight
RSPG	Radio Spectrum Policy Group
TDD	Time Division Duplex
UL	Uplink
VSAT	Very Small Aperture Terminal
WiMAX	Worldwide Interoperability for Microwave Access
WLL	Wireless Local Loop

1 INTRODUCTION

This ECC Report aims to address defragmentation challenges and reorganisation of the 3400-3800 MHz band in order to enable availability of wide bandwidth and contiguous spectrum for high throughput 5G uses on a national basis. The ECC has developed successive Decisions (ECC Decision (07)02 [6], and ECC Decision (11)06 [3]) during the last years, noting that ECC Decision (07)02 was withdrawn in July 2018. CEPT Administrations have assigned spectrum according to the ECC Decision (11)06, namely for the 3400-3600 MHz either in the TDD mode or FDD mode or for the 3600-3800 MHz in TDD mode. It is also the case of EU Member States fulfilling the obligation of mandatory harmonisation according to the EC Decision 2014/276/EU [7]. Nevertheless, some CEPT countries have assigned spectrum in line with the paired arrangements in CEPT/ERC/Recommendation 12-08 (1998) [8] for low, medium and high capacity fixed links. In CEPT countries, the 3400-4200 MHz band has been used for many years by the FSS for space-to-Earth links (downlink).

Consequently, the current situation sees the band fragmented and assigned to different users, on national and sometimes regional and local level.

Successful timely 5G launch in CEPT countries will benefit from the availability of large contiguous blocks of spectrum in all or part of the pioneer 5G band (3400-3800 MHz). In particular, in order to respond to market demand, as expressed by industry, to ensure a possible introduction of MFCN systems requiring very large contiguous bandwidths (80-100 MHz), on the basis of nationwide coverage, it may be necessary for the administrations to reorganise the 3400-3800 MHz band in order to provide wide contiguous spectrum with the exact contiguous bandwidth per licensee to be determined by national award processes. Current 5G NR specifications support channel bandwidths up to 100 MHz, but this should not preclude administrations allowing operators to obtain smaller bandwidths for lower throughput 5G applications on a national basis as required¹. According to CEPT Report 67 [15], the spectrum should be provided in a manner allowing for at least 3x50 MHz of contiguous spectrum.

In response to the EC Mandate on 5G, CEPT has developed harmonisation measures on the 3400-3800 MHz (named 3.6 GHz 5G pioneer band) further to assessment of the "Suitability for 5G of the existing regulatory framework for the 3400-3800 MHz range". The results could be found in ECC Report 281 [9]. That ECC Report and revised ECC Decision 11(06) provide relevant information for administrations to harmonise technical conditions for spectrum use in support of the introduction of next-generation (5G) MFCN.

Review of the existing CEPT regulatory framework and its adaptation for 5G is key for initial 5G deployments around year 2020. However, to allow successful 5G deployments there is a need to ensure timely availability ideally in all of the 3400-3800 MHz band and thus resolve the fragmented usage across Europe including national, regional (FWA, WLL, BWA, WiMAX, LTE) and local authorisations, Fixed Service point to point links, Fixed Satellite Service Earth station receivers.

Timing of existing authorisations also varies across Europe. Some countries have already conducted awards, while others are expected to do so before year 2020 in line with the 5G calendar (see Section 3.1). However, there are a number of countries where existing authorisations will expire in 2021, 2025, 2030 and even 2035. Responses to previous questionnaires have shown that significant amounts of spectrum are not used based on the existing authorisations [10]. Thus, CEPT guidance on how to best transition from the existing fragmented authorisations to the "5G ready" conditions in a timely manner will play key role for a coordinated Europe-wide approach.

In order to enable 5G in the band by 2020, national administrations can consider a number of options that can be used independently or combined, including but not limited to:

- i. Early termination of incumbent licences which are set to expire beyond 2020;

¹ Options for 5G NR channel bandwidth in the 3400-3800 MHz range: 10, 15, 20, 30, 40, 50, 60,70, 80, 90, 100 MHz (source 3GPP).

- ii. Moving incumbent licences to alternative bands;
- iii. Liberalising existing authorisations which expire beyond 2020 to allow them to be used for 5G services and implement where needed trading and leasing across the band so that interested parties can acquire spectrum usage rights on a commercial basis;
- iv. Move incumbent licences into one part of the band in order to release the largest contiguous spectrum for an award that enables 5G services.

Each of these options, their advantages and disadvantages are dealt with in detail in section 6 of this Report. Most importantly, each CEPT country will need to take account of:

- In respect of i, ii and iii the damage to regulatory certainty that such actions would bring about;
- In respect of iv, the time required to achieve this action and the willingness parties interested in the provision of 5G in funding these activities.

2 5G IN EUROPE BY 2020

2.1 EC ACTION PLAN AND CEPT ROADMAP

In November 2016, Radio Spectrum Policy Group (RSPG) provided their guidance on spectrum for 5G in "Strategic Roadmap towards 5G for Europe: Opinion on spectrum related aspects for next-generation wireless systems (5G)" [12] and in particular on the 3400-3800 MHz band. This spectrum, which offers wide channel bandwidth is already harmonised for mobile usage in CEPT countries and could be used for 5G before 2020.

In the European Commission (EC) mandate on 5G (December 2016) to the European Conference of Postal and Telecommunications Administrations (CEPT) [11], it is noted that the frequency range 3400-3800 MHz is prime spectrum suitable for the introduction of 5G-based services across the European Union.

In January 2018, RSPG reconfirmed that "the availability of the primary 5G band 3.4-3.8 GHz in Europe will be key for the success of 5G in Europe" in a Second Opinion [4] and expressed view that "Member States should consider appropriate measures to defragment this band in time for authorising sufficiently large blocks of spectrum by 2020." Therefore, completion of CEPT activities on the 3400-3800 MHz band and their timely implementation at national level is crucial to build Europe's 5G readiness and to make this new ecosystem a reality.

The RSPG Second Opinion considered the sharing potential between 5G and existing users. In some countries the existence of satellite earth stations receivers operating in the 3400-3800 MHz band will need to be considered when authorising 5G services. CEPT has provided a technical toolkit (ECC Report 254 [5]) for administrations to consider coexistence with earth stations in the frequency band 3600-3800 MHz. European administrations should ensure the proper balance between the benefits of allowing 5G use and keeping access to satellite operators in this frequency band. Administrations should consider how to use the toolkit taking into account specific national situations while at the same time facilitating practical deployment of 5G networks in this band.

In some countries the existence of other primary services operating in the 3400-3800 MHz band will need to be considered when authorising 5G services. Administrations may want to consider how to use the toolkit taking into account specific national situations, while at the same time facilitating deployment of 5G networks and promoting a greater spread of 5G by clearing the band in full for licensing mobile network operators.

Under this EC Mandate, the CEPT has amended (completion June 2018) the existing harmonised technical conditions for the 3400-3800 MHz band ensuring it is suitable for 5G.

In November 2016, ECC approved a "CEPT roadmap for 5G" [1] with a comprehensive list of actions related to 5G, which is reviewed and updated on a regular basis.

Two important actions on the 3400-3800 MHz band are listed in the CEPT roadmap:

- "A.1 Review as a matter of urgency the suitability of 3.4-3.8 GHz ECC decision for 5G."
- "A.2 Provide guidance to administrations for defragmenting the 3.4-3.8 GHz band, in which there are existing licences in many CEPT countries and for developing plans and intended timescale for the future utilisation of this band."

CEPT has concluded work under action A.1. The results are in ECC Report 281, "Analysis of the suitability of the regulatory technical conditions for 5G MFCN operation in the 3400-3800 MHz band" [9].

2.2 THE 3400-3800 MHZ BAND: THE PRIMARY 5G BAND

The lack of low frequencies bands supporting wide channels makes the 3400-3800 MHz band crucial for 5G deployments. The primary 5G band offers a combination of higher bandwidth and higher capacity as well as a good potential to become a future roaming band for 5G.

The 3400-3800 MHz band has already been harmonised for MFCN in CEPT and is recognised to be the 5G primary band in Europe. The development of the mobile ecosystem in this frequency band is favoured by World Radiocommunication Conferences (WRC-07 and WRC-15) decisions with identification of 3400-3600 MHz for IMT in Region 1 and up to 3700 MHz in 5 countries in Region 2 and in many countries in Region 3 on a co-primary basis with existing services.

Many national administrations within CEPT plan to enable initial 5G deployments in the 3400-3800 MHz band. At the date of publication of this report some European countries e.g. Hungary, Ireland, , Italy, Latvia, Romania, Slovakia, Spain and the UK have already awarded frequencies in the 3400-3800 MHz band and some others e.g. Austria, Cyprus, France, Germany Portugal and the UK² are planning to conduct similar auctions. Spectrum awards both at national and regional level have been considered by administrations within this band.

2.3 IMPORTANCE OF TIMELY AVAILABILITY OF WIDE CONTIGUOUS SPECTRUM FOR 5G

3GPP plans to complete 5G Release 15 in June 2018, thus equipment is expected to be available in 2018. Provision of 5G services supporting channel bandwidth up to 100 MHz, based on 3GPP R15 standard, could be enabled by the end of 2018, if sufficient contiguous spectrum is made available to enable operation of MFCN with wide channel bandwidth. As well as sufficient contiguous spectrum, actual deployment also depends on many other technical and commercial aspects for the operators.

It is important for licensees to have access to large contiguous channels, supporting a variety of applications with high data rates and/or low latency and improved user experience. In the interest of technology neutrality, this band should also allow for smaller bandwidths in multiples of 5 MHz if there is market demand for such applications on a national basis – as shown in recent awards in this band.

Administrations should allow for the availability of large contiguous blocks of spectrum and should consider prompt action if problems arise resulting from fragmented usage of the 3400-3800 MHz band to enable timely 5G rollout.

² Additional frequencies planned to be awarded following the first award of 3410-3600 MHz

3 OVERVIEW OF THE CURRENT USAGE AND EXISTING PLANS FOR THE FUTURE USAGE OF THE 3400-3800 MHZ BAND IN CEPT COUNTRIES

3.1 INFORMATION ON EXISTING LICENCES IN THE 3400-3800 MHZ BAND

There is a need to review the current utilisation of the 3400-3800 MHz band by administrations with the main purpose to identify the potential amount of available contiguous spectrum enabling the deployment of 5G networks in this band that administrations might be able to award, and in what timeframe. There are several CEPT countries for which spectrum licences in the 3400-3800 MHz band will be still valid after 2020; and it is necessary to consider the options an administration can take to facilitate this purpose.

In November 2016, ECO ran a questionnaire on the availability of the 3400-3800 MHz band for 5G to which 30 CEPT administrations provided responses [10]. The results from the questionnaire provide a very useful snapshot of the characteristics of existing uses at that time. The questionnaire, in particular, collected full information for all licences including detailed frequency information, exact licence expiry dates and licence holder names

Figure 1 below summarises the applications reported by the administrations and their allocations as of November 2016. Note that the situation has changed in some countries (see section 7):

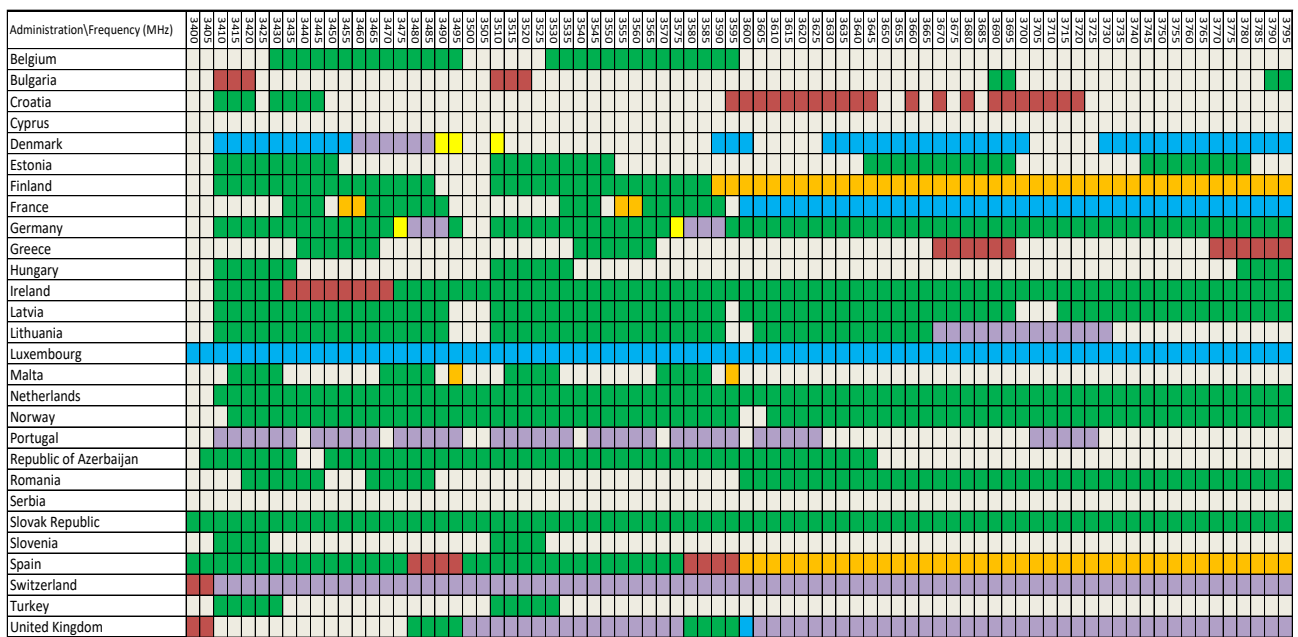


Figure 1: Summary from ECO questionnaire in 2016

The colour code corresponds to the different applications as shown in Table 1 below, which also includes the % allocated to each application. Table 1 shows that most of the 400 MHz in the range are either vacant or already allocated to mobile or BWA services.

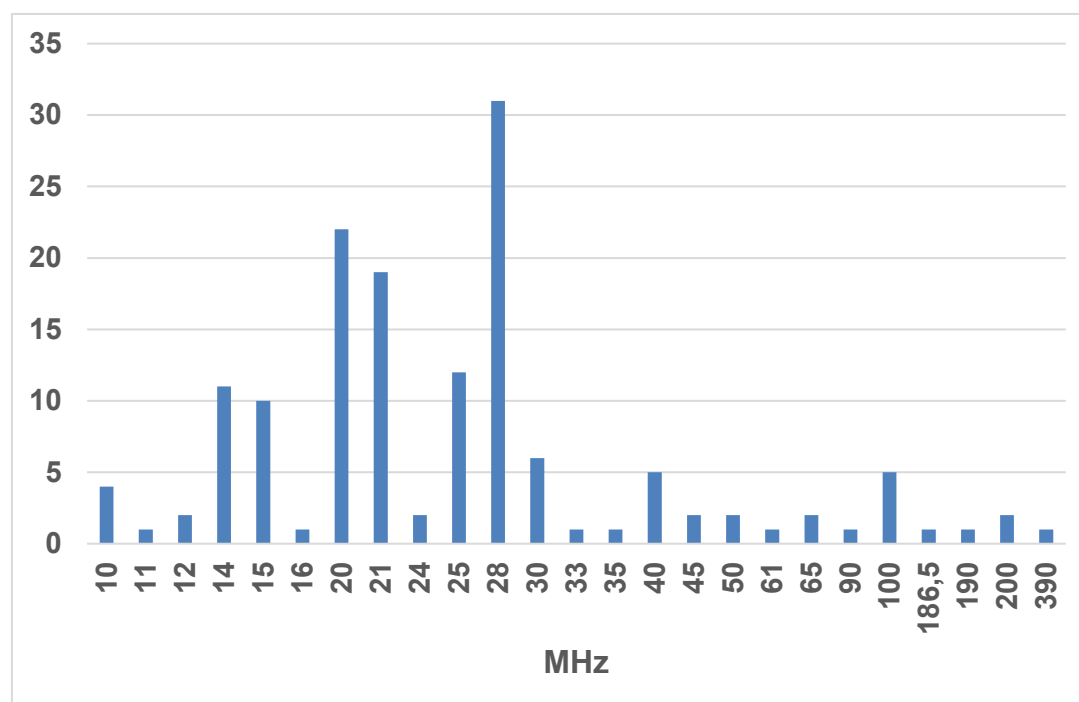
Table 1: Applications associated to the licences

	Category	Definition	% of the spectrum
1	Vacant	Unused or no information provided	40.6%
2	Mobile/ wireless broadband	Includes MFCN, BWA (FWA, WLL & WiMAX), LTE and similar terms	36.4%
3	FS	Fixed Service point to point links	3.9%
4	FSS	Fixed Satellite Service Earth station receivers	7.3%
5	Other	Includes Military and related terms, PMSE/ENG-OB, amateur and other miscellaneous terms	2.6%
6	Unknown	Technology neutral or information not available	0.2%
7	Mixed	Combination of 2 or more above categories in use within the same range	8.9%

3.1.1 Characteristics of existing mobile and wireless broadband use

3.1.1.1 Bandwidth of the individual licences

The questionnaire provides information on the size of the blocks that administrations have licensed. The chart below shows the number of licences of a given block size across the 30 countries that responded to the questionnaire, for mobile/wireless broadband applications. Block sizes of 28 MHz and 20 MHz are the most frequent. Paired assignments count as two blocks of the same size.

**Figure 2: Number of assignments of a given block size**

Note: Since the conduct of the questionnaire, the following countries have conducted awards and the block sizes per operator are shown;

Ireland:

- Vodafone Ireland: 105 MHz/85 MHz urban/rural regions;
- Three Ireland: 100 MHz nationally;
- Meteor Mobile: 85 MHz/80 MHz in urban/rural regions;
- Imagine: 60 MHz in rural regions;
- Airspan: 60MHz/25 MHz in urban/rural regions.

UK:

- Vodafone: 50 MHz nationwide;
- Hutchison 3G UK, 20 MHz nationwide (to add to existing holdings of 2 x 20 MHz and 1 x 84 MHz);
- Telefonica UK: 40 MHz nationwide;
- BT/EE: 40 MHz nationwide.

Spain, 3600-3800 MHz

- Orange: 60 MHz nationwide;
- Telefonica: 50 MHz nationwide;
- Vodafone: 90 MHz nationwide.

Detailed information of the awards in Ireland and the UK is in 7.3 and 7.4 respectively.

3.1.1.2 Coverage, pairing, trading of spectrum usage rights and technology neutrality

Table 2 to Table 5 below summarise the characteristics in terms of coverage, paired/unpaired allocation, trading conditions and technology neutrality of the spectrum blocks assigned to mobile/wireless broadband across the 30 administrations.

Table 2: Licences’ geographic scope

Coverage	Number of blocks	% of total
National	75	51%
Regional	67	46%
Individual transmitter	1	1%
Unspecified	3	2%

Table 3: Paired vs. unpaired licences

Paired block	Number of blocks	% of total
No	55	38%
Yes	91	62%

Table 4: Licences' tradability

Is trading allowed	Number of blocks	% of total
No	59	40%
Yes	87	60%

Table 5: Technology/service neutrality of licences

Block is licensed under technology/service neutral conditions?	Number of licences	% of total
No	44	30%
Yes	102	70%

3.1.1.3 Licence expiration

The following Figure 3 shows a timeline of expiration dates, and the number of mobile/wireless broadband licences that expire at different dates. The chart considers paired blocks as a single licence, and excludes 14 licences that are of indefinite duration. A significant number of licences (63% of the total) expire after 2020.

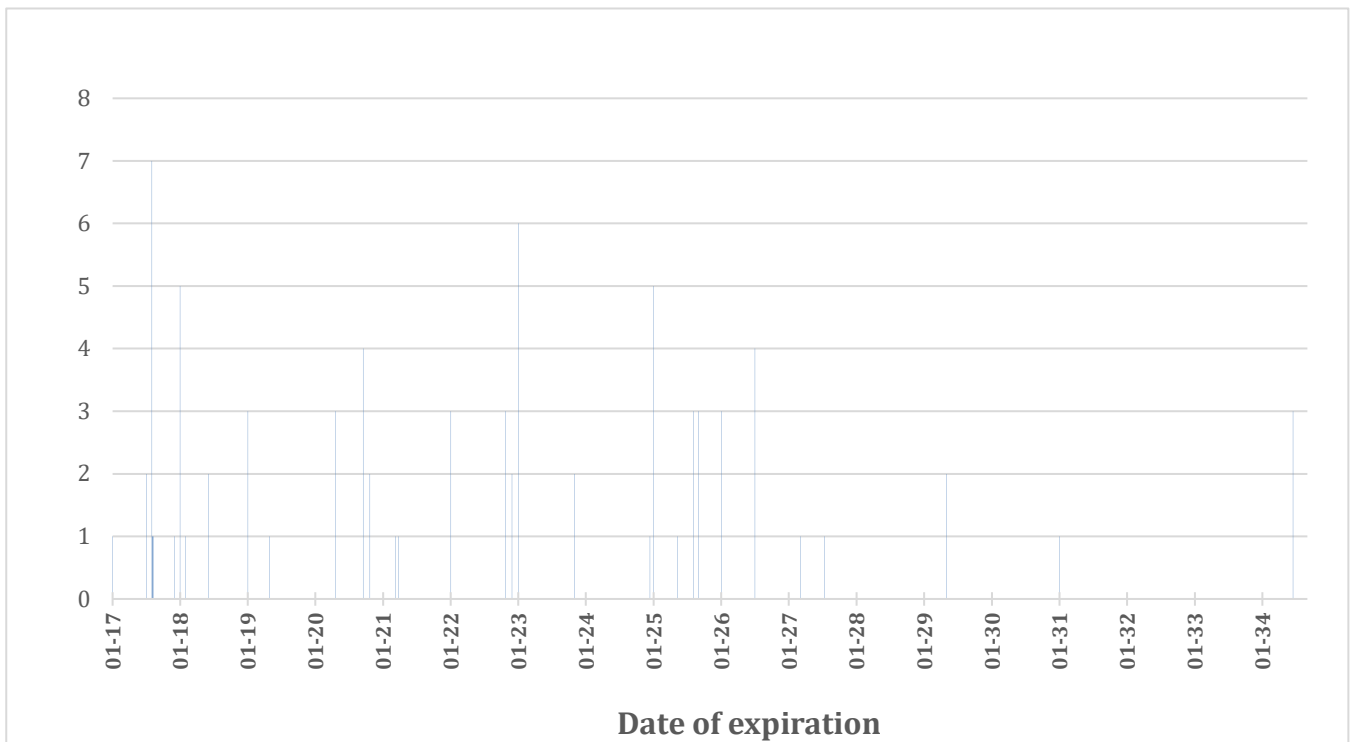


Figure 3: Number of licences per expiration date

3.1.2 Additional comments from some administrations

Some administrations also provided qualitative observations in their response to the questionnaire ran by ECO. These are summarised below:

3.1.2.1 *Current situation*

Mobile and wireless broadband services

Administrations reported that actual utilisation for MFCN/BWA is generally limited, 17 administrations indicated that services were operational mainly in the frequency band 3400-3600 MHz. Deployments would be typically focussed on specific areas, e.g. for rural coverage, typically using WiMAX.

3 administrations specifically noted that they had authorisations which were not in use at the time. A further 3 administrations had no authorisations for mobile services in this range. In some cases information on actual usage was not available as this had not been provided to the administration.

Other existing usage

3 administrations noted that fixed link usage (point-to-point links) had been expected to decrease or be migrated to other bands, 1 administration expected existing usage to continue.

1 administration noted video PMSE usage was planned to continue in 3400-3600 MHz, and 1 noted temporary usage for ENG/OB with national licences.

1 administration noted a satellite earth station, used for reception of defence services and requiring protection, which resulted in restrictions on mobile broadband usage within 3410-3800 MHz. 1 administration reported registered FSS and VSAT stations.

3.1.3 **National plans with regard to the future utilisation of the band**

22 administrations reported in 2016 to have plans and 8 not have plans. Those that had plans:

- 11 administrations were currently reviewing or planning to review the use of the band for MFCN (including future 5G), but had not made final plans. Many were undergoing or planning public consultations to determine the market needs. Decisions were also subject to sharing studies with existing services and ongoing international work in this band;
- 7 administrations had decided to release at least parts of the band for MFCN. In some cases the final plans were still subject to public consultation;
- 1 administration was undergoing an award process at the time;
- 3 administrations indicated that the majority of spectrum was already available for MFCN.

With regards to the timing of the plans:

- 5 administrations intended to make final decisions and start award process in 2017, 3 by 2018, 1 by 2019, 1 by 2020, 1 by 2021 and 2 by 2022;
- 8 administrations had not yet decided at the time of the questionnaire, and 1 administration was undergoing an award at that time with services planned to be launched in 2017.

The questionnaire also asked if administrations intended to facilitate the early availability of a large contiguous spectrum blocks for the initial deployment of 5G networks. 8 administrations responded that they intended to facilitate large contiguous blocks. In some cases this would depend on market and award designs. 10 administrations had not made any decisions yet, 3 administrations indicate that this was already possible with available spectrum, subject to market demand, and 1 administration believed it was not necessary to make specific plans to facilitate 5G as the licences would be technology neutral.

3.1.4 **Summary of questionnaire's main findings**

In summary, the questionnaire provides the following key findings about spectrum usage in the 3400-3800 MHz band in 2016 (in the 30 CEPT countries that responded to the questionnaire):

- 40% of the spectrum in the range is reported as unused or no information provided, 36% is reported as assigned to a service of the mobile or broadband wireless types (includes MFCN, BWA, FWA, WLL,

WiMAX, LTE and similar terms). Putting together the information from the 30 countries, there are 146 blocks assigned to these types of uses;

- With regards to the spectrum currently assigned to mobile/wireless broadband use:
 - Spectrum is assigned in blocks of sizes that vary from 10 to 390 MHz. However, blocks sizes of 28 MHz and 20 MHz are the most frequent;
 - Geographic coverage of the blocks is evenly split, 51% give nationwide access rights and the rest either regional, local or per transmitter rights;
 - The majority of the blocks (62%) are licensed paired with another block;
 - Trading is allowed in 60% of the blocks and licence conditions are technology/service neutral in 70% of blocks;
 - 63% of the licences expire after 2020 (including 14 that have indefinite duration).

The review also shows that in most European countries this band has been used to a very limited extent for MFCN, despite regional and national authorisations in force.

3.2 BENEFITS OF THE HARMONISATION OF THE 3400-3800 MHZ BAND FOR MFCN

Current utilisations of the 3400-3800 MHz band should be reviewed with the main goal of identifying the potential amount of contiguous spectrum for 5G deployment, also assessing in which time frame this spectrum could be made available.

As the amount of spectrum required for mobile services increases, it is suitable for existing and newly allocated and identified spectrum to be harmonised. The benefits of spectrum harmonisation are various: facilitating economies of scale, enabling global roaming, reducing equipment design complexity, preserving battery life, improving spectrum efficiency and potentially reducing cross-border interference. Typically, a mobile device contains multiple antennas and associated radio frequency front-ends to enable operation in multiple bands to facilitate roaming. While mobile devices can benefit from common chipsets, variances in frequency arrangements necessitate different components to accommodate these differences, which lead to higher equipment design complexity.

Therefore, harmonisation of spectrum for IMT will lead to commonality of equipment and consequently will result in economies of scale and affordability of equipment.

5G will have improved link budget and better spectrum efficiency when compared with 4G, and this will result in better peak and average data rates for similar channel bandwidths. However, large bandwidths are still required to meet the performance requirements associated with 5G usage scenarios as described in ITU-R Recommendation 2083 [13]. ANNEX 1: shows the theoretical data rates that 5G is expected to achieve for a given bandwidth and the measured data rates in a test.

4 MAIN OBJECTIVES FOR THE 3400-3800 MHZ BAND

4.1 OBJECTIVE #1: SUCCESSFUL 5G DEPLOYMENTS IN EUROPE BY 2020

In the 5G Action Plan [2], the EC proposed a harmonised roadmap towards 5G across the European Union, with trials starting from 2018 and initial commercial launches in 2020. One key objective is to ensure that every Member State will identify at least one major city to be "5G-enabled" by the end of 2020 and that all urban areas and major terrestrial transport paths have uninterrupted 5G coverage by 2025. The "5G Pan-European Trials Roadmap"³ released at the 4th 5G Global Event on 22-24 November 2017 in Seoul [14] expanded the work initiated in the context of the 5G Action Plan. One of its main objectives is to "support global European leadership in 5G technology, 5G networks deployment and profitable 5G business."

In its "Strategic Roadmap towards 5G for Europe: Second Opinion on spectrum related aspects for next-generation wireless systems (5G)" [4], the RSPG considers the frequency band 3400-3800 MHz to be the primary band suitable for the introduction of 5G-based services in Europe even before 2020, which will be key for the success of 5G in Europe. Therefore, Member States should consider appropriate measures to defragment this band in time for authorising sufficiently large blocks of spectrum by 2020. Large blocks are important for the successful deployment and are discussed in more detail in objective #3.

Therefore, completion of CEPT activities (technical conditions, decision, defragmentation and synchronisation) on the 3400-3800 MHz band and their timely implementation at a national level are necessary to build Europe's 5G readiness and to make this new ecosystem a reality.

4.2 OBJECTIVE #2: COMMON TECHNICAL CONDITIONS WITH A HARMONISED TDD BAND PLAN

The ECC Report 281 "Analysis of the suitability of the regulatory technical conditions for 5G MFCN operation in the 3400-3800 MHz band" [9] proposes Least Restrictive Technical Conditions (LRTCs) that are compatible with 5G NR and with LTE. The LRTCs of the assignments in the band should be in line with this Report and with the ECC Decision (11)06 as amended in 2018 [3].

The ECC Decision (11)06 states in its Annex 1 that the frequency arrangement for the 3400-3800 MHz is a TDD band plan. TDD has been specified in 3GPP as the duplex method for 5G in 3400-3800 MHz. ECC Report 281 explains the advantages of this duplex method for this frequency range; notably supporting UL/DL traffic asymmetry and the ability to exploit channel reciprocity for effective AAS implementation.

4.3 OBJECTIVE #3: MAKE AVAILABLE LARGE CONTIGUOUS BLOCKS FOR MFCN

According to CEPT Report 67 [15], the spectrum should be provided in a manner allowing for at least 3×50 MHz of contiguous spectrum. In order to respond to market demand, as expressed by industry, large bandwidths of 80-100 MHz contiguous spectrum are important to deliver high throughput 5G services in the 3400-3800 MHz frequency band. A large bandwidth will enable provision of increased data rates to support new usages e.g. related to eMBB, but will also support URLLC and will facilitate cost effective rollouts (more details in ANNEX 1:). 5G has the potential to deliver substantial performance and capacity improvements with largest amount of spectrum below 6 GHz.

Ideally, large contiguous blocks of harmonised spectrum are made available to provide high throughput 5G based services in this range with the exact bandwidth per licensee to be determined by national award processes. By design, 5G NR will optimally support wideband operation, allowing operators to take full advantage of larger allocations of contiguous spectrum to increase peak rates and user experience, with

³ https://5g-ppp.eu/wp-content/uploads/2017/05/5GInfraPPP_TrialsWG_Roadmap_Version2.0.pdf

manageable terminal complexity and minimal power consumption. Therefore, timely release of sufficient spectrum at reasonable prices is needed, if the 5G target launch date is to be met.

Ideally the whole 400 MHz would be made available in the band, noting that this may not be possible for all administrations. Facilitating the availability of large contiguous blocks in any spectrum award in this band will enable competition to determine the amount of contiguous spectrum each licensee can acquire in the award.

4.4 OBJECTIVE #4: INVESTMENT AND PLANNING CERTAINTY

The current licensing arrangements in the band based on the previous ECC Decision (11) 06 (from 2014) across Europe may not be supportive of the introduction of 5G within the timeframe. National, regional or even local licences have been granted in this band. In some countries, relevant local/regional spectrum usage rights have been subject to trading in order to establish national footprint.

Technical conditions suitable for 5G have been developed with the assumption of individual authorisation. Further activities are on-going on synchronisation between 5G networks in a competitive environment and between 4G and 5G networks.

Regulatory certainty and stability are necessary to incentivise operators/and other stakeholders (verticals) to invest in networks. Technical conditions to operate the network should be defined prior to the award, regardless of the type of authorisation regime, in order to give sufficient visibility to investors.

The establishment of regulatory frameworks which incentivize investment in national MFCN infrastructures in the European primary bands are essential to the success of 5G in Europe. If the 3400-3800 MHz band is intended for macro coverage for 5G on a national basis, national licences are preferred. Early re-allocation measures, freeing up enough spectrum in the 3400-3800 MHz band for 5G purposes will allow industry to plan investments with greater certainty.

5 POSSIBLE WAY FORWARD

The situation of the band as depicted in section 4 is not supportive of the objectives outlined above. In particular, there is still a significant amount of spectrum dedicated to uses that cannot be considered terrestrial systems capable of supporting MFCN. Some administrations still reserve nationwide blocks for services such as fixed links and military radars.

In practice, FDD technology solutions have not been introduced in the market, so that assignments of paired spectrum are actually used for TDD usage mode. To improve efficiency, the rearrangement of FDD spectrum should be considered so that contiguous assignments are available to licensees.

Furthermore, most of the spectrum licensed for MFCN (mobile or fixed broadband) is not supportive of key 5G objectives such as large contiguous bandwidths, national use or TDD allocations.

5.1 EXISTING NON-MFCN USAGE

To enable 5G services in the band administrations should consider what actions might be required with regard to existing usage rights that are not compatible with the existing MFCN framework.

5.1.1 Fixed Service

Due to the varying characteristics of different types of FS systems and their deployment, no single separation distance, guard band or signal strength limit can be provided to guarantee co-existence with 5G systems. Co-existence can be achieved through national coordination on a case-by-case basis nevertheless it introduces national complexity. It is therefore recommended to assess to possibility to relocate the fixed service to another band in the areas intended for 5G, and to assess the impact to regulatory certainty this may cause.

5.1.2 Fixed Satellite Service (FSS)

In CEPT countries, the 3400-4200 MHz band has been used for many years by the FSS for space-to-Earth links (downlink), together with the 5850-6725 MHz frequency band for Earth-to-space links (uplink). The 3600-3800 MHz and 3800-4200 MHz are usually used more extensively by FSS earth stations than the lower part 3400-3600 MHz.

CEPT has concluded that co-channel sharing is not possible between FSS and MFCNs in the same geographic area, and that sharing between FSS and MFCNs requires a sufficient separation distance between the services. The required distance varies considerably depending on system specifications (see ECC Report 203 [16]) and local geography. ECC Report 254 [5] provides a technical toolkit for coexistence between MFCN and FSS in the frequency band 3600-3800 MHz.

In areas intended for 5G, such as urban, suburban areas, or along transport routes such as roads and railways, it is recommended that administrations consider relocation to a different geographical location or to a different band above 3800 MHz, taking into account considerations such as the impact on the FSS business (the cost of physical relocation, the cost of changing equipment), its level of use of the spectrum, the high-level target of introduction of 5G by 2020 and the opportunity cost of precluding 5G use in that area.

In areas not intended for 5G, administrations could consider maintaining existing FSS installations. These installations could be protected with spectrum sharing mechanism as described in ECC Report 254:

- Approach A: Specifying the maximum permitted interference powers or electric field strengths at the FS/FSS receivers and allowing full flexibility to the MFCN operators to comply with the specified limits. These may be expressed in terms of protection zones;

- Approach B: Specifying explicit restrictions on the frequency, or geographic location, or the e.i.r.p. levels (or a combination thereof) for the MFCN deployments. These restrictions can be expressed in terms of exclusion zones and/or restriction zones.

In the areas where 5G is intended administrations are recommended not to issue authorisations to new sites in this band for FSS and to consider the higher bands above 3800 MHz for future FSS usage.

5.1.3 Broadband Wireless Access (BWA)

Considering the similarity between BWA and MFCN systems, it is concluded that BWA can co-exist under some conditions with MFCN systems that are licensed under the new BEM licensing regime (ECC Decision (11)06 revised 2018 [3]) or the previous one (ECC Decision (11)06 revised 2014). It shall be noted that various CEPT studies refer to the coexistence between BWA and MFCN (see CEPT Report 49 [17] and 67 [15] for example).

- In particular, according to CEPT Report 49, it has been noted that BWA systems compliant with previous framework may suffer from interference from MFCN systems operating according to the regulatory framework (ECC Decision (11)06 [3] as updated in 2014). Either a frequency separation or the application of BEM elements (2014) has been recommended⁴:
- The last CEPT studies (CEPT Report 67 [15]) highlighted the coexistence issues between LTE and 5G NR systems in adjacent frequencies and the conditions to be fulfilled to ensure the coexistence between either synchronised operation for AAS or non-AAS systems or unsynchronised operation for AAS or non-AAS systems.

As a consequence administrations should assess the need to reorganise the BWA usage in order to make sufficient contiguous spectrum available for high throughput 5G applications. The reorganisation if needed should be engaged with no delay in order to make sufficient contiguous spectrum available suitable for 5G. Synchronisation between existing BWA networks and 5G are of importance for 5G introduction. The lack of synchronisation of these networks BWA/5G MFCN could imply the need of guard band between both networks. Synchronisation issue is currently being assessed by ECC. Specific implementation cases may be defined at national level⁵. CEPT is developing a toolbox for the most appropriate synchronisation regulatory framework between 5G NR and LTE to help either network operators or administrations to address relevant coexistence issues.

Moreover in order to ensure a more efficient usage of spectrum, administrations may also assess the opportunities in some geographical areas to share the spectrum between LTE and 5G systems on co-channel basis. Possible re-used of relevant cross-border coordination limits within a co-channel national context between LTE and 5G systems should be further assessed on the basis on the future update of the ECC Recommendation (15)01 [18].

5.1.4 Cross-border coordination

Cross-border coordination is not expected to be a significant issue between MFCN systems even in the context of fragmented usage in the bands. It is expected that reorganisation of the band will facilitate the bilateral and/or multilateral negotiations. CEPT will develop relevant guidance for 5G cross-border coordination. This will address also the LTE/5G NR cross-border coordination responding to various national migration approaches. On the basis of this future update of the ECC Recommendation (15)01 [18], it will be also appropriate to assess to reuse the LTE/5G systems cross-border coordination limits within a co-channel national operation.

⁴ See CEPT Report 49 [17]

⁵ See CEPT Report 67

5.2 EXISTING MFCN LICENCES

Existing licences that are compatible with the existing MFCN framework (ECC Decision (11)06 [3] and EC Decision 2014/276/EU [7]) can be preserved and upgraded as these licences could be used to deploy 5G services.

However, administrations should consider two aspects:

- Are the existing MFCN-compatible licences likely to result in actual usage? Administrations should assess the ability and intent of the licensee to deliver and invest on 5G services. From technology view point, the size of the licensed blocks and the duplex mode shall be carefully assessed in order to ensure they are compatible with 5G (see update harmonised technical conditions). The administrations could consider the licensee's existing level of deployment, financial, operational and commercial capability. Licence obligations, for instance in terms of coverage or deployment of stations, should be assessed carefully. If licence holders have not yet deployed services of any kind, and they are unlikely to do so in the future, then administrations could consider setting other incentives to encourage surrender or trade of licences depending on national circumstances. If this is not possible, administrations could consider not renewing the licences at expiration (use it or lose it approach);
- What changes to MFCN-compatible licences are required? The technical licence conditions of existing licences are unlikely to align with the technical conditions in the amended ECC Decision (11)06 [3]. In addition, in some cases the licences may not be technology neutral or support trading of spectrum usage rights. It is therefore recommended that administrations vary the technical licence conditions of existing licences to align with the amended Decision, and that they vary the general licence conditions to allow trade of the access rights granted by the licences, and that administrations remove any conditions mandating specific technologies and application. Competition issues should be taken into due consideration in case of change of technical conditions. These interventions could facilitate market trades that result in a more efficient arrangement of the band. However, the variation of licences should not preclude continued operation of the already deployed equipment (compliant with the current MFCN regulatory framework). This is ensured by the fact that the amended ECC Decision (11)06 [3] is being defined so that "continued operation of existing MFCN equipment compliant to ECC DEC (11)06 is to be ensured, without impacts".

5.3 FRAGMENTATION OF THE SPECTRUM OF EXISTING MFCN LICENCES

The 2016 ECO questionnaire [10] (Figure 1 in section 3) shows that a majority of existing MFCN licences have a bandwidth of 30 MHz or lower. A majority of licences (62%) are for paired blocks. These licences are not appropriate for the current TDD band plan for 5G (see ECC Report 281 [9] and ECC Decision (11)06 as amended in October 2018) [3] in the 3400-3800 MHz and do not support the wide bandwidths required for 5G. In addition, some existing licensees may want to deploy 5G in the band, whilst others may prefer to continue using their existing technology (WiMAX, LTE) or to deploy something else (LTE most likely).

Bearing in mind the diversity of scenarios, administrations may nevertheless want to consider to:

- Take advantage of technology migration. The band has been assigned in various countries for Broadband Wireless Access (BWA) applications. In practice FDD technology solutions have not been introduced in the market, so that assignments of paired spectrum are actually used for TDD usage mode. These systems may have consistently migrated from WiMAX to LTE technology over the recent years. This market-driven migration process from WiMAX to LTE equipment could be exploited to accommodate defragmentation, while maximising possible spectrum availability for 5G deployments.
- Encourage licence trading and facilitate larger contiguous blocks, so that the band becomes less fragmented. Some of licensees that hold small and paired blocks may be willing to deploy 5G. It may be

possible to re-arrange those blocks into larger and contiguous blocks. This would require little intervention from the administration besides making the licences tradable.

- Take advantage of the award to further remove fragmentation. Design appropriate market based award mechanisms that do not exclude existing incumbents in obtaining spectrum rights of use in an appropriately sized geographic area to continue providing services. If the release of new spectrum in the band takes the form of an auction, a final auction stage (an assignment stage) can be put in place where participants bid to choose where exactly in the band their holdings are placed. Existing licensees can be offered to participate in this stage, bringing their existing spectrum holdings to the pool of spectrum to be re- assigned. The benefit for existing licensees would be that they can bid to unify their current holdings in a single contiguous block if they are still non-contiguous, or to unify their current holdings with new spectrum that they might have obtained at the award
- Stack existing licences together, so that a large contiguous sub-band can be made available for 5G services. In some countries there are unused blocks that are interlaced with the MFCN licences. It is suggested that administrations re-organise these unused blocks so that licences already assigned for MFCN are next to each other. This would allow to move all the empty blocks together, and hence to make available a larger, contiguous block that can be released for 5G services (see Figure 6 below for an example of this process).

5.4 COEXISTENCE OF DIFFERENT TECHNOLOGIES IN ADJACENT BLOCKS

A TDD band plan has been chosen by ECC for the amended ECC Decision (11)06 [3]. Interference between networks can be a problem when different operators deploy TDD networks in adjacent blocks. This problem can be addressed with common synchronisation and alignment of UL/DL transmissions, or with guard bands, or with geographical separation of the transmitters. The most efficient solution, from the perspective of spectrum use, is to adopt synchronisation. In this case, the networks can operate in adjacent spectrum and collocated. ECC Report 281 [9] and the Report on synchronisation that ECC will produce address this in more detail.

A particular case is a frequency adjacency between 4G LTE and 5G NR networks. Synchronisation of 5G NR with LTE may not be possible or desirable, in which case guard bands or geographic separation are the only possible solutions to avoid interference.

In scenarios where guard bands are appropriate it is important to reduce the number of adjacencies between the two technologies. Administrations could consider migrating all existing LTE networks to an end of the 3400-3800 MHz band, so that there is only one 5G-LTE boundary. In practice this would be akin to establishing two sub-bands, one for LTE (or other technologies) and another for 5G NR.

Admittedly, it may not be possible for administration to get a clear view of which licensee will use which technology. Furthermore, some licensees may decide to operate LTE for a period of time and then migrate to 5G NR. However, to the extent possible administrations should try to get information about the technology plans of the licensees and re-organise the frequency position of the blocks accordingly.

5.5 GEOGRAPHIC FRAGMENTATION

5.5.1 Considerations on the geographic scope of licences

Spectrum licences can be awarded with a range of different geographic scopes, i.e. the geographical areas where the use authorised by the licence can take place. MFCN licences typically authorise use of a block of frequencies over a whole country, e.g. national licences in 900 MHz, 1800 MHz for 2G, 2100 MHz for 3G, 800 and 2600 MHz for 4G.

However, smaller geographic scopes are possible and have been used in the past for other services, such as FWA. As captured by the ECO questionnaire and shown in section 4, regional licences have been issued by administrations in the past.

Possible alternatives, which may be considered by administrations when deciding on the geographical area that a licence can cover, are described below:

- National licence: The licence authorises use of a block of spectrum over the whole area under the jurisdiction of the issuing administration, i.e. the country. The licence is typically issued after a competitive award such as an auction or a beauty contest. National licences reduce the risk of co-channel interference that may exist with regional/geographical licences;
- Regional/geographic licence: The licence authorises use of a block of spectrum over a defined geographical area. Administrations can define the areas in different ways based on regional and local boundaries or a geometric grid (for example 50kmx50km squares). The award process can provide for the availability of multiple regional licences so that an applicant has the possibility to combine regional licences to obtain the equivalent of a national licence;
- Individual transmitter(s): The licence authorises the use of one (or more) transmitters whose characteristics are defined in the licence. These characteristics would notably include the location, height and transmitted power and therefore indirectly define the coverage and usage area. The licences may also allow the use of mobile devices, under the requirement that they are controlled by the main transmitter⁶;

Unlike national and regional licences, these licences are normally issued on request of applicants on a case by case basis and not by means of an award. Applicants would specify in their applications the characteristics of the transmitters according to their business requirements. They are typical of private mobile networks and issued on a first come first served basis.

In determining the appropriate geographic scope of the spectrum assignments, administrations should be guided by their statutory objectives which may include:

- ensuring the efficient management and use of the radio frequency spectrum;
- contributing to the development of the internal market;
- promoting the interests of users within the community;
- providing for technological neutrality;
- promoting competition.

Further to the above, in considering the geographic extent of an award, Administrations should choose an approach that is most appropriate to their national situation, in this regard considerations may include:

- the geographic extent of the current users of the band be it national, regional or individual transmitters;
- the population density of specific geographic areas;
- spectrum efficiency considerations, including whether there are different potential use cases in different areas of the country, e.g. urban or rural.

The award of regional licenses may require additional regulatory considerations and it needs to be balanced in determining an award design. Additional matters to consider in designing regional awards include:

- the definition of the boundaries between regions;
- the coexistence rules at the boundaries or regions (ECC Recommendation 15(01) [18] considers cross-border coexistence in the 3400-3800 MHz band which may be useful to consider in this context and in particular the future update addressing co channels issues between LTE and 5G systems.);
- the coordination mechanism between operators to allow for the more detailed sharing of networks across boundaries;
- whether networks are envisaged for national transport paths (i.e. along national rail and road corridors)

⁶ A variation of the individual transmitter licence is one where the licence specifies a geographical area and authorises the use of certain type of equipment, perhaps with a limitation on the number of devices. This licence would also be issued on the demand of an application, who would specify in its application the geographical area of its interest (for instance as a polygon)

- the use of an award mechanism where both regional and national licences are available subject to demand may in some national situations assist in defragmenting the band as it may allow an opportunity for existing regional licensees to maintain and enhance services while also allowing national licences to be issued for the introduction of large contiguous bandwidths for 5G services.

Annex 2 contains a detailed assessment of the advantages and disadvantages of national, regional and individual licences in the context of mobile use. The table below summarises advantages and disadvantages from a more general perspective.

Table 6: Advantages and disadvantages of different licensing scopes

Licensing scope	Advantages	Disadvantages
National licence	<ul style="list-style-type: none"> ▪ Reduced regulatory burden ▪ Support national networks and operators 	<ul style="list-style-type: none"> ▪ Restricts access to smaller organisations ▪ Low incentive for roll out in rural areas, in absence of roll out obligations
Regional licence	<ul style="list-style-type: none"> ▪ Flexibility for operators to bid for the regions they are interested in ▪ Regional players may emerge ▪ Enables existing regional incumbents to continue operating ▪ Promotes competition and other MFCN services 	<ul style="list-style-type: none"> ▪ Buffer zones at the boundaries to avoid co-channel interference between users at each side ▪ Additional burden for the administrator to define, issue and manage licences, and for the operators to plan and run networks ▪ Seamless coverage along transport paths (rail, roads) becomes complicated ▪ Does not facilitate localised, private networks
Individual transmitter(s)	Suitable for private networks Access rights are only awarded where and when there is demand	Regulatory burden is high for deployment of MFCN networks Not suitable for locations with excess demand

5.5.2 Dealing with geographic fragmentation

Several European administrations are in a situation where regional or local licenses have been issued in the band. Regional assignments have been made in previous years (2007-2009) for the 3400-3600 MHz which at that time was not considered as a key band for 4G, but rather a FWA band or a promising band for hotspot coverage with limited take-up. These countries may now consider migrating the band to national licences for 5G use. In this context, these administrations could consider, independently or combined, the guidance in point i) to iv) in section 8 and the impact on regulatory certainty that these actions could bring about.

Administrations could also consider the following more specific actions:

- Clearance of existing regional licences. In some cases the licensees have very little use of the spectrum, or do not have the financial capability to invest in the network or develop a 5G service in the future, an administration could consider the guidance in points i) to v) mentioned above
- Facilitate consolidation. Encourage trades of spectrum rights of use that result in bigger players, or in national MFCN operators acquiring the regional licences. Secondly, if one single organisation holds several regional licences, the administration may be able to upgrade those disparate regional licences into one single national licence. However, if the regional licences are in different frequency blocks, it would be necessary to migrate them first to a single block. This upgrade would normally involve a one-off payment from the licensee, or an increase in the annual licence fee, and would therefore require the agreement of the licensee.

- The existing regional licences, when considered all together, may not cover the whole country (“Swiss cheese” scenario). This may happen, for instance, if the licences are based on local authority areas and a significant number of them have gone unsold. In this case, the administration may consider issuing an overlay national licence for 5G, which gives the right to use the spectrum in the areas without existing regional licences. The administration could as well facilitate and encourage trades between the existing licensees as the holder of the overlay.

6 EXAMPLE STEPS TO CONVERT FRAGMENTED AUTHORISATIONS TO LARGE CONTIGUOUS BLOCKS

6.1 EXAMPLE 1: STEP BY STEP DEFRAGMENTATION

This hypothetical example assumes a starting scenario where part of the 3400-3800 MHz is already licensed for MFCN services (including FWA), and the rest of the band is either licensed to other services or not used. The target of the administration would be to achieve large contiguous blocks for 5G, but preserving the existing MFCN licences.

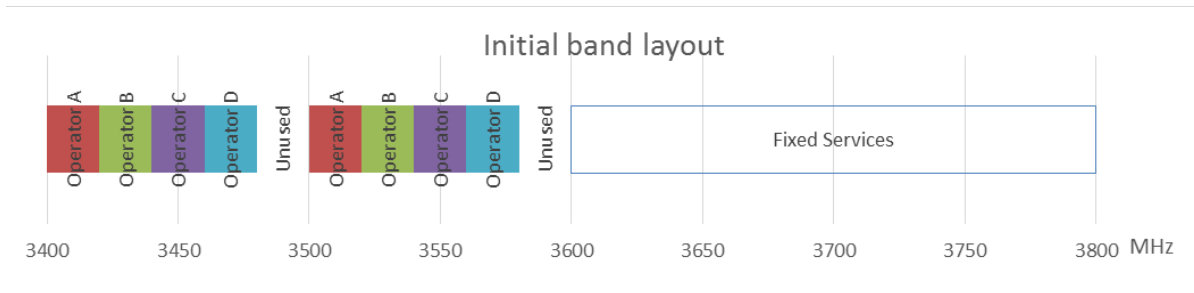


Figure 4: Example 1, starting point

Proposed steps towards large contiguous blocks for 5G use:

- 1 Serve notice of revocation to existing fixed services licensees in 3600-3800 MHz;
- 2 Assess whether the four licence holders below 3600 MHz have deployed networks, or have credible plans to deploy in the future. If not, revoke the licence(s);
- 3 Vary the licence conditions of existing licensees to align with the amended ECC Decision (11)06 [3] and to allow trading;
- 4 Encourage existing licensees to trade in order to reach a situation with larger, contiguous blocks. This could ideally result in a situation as shown in Figure 5 below.

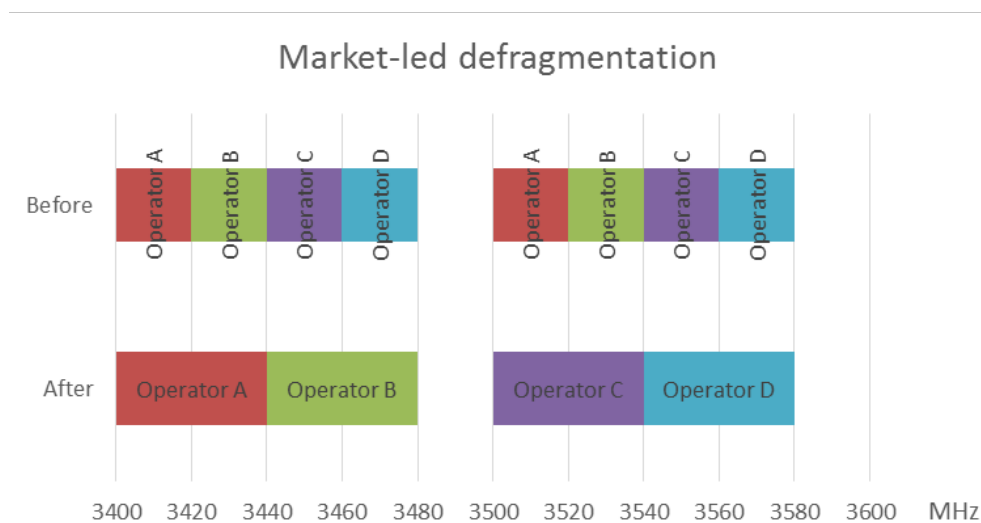


Figure 5: Example 1, defragmentation through market trades

- Remove the gaps between existing licences (Stack) in order to create a large contiguous sub-band, unencumbered of existing use, ready for release. Figure 6 below shows what this would look like;

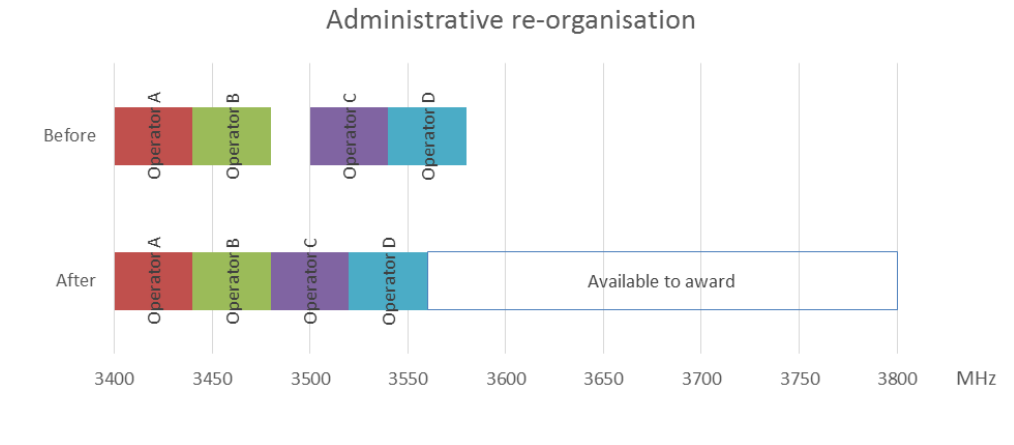


Figure 6: Example 1, stack existing licensees to create a large block ready for release

- Award the free block under terms that facilitate 5G adoption and 5G policy goals. These include technology and service neutrality, licence conditions in line with the amendment of ECC Decision (11)06 [3], and the right to trade the spectrum rights of use;
- Encourage existing licensees to participate in the assignment stage of the award. These licensees would bring their current blocks to the assignment stage, and bid to position those blocks adjacent to the new blocks gained in the first stage of award. Alternatively, the administration could intervene to re-organise the band after the award so that no licensee holds dis-contiguous blocks. An example is in Figure 7 below;

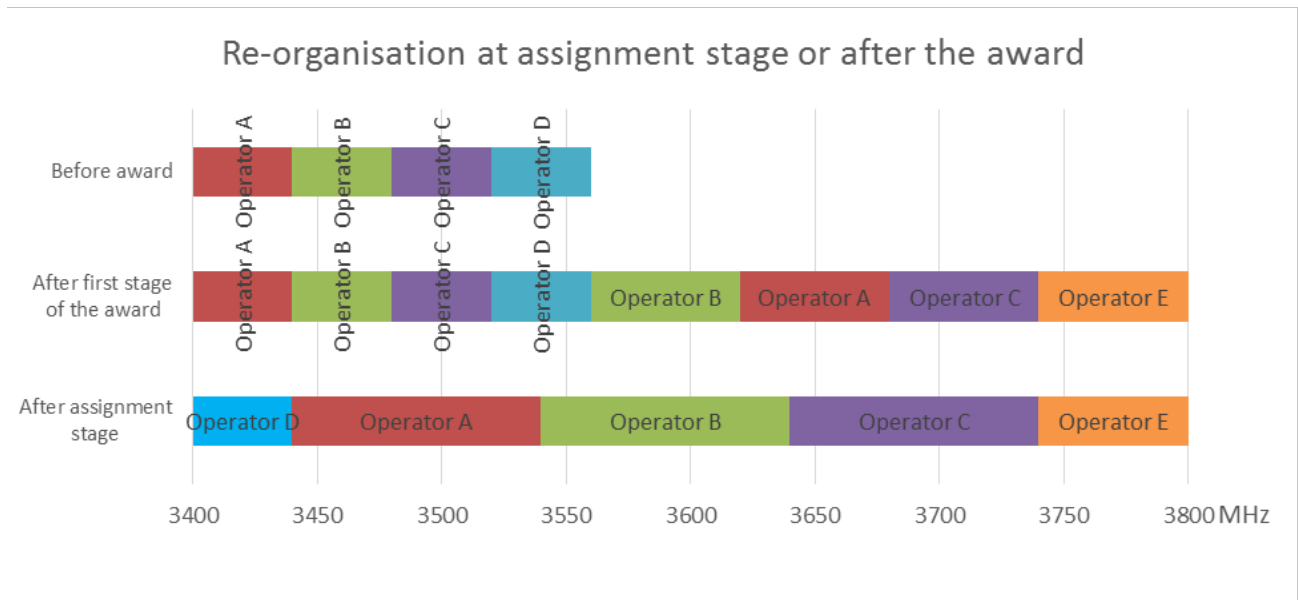


Figure 7: Example 1, defragmentation at the assignment stage or after the award

6.2 EXAMPLE 2: DEFRAGMENTATION IN THE GEOGRAPHIC DOMAIN

This hypothetical example assumes a starting scenario where the 3400-3600 MHz band is licensed as four 2x25 MHz blocks, and the country is divided in 12 geographical areas: 8 regional licences according to regional boundaries and covering the entire country, but excluding the main 4 urban areas, and 4 local

licenses for those 4 urban areas. Regions 6 and 8 have the lowest population density and some blocks have gone unsold in those regions. Five companies obtained licences at the time of the award. Company D has not deployed networks, and company E has focused on the urban areas. The administration would seek to facilitate and encourage market trades, and intervene to consolidate when possible, in order to achieve national blocks.

The hypothetical starting point is shown in Figure 8 below:

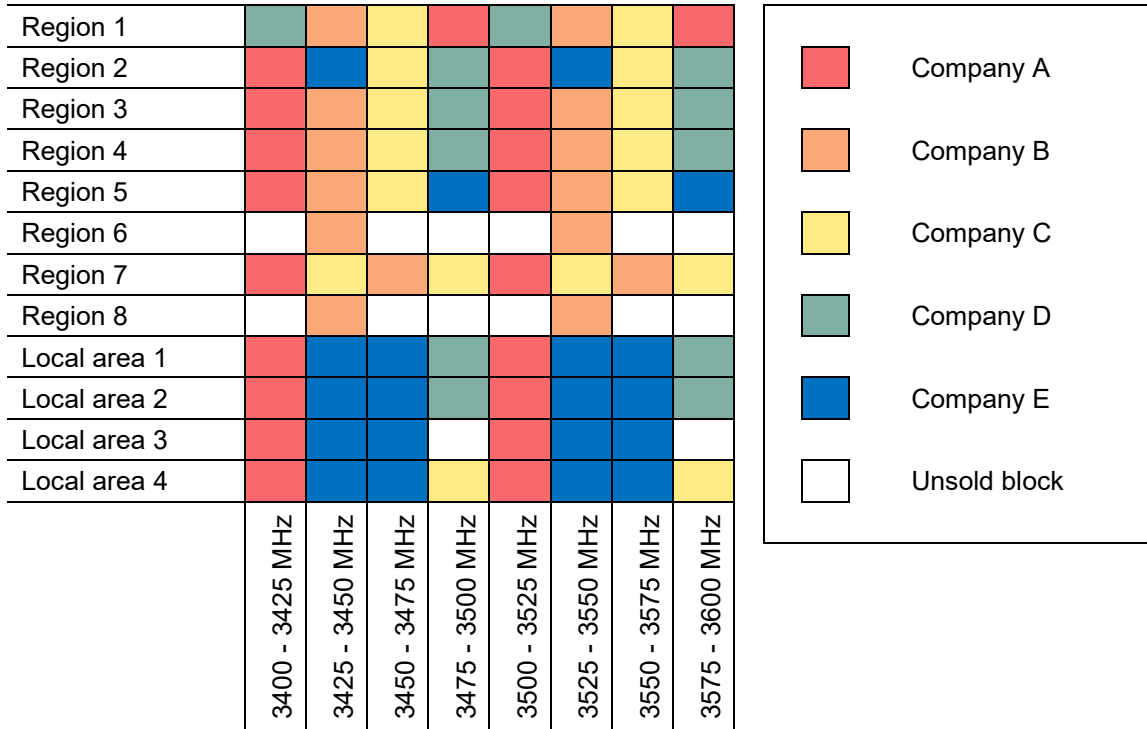


Figure 8: Example 2, starting point

As a first step, company D relinquishes its licences. This could be through revocation, if the administration has the power to do so, or through incentives such as tax breaks, or through expiration of the licence. Company D could also be encouraged to trade one or more of the regions that it holds. For instance, it could trade its block in Region 1 with company A, which would achieve an almost national coverage with this. The figure below shows the lay out after this trade has taken place and after the licences from company D have been surrendered.

Region 1	Red	Orange	Yellow	White	Red	Orange	Yellow	White
Region 2	Red	Blue	Yellow	White	Red	Blue	Yellow	White
Region 3	Red	Orange	Yellow	White	Red	Orange	Yellow	White
Region 4	Red	Orange	Yellow	White	Red	Orange	Yellow	White
Region 5	Red	Orange	Yellow	Blue	Red	Orange	Yellow	Blue
Region 6	White	Orange	White	White	White	Orange	White	White
Region 7	Red	Yellow	Orange	Yellow	Red	Yellow	Orange	Yellow
Region 8	White	Orange	White	White	White	Orange	White	White
Local area 1	Red	Blue	Blue	White	Red	Blue	Blue	White
Local area 2	Red	Blue	Blue	White	Red	Blue	Blue	White
Local area 3	Red	Blue	Blue	White	Red	Blue	Blue	White
Local area 4	Red	Blue	Blue	Yellow	Red	Blue	Blue	Yellow
	3400 - 3425 MHz	3425 - 3450 MHz	3450 - 3475 MHz	3475 - 3500 MHz	3500 - 3525 MHz	3525 - 3550 MHz	3550 - 3575 MHz	3575 - 3600 MHz

Figure 9: Example 2, revocation of licences of Company D & trade between A & D

Company E is only interested in urban areas, so it could be encouraged to surrender or trade its holdings in Region 5 and in Region 2. These licences may also become available due to licence expiration. In addition, companies B and C could swap their blocks in Region 7. The layout would then look as follows:

Region 1	Red	Orange	Yellow	White	Red	Orange	Yellow	White
Region 2	Red	Orange	Yellow	White	Red	Orange	Yellow	White
Region 3	Red	Orange	Yellow	White	Red	Orange	Yellow	White
Region 4	Red	Orange	Yellow	White	Red	Orange	Yellow	White
Region 5	Red	Orange	Yellow	White	Red	Orange	Yellow	White
Region 6	White	Orange	White	White	White	Orange	White	White
Region 7	Red	Orange	Yellow	Yellow	Red	Orange	Yellow	Yellow
Region 8	White	Orange	White	White	White	Orange	White	White
Local area 1	Red	Blue	Blue	White	Red	Blue	Blue	White
Local area 2	Red	Blue	Blue	White	Red	Blue	Blue	White
Local area 3	Red	Blue	Blue	White	Red	Blue	Blue	White
Local area 4	Red	Blue	Blue	Yellow	Red	Blue	Blue	Yellow
	3400 - 3425 MHz	3425 - 3450 MHz	3450 - 3475 MHz	3475 - 3500 MHz	3500 - 3525 MHz	3525 - 3550 MHz	3550 - 3575 MHz	3575 - 3600 MHz

Figure 10: Example 2, further trades between licensees

The administration could now propose to companies A and C to extend the coverage of their licences to Regions 6 and 8, for a fee. The administration also now has the option to release the 3475-3500 MHz/3575-3600 MHz blocks as single licence for the country bar Region 7 and Local Area 4. The newcomer could negotiate a trade a spectrum usage rights for these two regions with company C – who holds the licences in the blocks – and thus achieve national scope.

If company A and B accept to extend their licences, then a large part of the band would be available in geographically contiguous blocks. As part of the process, the administration should also consider defragmentation in the frequency domain. If all parties involved are supportive of this, the final assignments could become as shown below – a significant improvement compared to the starting scenario.

Region 1	Company A	Company B	Company C	Newcomer				
Region 2								
Region 3								
Region 4								
Region 5								
Region 6								
Region 7								
Region 8								
Local area 1	Company E							
Local area 2								
Local area 3								
Local area 4								
	3400 - 3425 MHz	3425 - 3450 MHz	3450 - 3475 MHz	3475 - 3500 MHz	3500 - 3525 MHz	3525 - 3550 MHz	3550 - 3575 MHz	3575 - 3600 MHz

Figure 11: Example 2, final assignments

7 EXAMPLES OF NATIONAL EXPERIENCES

7.1 FRANCE

In France, the work has started with a public consultation since the mid of 2017 to prepare for the launch of 5G in the frequency band 3400-3800 MHz.

An overall reorganisation of the radio spectrum in the band 3400-3600 MHz is on-going and existing BFWA 3400-3600 MHz band licences will be regrouped, in the form of contiguous blocks, towards the bottom part of the band in order to make sufficient contiguous spectrum suitable for 5G. Moreover, France intends to grant new authorisations, in accordance with EC Decision 2014/276/EU [7], in allowing 40 MHz (3420-3460 MHz) to be used to provide BFWA (superfast fixed internet access) in whose areas that will not otherwise have satisfactory solutions in the short or medium term Spectrum Refarming Fund is used to realise the migration of services currently using the band (fixed service) speed up the process.

The targeted reorganisation of the band intends to make possible to have more than 300 MHz of contiguous spectrum available for 5G by 2020, and 340 MHz by 2026.

7.2 LATVIA

The frequency band 3400-3800 MHz currently is open for networks in accordance with 2014/276/EU [7], ECC Decision (11)06 [3] and ECC Decision (07)02 [6] decisions in Latvia. The 3410-3800 MHz band is used by five operators for Broadband Wireless Access (BWA) point-to-multipoint systems in FDD and TDD mode with the channel arrangement both Nx5 MHz and differing from Nx5 MHz.

Such use is foreseen until end of 2018. During this transition time rearrangements in the band planned to be completed providing operation of MFCN in TDD mode in the whole 3400-3800 MHz band.

The frequency band 3400-3800 MHz planned to be rearranged into 8x50 MHz TDD contiguous spectrum blocks from January 2019 both for national and regional use. The minimal contiguous frequency block size for implementation of MFCN starting from January 2019 in the frequency band 3400-3800 MHz will be 50 MHz per one operator. Such was the agreement of operators and regulatory bodies. In result of replanning existing users (operators) will maintain currently assigned spectrum in the band normalised to 50 MHz contiguous frequency blocks.

In result of this replanning/defragmentation of the band additionally 2x50 MHz frequency blocks were made available for new users. The auction of these two 50 MHz frequency blocks took place in Riga in November 2017 and concluded successfully. In parallel, frequency coordination negotiations with neighbouring countries are in progress for MFCN in this band (see also Doc. ECC PT1(17)034 [19]).

7.3 IRELAND

A case study has been prepared to detail the approach taken by the Commission for Communications Regulation (ComReg) in Ireland for the release of the spectrum rights of use in the 3400-3800 MHz band. This document is in Annex 3

On 01 June 2017, ComReg published the results of its 3.6 GHz Band Spectrum Award ("Award") in ComReg Document 17/46, "Information notice on results of the 3.6 GHz Band Spectrum Award" [20].

As set out in ComReg Document 17/38, "Results of ComReg 3.6 GHz Spectrum Award including the provisional frequency plan" [21], the Award resulted in five Winning Bidders as follows:

- Airspan Spectrum Holdings Ltd ("Airspan") 60MHz/25 MHz in urban/rural regions;
- Imagine Communications Ireland Ltd ("Imagine") 60 MHz in rural regions;
- Meteor Mobile Communications Ltd ("Meteor") 85 MHz/80 MHz in urban/rural regions;
- Three Ireland (Hutchison) Ltd ("Three") 100 MHz nationally;

- Vodafone Ireland Ltd (“Vodafone”). 105 MHz/85 MHz urban/rural regions.

Key points from Ireland’s 3.6 GHz Spectrum award included:

- Largest incumbent obtained a regional licence;
- New entrant;
- All MNO’s getting large contiguous blocks of spectrum in the order of 80-100 MHz;
- Existing use (state services) was maintained.

No spectrum floor was set in the award, only a Competition cap of 150 MHz per region. The Final Frequency Plan is as set out in Figure 12:

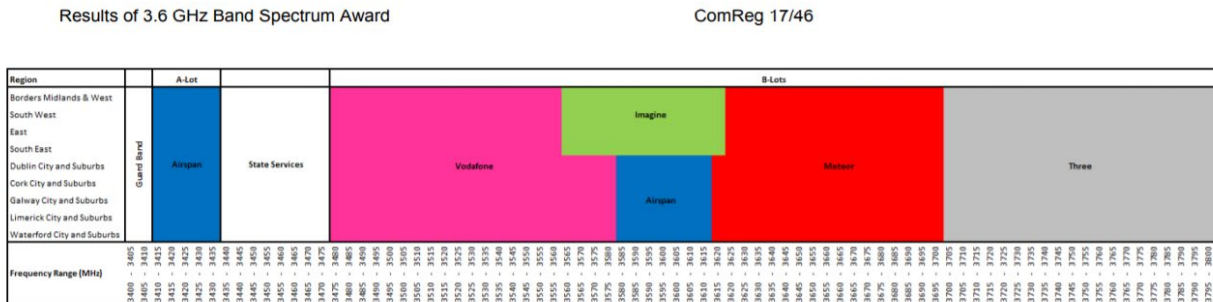


Figure 12: Final frequency plan from the Irish spectrum award

7.4 UNITED KINGDOM

The UK has made 3410-3600 MHz available for MFCN and intends to make 3600-3800 MHz available for MFCN by the end of 2019. In the 3410-3600 MHz award in April 2018, the UK included an assignment stage in the auction design which would allow for defragmentation of the existing mobile holdings of Hutchison 3G UK in the band (3480-3500 MHz and 3580-3600 MHz). Hutchison 3G UK chose not to bring its existing holdings to the assignment stage of the auction, resulting in a split assignment.

In 2016, the UK initiated work to make the spectrum not already assigned for electronic communications services in the 3600-3800 MHz band available for future mobile services including 5G in compliance with 2014/276/EU.

In October 2017 the UK confirmed its approach to make the band available for mobile and commenced the statutory process of notifying licensees and grant-holders of the proposed revocations and/or variations to their licences.

Having taken into account stakeholders’ representations, on 2 February 2018 the UK published its update outlining the outcome of its decision. The UK issued notices to revoke all 24 fixed links licences in the band as proposed, with an effective date of 23 December 2022; the UK varied 12 Permanent Earth Station licences and three grants of recognised spectrum access (RSA) as proposed, with an effective date of 1 June 2020; and the UK varied one grant of RSA with an effective date of 1 September 2020.

In those areas where future mobile deployment would be constrained by existing users, spectrum will nevertheless be available to enable future mobile services to be deployed in many areas from June 2020, but not necessarily nationwide before the end of 2022. In other areas these frequencies could be used from the date on which the new licences are acquired in the award. The UK intends to deliver the award of the spectrum not already assigned for electronic communications services in the second half of 2019.



Figure 13: MFCN holdings in the UK after the 3400-3600 GHz award

7.5 ITALY

The Ministry for the Economic Development (MISE) is about to release spectrum in the 3600-3800 MHz range: bidding will take place in September 2018. Bidders will submit their economic offers for two blocks of 80 MHz and two blocks of 20 MHz. Spectrum will be assigned with individual usage rights on a nationwide basis, with some sharing provisions with incumbent systems. A spectrum cap of 100 MHz is applied across the whole 3400-3800 MHz band.

The 3400-3600 MHz range was organised in 21MHz paired blocks and was assigned in 2008 to several licensees on a regional basis, a portion within this range (2x37 MHz) is currently under the responsibility of the Ministry of Defense. AGCOM (Autorità per le Garanzie nelle Comunicazioni) has recently reviewed a request from the licensees to extend their licences, initially expiring in 2023, to 2029. AGCOM has responded positively to the request although not for all existing licensees. The licence extension will come with attached conditions, notably:

- The extension is authorised until December 31st 2029;
- The beneficiaries of the extension must comply with the technical and legal obligations of the existing rights of use until the new deadline; they will have to adapt to the harmonisation standards and the employment parameters related to the new 5G standards with TDD channels, as well as to any coexistence measures that may be necessary for the development of 5G systems;
- The extension may be granted up to a maximum of 40 MHz for each of the assigned lots;
- The beneficiaries of the extension are required to send to the Ministry of Economic Development and to AGCOM, on an annual basis, a detailed report of sites, coverage, investment and technologies being used;
- The beneficiaries of the extension undertake to adhere to a reorganisation plan for the frequency defragmentation of the band;
- The beneficiaries of the extension undertake mitigation and coordination measures, including specific synchronisation parameters.

7.6 SPAIN

Spain released the 3600-3800 MHz block in July 2018 by means of a competitive award. The award saw the release of 40 blocks of 5 MHz in two stages:

- Principal stage consists of a Simultaneous Multiple Round Auction of generic blocks,
- Assignment stage where the Auction Board would assign specific blocks to the winning bidders, on the basis of a proposal to be submitted jointly by the bidders. Their proposal must be for contiguous blocks.

A key feature of the award was a spectrum cap of 120 MHz for holdings in 3400-3800 MHz. The characteristics of the licences offered are:

- National scope;
- 20 years duration (renewal not guaranteed);
- Technology and service neutral;
- Technical conditions as specified in EC Decisions 2008/411/CE and 2014/276/EU;
- TDD bandplan;
- Auction fees payable in annual instalments over 20 years;

- Subject to annual licence fees (in addition to the auction fees);
- Trading allowed but not until two years after the auction;
- No coverage or deployment obligations;

The results of the principal stage are as follows:

- ORANGE: 60 MHz;
- TELEFÓNICA: 50 MHz;
- VODAFONE: 90 MHz.

As of August 2018, the assignment stage is not completed. The winning bidders are expected to present a common proposal in this stage for the arrangement of the band, on the basis of contiguous assignments.

The 3400-3600 MHz block is already assigned for use in accordance with EC Decisions 2008/411/CE and 2014/276/EU, with the exception of 2x20 MHz reserved for Defence use. Masmovil, one of the four Spanish mobile operators, acquired in 2018 two of the existing licences in 3400-3600 MHz thus gaining access to 2x40 MHz in the band.

The layout of the 3400-3800 MHz block as of August 2018 is as follows:

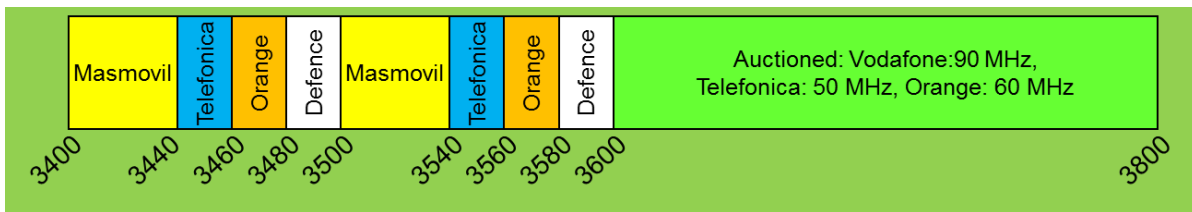


Figure 14: Layout of 3400-3800 MHz band in Spain

Following the trades by Masmovil and the auction, all spectrum rights for the band excluding the Defence blocks are in the hands of the four mobile operators. It is expected that the operators will negotiate arrangements that result in defragmentation of the band.

8 GUIDANCE TO ADMINISTRATIONS ON DEFRAGMENTATION OF THE 3400-3800 MHZ BAND

The current situation concerning the availability of the 3400-3800 MHz is very complex. In 2016, CEPT carried out a questionnaire on the use of the band. 40 responses were received to the questionnaire, including 30 from administrations and 10 from industry. As explained in detail in section 4, this questionnaire addressed the current situation at the time, including the actual utilisation (e.g. deployment areas) and the authorisation of the 3400-3800 MHz band. In addition, it considered the future plans of the authorised users in the band and the national plans.

This ECC Report provides some guidance to facilitate defragmentation of the 3400-3800MHz band, which includes facilitating 5G usage and fulfilling the following objectives:

- Successful 5G deployments in Europe by 2020;
- Common technical conditions with a harmonised TDD band plan;
- Availability of large contiguous blocks of spectrum to licensees;
- Investment and planning certainty.

These guidelines are not mandatory to administrations. Certain countries have already completed spectrum awards or are in the process of doing so. Therefore, some administrations have already made policy decisions on fragmentation aspects, and thus the guidelines in this section may not be applicable to them. On the other hand, administrations that still have to develop their policy for the band would find this section useful to inform their decisions.

Administrations should establish national plans, consistent with the RSPG recommendation to enable 5G deployments by 2020, to make available sufficient contiguous spectrum for 5G/IMT-2020, this may impact some of the current rights of use of incumbent users. National administrations can consider a number of options that can be used independently or combined, including but not limited to:

- i. Early termination of incumbent licences which are set to expire beyond 2020;
- ii. Moving incumbent licences to alternative bands;
- iii. Liberalising existing authorisations which expire beyond 2020 to allow them to be used for 5G services and implement where needed trading and leasing across the band.
- iv. Move incumbent licences into one part of the band in order to release the largest contiguous spectrum for an award that enables 5G services.

Each of these options, their advantages and disadvantages are dealt with in detail in section 5 of this Report.

While any change to the authorisation regime in the band might take some time, it is important that administrations disclose their plans for the whole 3400-3800 MHz range to give legal certainty to all stakeholders and facilitate their plans for future investments in this band.

A review of the 3400-3800 MHz band shows that in many European countries this band has remained used to a very limited extent. This spectrum will be key to enable timely initial 5G deployments (around 2020), which is expected to bring substantial social and economic benefits for Europe.

Mobile communications play various, continuously evolving roles in everyday life. Future IMT systems will support emerging new use cases, including applications requiring very high data rate communications, a large number of connected devices, and ultra-low latency and high reliability applications. It is proposed that administrations consider the following guidance:

- 1 Decisions from administrations could be supported by national measures such as carrying out public consultation and taking into account the market demand as well as the assessment of the competitive, technical and economic situation;

- 2 Administrations need to duly consider at a national level competition issues namely in order to avoid market distortions when measures are proposed to enable 5G usage;
- 3 New assignments should be based on the harmonised technical conditions (ECC Decision (11)06 revised in 2018 [3]) to allow the deployment of 5G and should follow the principle of technology and service neutrality to enable the deployment of 5G technology and provision of various 5G use cases;
- 4 Administrations should facilitate the availability of large contiguous blocks of spectrum in spectrum awards which will enable competition to determine the amount of contiguous bandwidth each licensee can acquire. Large bandwidths of 80-100 MHz contiguous spectrum are considered by industry as important to deliver high throughput 5G services in the 3400-3800 MHz frequency band
- 5 Reassigning the 3400-3800 MHz band and making it available in a timely manner for initial deployments around 2020 will ensure a harmonised European-wide successful 5G introduction. Enable stakeholders to undertake 5G pilot projects;
- 6 Review current authorisations in force in that band: BWA, fixed links, satellite earth stations, and retain only those which were delivered according to the new EC and CEPT regulatory framework i.e. 2014/276/EU [7] and ECC Decision(11)06 [3]. In areas intended for 5G, it is recommended that administrations consider relocation to a different geographical location or to a different band above 3800 MHz, with the goal of making the band substantially available by 2020. ECC Report 254 [5] provides guidance to administrations for spectrum sharing to support the implementation of the current ECC framework in the 3600-3800 MHz range, and for co-existence with FS and FSS;
- 7 Concerning BWA, administrations should assess the need to reorganise the BWA usage in order to make sufficient contiguous spectrum available for high throughput 5G applications. The lack of synchronisation of these BWA networks with 5G MFCN could imply the need of guard band between both networks. Specifics implementation cases may be defined at national level. CEPT is developing a toolbox for the most appropriate synchronisation regulatory framework between LTE and 5G NR to help either network operators or administrations to address relevant coexistence issues. Moreover in order to ensure a more efficient usage of spectrum, administrations may also assess the opportunities in some geographical areas to share the spectrum between LTE and 5G systems on co-channel basis. Possible re-use of relevant cross-border coordination limits within a LTE and 5G systems co channel national operation should be further assessed on the basis on the future update of the ECC Recommendation (15)01.
- 8 Consider impact of technical issues, such as synchronisation, guard-band, coexistence etc. when designing 5G licensing principles (including ECC Report 281 [9] and the ongoing synchronisation work in ECC). Minimising the number of frequency boundaries between technologies is preferred;
- 9 The coexistence of different type of technologies (including duplex access schemes) needs to be taken into account e.g. as TDD networks synchronisation (see ECC Report 216 [22]) and FDD vs TDD coexistence;
- 10 Other issues, such as Cross-border coordination could be managed on bilateral/multilateral basis. CEPT will develop relevant guidance for 5G and LTE/5G cross-border coordination.

Section 5 outlines possible ways forward to implement this guidance.

9 CONCLUSIONS

Successful timely 5G launch in CEPT countries will benefit from the availability of large contiguous blocks of spectrum in all or part of the pioneer 5G band (3400-3800 MHz). In particular, in order to respond to market demand, as expressed by industry, to ensure a possible introduction of MFCN systems requiring very large contiguous bandwidths (80-100 MHz), on the basis of nationwide coverage, it may be necessary for the administrations to reorganise the 3400-3800 MHz band in order to provide wide contiguous spectrum with the exact contiguous bandwidth per licensee to be determined by national award processes.

Due to the current fragmentation of the band, this may not be reached in some CEPT countries by 2020. CEPT Administrations should therefore assess the necessary actions to make large contiguous blocks of spectrum available for high throughput 5G services in a timely manner.

National actions are required to consider how to reorganise the entire band, to make it available for 5G before 2020 to give Europe the advantage of being a leading region for innovative 5G services, and to maximise social/economic benefits. It is up to each national administration to introduce 5G according to national policy objectives. New assignments should be based on technical conditions for the usage of 5G in this band settled in the amended ECC Decision(11)06 [3] in 2018, which have been developed on the basis of technology neutrality principle.

Administrations should not preclude award outcomes with smaller bandwidths, and existing MFCN incumbents should not be excluded from obtaining spectrum rights to continue providing services.

Timely availability of the 3400-3800 MHz band for 5G deployments is crucial for the success of 5G in Europe. National administrations are expected to apply appropriate measures, such as those in sections 5 & 8 of this report, to defragment this band for authorising large spectrum blocks by 2020.

ANNEX 1: BENEFITS OF LARGE CONTIGUOUS BLOCKS TO SUPPORT 5G INTRODUCTION

This annex gives background and explains the benefits of large contiguous blocks (of 80/100 MHz per licence).

A1.1 5G-NR IS DESIGNED FOR LARGE BANDWIDTHS

By design, 5G NR will optimally support wideband operation, allowing operators to take full advantage of larger allocations of contiguous spectrum to increase peak rates and user experience, with manageable terminal complexity and minimal power consumption (e.g. without requiring carrier aggregation in case of New Radio).

5G NR on large bandwidths will reduce terminal front end complexity and power consumption, compared to LTE using multiple 5 to 20 MHz carrier aggregations to exploit a similar large bandwidth. Wideband carriers and flexibility in sub-carrier spacing result in an efficient RF front-end for NR, and in addition baseband processing with improved power consumption per Mbit/s and per MHz. LTE can use Carrier Aggregation to aggregate multiple 20 MHz channels, but as the number of channels to be aggregated increases, LTE will become less efficient than a 5G-NR system which is designed to inherently leverage wideband TDD deployments and massive MIMO.

5G NR will also bring the ability to “multiplex” new forward compatible services with limited impact on eMBB capacity needs, and the ability to deliver simultaneous wireless backhauling and front-hauling capabilities to 5G NR base station. A wide bandwidth channel will significantly facilitate the use of these capabilities and therefore contribute to the faster introduction of new services.

Finally, it is worth noting that the key element for successful deployment of massive MIMO and active antennas is the availability of large contiguous bandwidths, as this will enable absolute gains from massive MIMO to support new usages related to eMBB.

A1.2 ON THE IMPORTANCE OF AT LEAST 100 MHZ CHANNEL BANDWIDTH PER OPERATOR FOR 5G

To ensure proper 5G eMBB user/service experience, the experienced rate needs to be in excess of 100Mbps. 100 Mbps can meet most service/application requirements. This is captured in ITU-R M.2410, which contains minimum requirements for IMT-2020 radio interfaces. M.2410 sets target values for the user experienced data rate in the Dense Urban – eMBB test environment:

- Downlink user experienced data rate is 100 Mbit/s.
- Uplink user experienced data rate is 50 Mbit/s.

More specifically and by way of example, some of the key 5G eMBB applications are related to video and to Virtual Reality (VR), which require very high data rates. For instance, 4K Video and HD 360° Video would require, respectively, 15~20Mbps and 80~100Mbps. Virtual reality (VR) and Augmented Reality (AR) applications also have high throughput and latency requirements. The table below shows the requirements for some VR and AR scenarios:

Table 7: VR & AR throughput requirements⁷

Use case	Resolution	DL: Peak rate per user (Mbps)	DL: Average rate per user (Mbps)	UL: Peak rate (Mbps)	UL: Average rate (Mbps)
AR shopping guide, no Head Mount Display		1	0.01	0.1	0.01
VR video, no eye tracking	30 pts / deg	2608	56	1	0.1
AR game, no eye tracking	30 pts / deg	260	1	62	60
VR game, no eye tracking	60 pts / deg photorealistic	25009	1000	2	0.2
VR game, foveated rendering ¹⁰ with eye tracking	60 pts / deg photorealistic	40011	23	2	0.2

Although the new 5G NR air interface will bring improvements in the spectral efficiency and the link budget, this has to be supported by sufficiently large BWs to provide the expected data rates. The spectral efficiency targets of IMT-2020 can be used to give an indication of the required BW to achieve a given data rate. The table below uses the IMT-2020 spectral efficiency targets in M.2410 to show the target data rates for 40 MHz and 100 MHz channel bandwidths:

⁷ Source: GSA

⁸ Tiles (pre-created video files for a certain viewing direction; 20 tiles cover full sphere)

⁹ 120 degree Field of View (FOV) with predictive head tracking

¹⁰ Foveated rendering: Only the central vision (~2 degrees) has full resolution and color, peripheral parts of the view have

reduced resolution (hence reduced bit rate) and even black&white can be used. Foveated rendering requires eye tracking in HMD and puts strict latency requirements on eye tracking to frame transmission.

¹¹ 3-8 degree FOV (variable) with prediction

Table 8: Target IMT-2020 data rates for 40 MHz and 100 MHz channel bandwidths

RF channel Bandwidth	Peak data rates ¹² (single user in a cell)	Average data rates ¹³	5th percentile data rates ¹⁴
40 MHz	1.2 Gbit/s	0.312 Gbit/s	9 Mbit/s
100 MHz	3 Gbit/s	0.78 Gbit/s	22.5 Mbit/s

Another useful quantitative characterisation of the importance of large BW is to look at the impact of different operator block sizes on network roll out (and hence on cost of deployment), for a given assumption on area traffic capacity. 3GPP 22.261 provides traffic density requirements for a number of deployment scenarios. For instance, for a dense urban scenario:

Table 9: Traffic density requirements for dense urban scenario

Scenario	Experienced data rate (DL)	Experienced data rate (UL)	Area traffic capacity (DL)
Dense urban	300 Mbps	50 Mbps	750 Gbps/km ²

In this dense urban scenario with 3-sector macro base stations, indoor CPEs, penetration loss 26dB, and downlink user edge rate 100 Mbit/s, an operator with a 60 MHz block would have to deploy 64% more BS than an operator with a 100 MHz block:

Table 10: Comparison of number of required sites for dense urban scenario

	DL Coverage Distance/Site (km)	Coverage area/site (sqkm)	Number of sites /sqkm	Site Increase Rate (%)
100 MHz	0.19	0.070395	14	reference
60 MHz	0.15	0.043875	23	+64%

A large BW not only results in increased data rates but it gives the operators better means of supporting URLLC applications. The figure below shows how the new 5G design allows for optimal trade-offs between capacity, latency and reliability (e.g. leveraging wider bandwidths to offset mission-critical capacity reductions).

Latency/capacity trade-off is shown in the first graph of Figure 14. Efforts in achieving lower latency (e.g., using a shorter TTI) might have an impact on overall system capacity as optimisation is now occurring on the way of communicating to cut down latency (more ACK/NACK thus more overhead), and using shorter packets means that optimisation is not for capacity. Note that this analysis is indicative and does not take

12 Peak spectral efficiency (SE) requirement for IMT-2020: 30 bit/s/Hz in DL (from ITU-R Report M.2410, "Minimum requirements related to technical performance for IMT-2020 radio interface(s). Peak data rate in M.2410 is 20 Gbit/s in DL (roughly equivalent to a total of 667 MHz with the considered SE).

13 Average SE requirement for IMT-2020: 7.8 bit/s/Hz in DL for Dense Urban scenario (3 x SE of IMT-Advanced, also considered in M.2410)

14 5th percentile SE requirement for IMT-2020: 0.225 bit/s/Hz in DL for Dense Urban scenario (3 x SE of IMT-Advanced, also considered in M.2410)..

into account other deployment issues which may impact latency, such as synchronisation. To optimize for higher reliability (second graph), there is also a trade-off with capacity. E.g., to achieve lower BLER, capacity might need to be sacrificed as well (e.g., more retransmissions). But to offset this, it would be possible to utilise wider bandwidth, which will give the system more capacity (in this case, showing a 3x capacity gain with 2x bandwidth in the third graph).

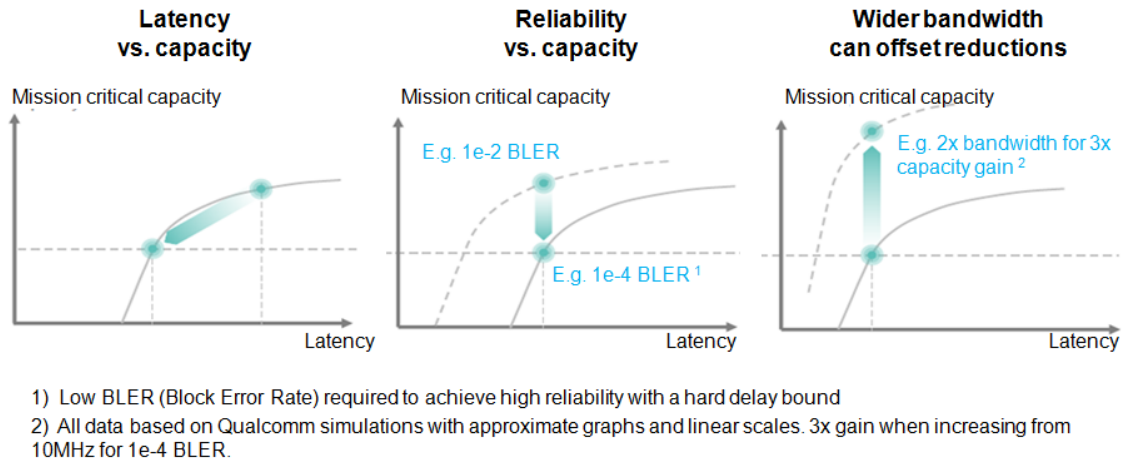


Figure 15: Latency versus capacity trade-offs

A scenario where these trade-off would be relevant is the support for VR and AR. A key requirement for VR/AR is that the delay between movement of the head and the changes on the screen (MTP, motion to photon) cannot exceed a 20 ms threshold. This puts stringent requirements on the network when the image is rendered remotely. However, the latency requirement can be relaxed if a broader video stream (for instance one that contains 360 degree video) is transmitted to the head mounted display, which can now adjust on its own for sudden head movements. In this case, the required throughput would be significantly higher but the latency requirement is relaxed.

As a result of the above considerations, 100 MHz has been generally agreed across the industry as the suitable bandwidth for 5G deployments in the 3400-3800 MHz.

A1.3 CONTIGUOUS VS. NON-CONTIGUOUS ASSIGNMENTS

For a given overall capacity, contiguous assignments present significant advantages over separate blocks. With regards to complexity and performance, a contiguous assignment of up to 100 MHz (in C-band) does not require intra-band Carrier Aggregation (CA) with NR (contrary to LTE). No extra CA management efforts within a single wide carrier for processing and scheduling, which results in less cell/carrier level signalling/control overhead. It is worth noting that while intra band carrier aggregation is supported by 3GPP Rel. 15, no specific band combination has been defined yet.

Some of the key differences between contiguous blocks and intra-band aggregation of non-contiguous blocks are presented next:

A1.3.1 Spectrum efficiency

Spectrum utilisation is less than 100% for all 5G NR channel bandwidth options because the resource blocks do not fully occupy the channel bandwidth. However, the utilisation decreases with the channel bandwidth as shown in the table below for 30 kHz SCS:

Table 11: 5G NR utilisation of channel bandwidth

Channel BW	Number of resource blocks	Transmission BW (MHz)	Lost BW (MHz)	Utilisation
100 MHz	273	98.280	1.720	98.3%
80 MHz	217	78.120	1.880	97.7%
60 MHz	162	58.320	1.680	97.2%
50 MHz	133	47.880	2.120	95.8%
40 MHz	106	38.160	1.840	95.4%
20 MHz	51	18.360	1.640	91.8%

The figure below, taken from 3GPP TS 38.104 section 5.3.3, illustrates this:

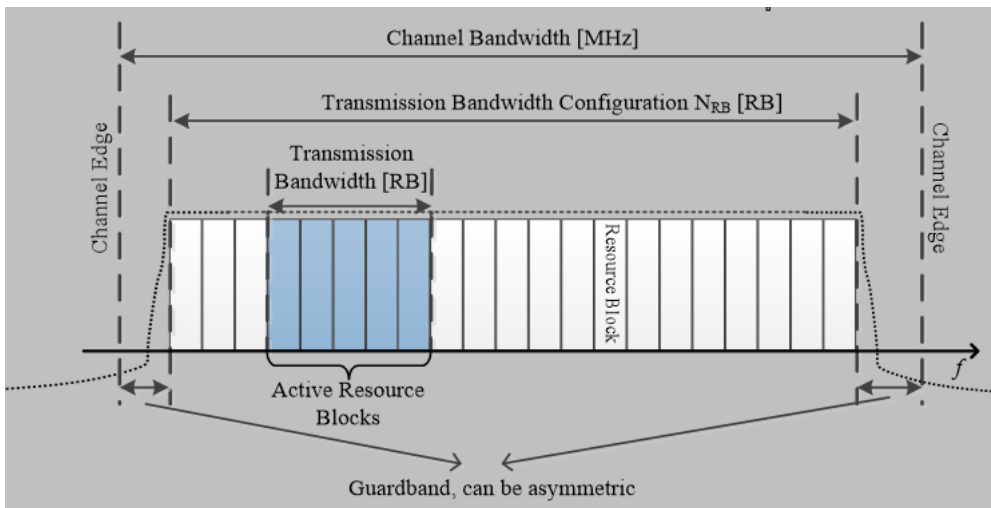


Figure 16: Illustration of 5G NR channel bandwidth utilisation

As a result of this NR configuration requirement, non-contiguous aggregation of two (or more) channels will always result in a loss of usable spectrum, and hence a degradation in performance when compared to a contiguous block of the same amount of spectrum:

Table 12: Performance loss for non-contiguous aggregation

Configuration ¹⁵	Performance loss compared to contiguous block
100 MHz contiguous, 273 PRBs	Baseline
CA 50+50 MHz, 133+133 PRBs	2.52 MHz less spectrum available vs. 100 MHz contiguous
CA 80+20 MHz, 217+51 PRBs	1.8 MHz less spectrum available vs. 100 MHz contiguous
CA 60+40 MHz, 162+106 PRBs	1.8 MHz less spectrum available vs. 100 MHz contiguous
80 MHz contiguous, 217 PRBs	Baseline
CA 40+40 MHz, 106+106 PRBs	1.8 MHz more spectrum available vs. 80 MHz contiguous

A1.3.2 Signalling overhead

The PDCCH overhead of a single 100 MHz carrier is 6.3%, and this would be roughly doubled to 12% for two carriers¹⁶. In addition a single wide carrier can save more than 20% cell configuration/addition/deletion overhead compared to a two carrier configuration. Two carriers also require more resources in the base band, as each cell requires certain processing to build the information for common channels and schedule/process user plane data.

A1.3.3 Physical layer flexibility

Multiple sub-bands can co-exist in one carrier, each sub-band could be configured with a specific numerology intended for a specific application / deployment scenario. Having a continuous carrier provides more flexibility than 2 non-contiguous carriers. To put it differently, 100 MHz provides more flexibility to the MNO in how the MNO decides to partition/allocate resources for different services, compared to the cases where the MNO would have multiple carriers.

A1.3.4 Latency performance

A CA configuration increases the delay to adapt the bandwidth. The carrier activation/deactivation delay is of 10ms order for a CA configuration, whereas a single wide carrier allows switching carrier Bandwidth Part (BWP) for control and data with less than 2ms delay. Furthermore, there is no cell setup delay for secondary cell in wideband operation.

A1.3.5 BS implementation aspects

Commercially available NR base stations operating in the 3400-3800 MHz have typically a bandwidth smaller than 400 MHz (sometimes referred to as “instantaneous bandwidth”). If an operator holds spectrum blocks that are separated further than the IBW, then two different radio units would be needed.

15 NR carriers in 3400-3800 MHz, with 30 kHz subcarrier spacing

16 This is approximate since more users need to be scheduled in the wideband carrier

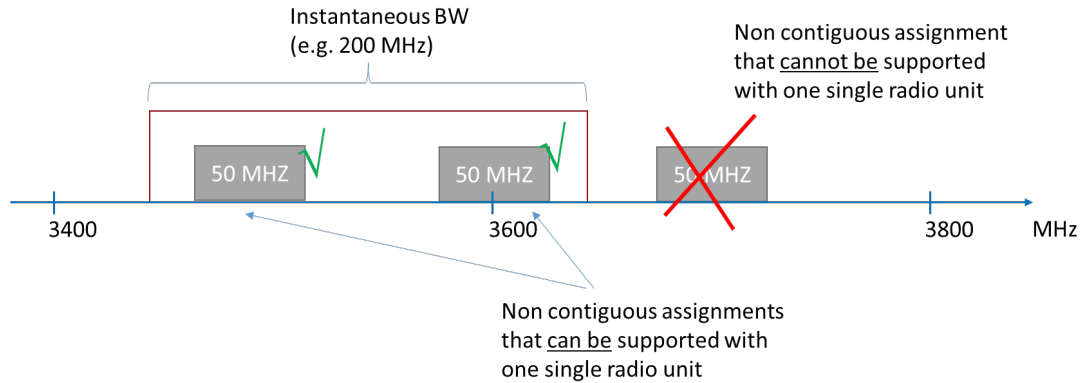


Figure 17: Example of BS support for non-contiguous assignments

A1.3.6 Spectrum management

Separate blocks results in additional boundaries between operators. This adds complexity in a scenario where networks are not synchronized. When networks are not synchronized, the OOB power limit requirement is strict (-43 dBm/5 MHz TRP for AAS according to the ECC Recommendation). This limit is difficult to meet and may require guardbands, which are spectrum blocks that cannot be used for transmission.

A1.3.7 UE aspects

Uplink CA (especially non-contiguous UL CA) is more complex thus usually not supported by all UEs (and RF requirements are not yet defined in 3GPP for intra-band CA in the C-band as noted above). In this context, a larger channel BW has benefits over a non-contiguous blocks:

A larger channel does not require UL CA to be supported by the UE to use the entire available UL channel bandwidth.

Higher trunking efficiency is achievable within continuous spectrum than non-continuous spectrum (since not all UEs will support or be configured with CA, and CA adaptation is slow)

In addition, UE power consumption increases significantly for CA. NR allows applying a reduced BWP for control monitoring in periods of low traffic activity, it also allows for less signalling and faster adaptation to bursty traffic within a single carrier. For Intra-band CA, there could be an increase in power consumption of up to 30mA for an additional component carrier. This means an increase of 50% ~ 90% in the power consumption of the RF block. For Inter-band CA, about additional 50-60 mA could be consumed for an additional carrier. Even if the second carrier is not activated, the CA configuration results in additional 5-10 mA consumed.

A1.3.8 Summary

The table below shows the advantages of a 100 MHz contiguous block over the same amount of spectrum but structured as two 50 MHz discontinuous blocks:

Table 13: Comparison of 100 MHz contiguous vs two 50 MHz non-contiguous blocks

	100 MHz	50 + 50 MHz
Complexity	Single carrier	Needs intra-band CA
Channel utilisation	98.3%	95.8%
Physical layer signalling	6.3% overhead	Approx. 12% overhead
Physical layer configuration	A single 100 MHz carrier offers more flexibility than 2x50 MHz carriers to configure sub-bands within the carrier	
Carrier activation /deactivation delay	2ms	10ms
BS implementation	Requires one radio unit only	May need two radio units
Spectrum management	Guardbands may be required if networks are unsynchronised	Two additional guardbands if networks are unsynchronised
UL support	No CA required in the UL	Uplink CA may not be supported by all UEs
UE consumption		30mA additional power consumption for the second CC (50-90% RF power increase over the non-CA case)

ANNEX 2: ADVANTAGES AND DISADVANTAGES OF LICENCES WITH DIFFERENT GEOGRAPHICAL SCOPE

The advantages and disadvantages of the national, regional and individual licences are described below:

A2.1 NATIONAL LICENCE

Advantages

- Reduced regulatory burden. National licences are the simplest of the three alternatives, in terms of number and complexity of the licences. This has benefits for both the administration and the licensees;
- Best support for national networks and operators. Exclusive national licences give mobile operators certainty that they can deploy their networks when and where there is demand from their customers. Mobile networks evolve as operators extend coverage to unserved areas, or increase capacity to locations with high traffic. This flexibility is key for an MNO business and should be preserved in 5G spectrum. Provision of 5G will not be substantially different from today's 4G or 3G services: mobile operators will run the networks and provide a service to end users. A change of the regulatory framework introduces uncertainty for operators in the access to spectrum and carries a risk that they do not invest in infrastructure and equipment to exploit the band. This results in a lack of infrastructure, chipsets and terminal equipment for this band;
- National licences remove the risk of co-channel interference that appears with geographical sharing.

Disadvantages

- No direct access to other players on a regional basis. However this can be mitigated with an obligation to offer wholesale access, or with use-it or lease-it conditions.

A2.2 REGIONAL/GEOGRAPHIC LICENCE

Advantages

- Flexibility for operators to bid for the regions they are interested in;
- Direct access to other players on a regional basis – regional players may emerge.

Disadvantages

- Buffer zones, where there is no service, are required the boundaries to avoid co-channel interference between users at each side. Buffer zones can be particularly problematic when the geographical areas are small, for instance if they are set up to follow local authority boundaries. This multiplies the length of boundaries where interference between networks at each side needs to be managed (up to several 1000 kilometres). It significantly increases the risk that a boundary falls on populated areas, with the result that the populated area ends up being unserved. The size of such impacted areas increases in case of unsynchronised adjacent networks (TDD-based);
- Additional burden for the administrator to define, issue and manage licences, and for the operators to plan and run networks. Regional assignments would increase the risk of interference between operators, and hence multiply the planning efforts in order to properly manage interference at the regions' borders (i.e. by ensuring the electromagnetic field strength at the borderline and at a certain distance from border as required by the regulator);
- Seamless coverage along transport paths (rail, roads) becomes complicated when the path crosses the border between two regional areas where not the same operators hold licences. This is further complicated in that one operator in one area may focus on providing 5G services to roads and railway routes while another operator in another area may not. This would lead to a poor service and reduced productivity for the consumer as they as they travel between areas;

- Regional licences do not facilitate access to spectrum to private network users. The geographic definition of the licence does not necessarily fit the coverage requirement of a private network user. This type of user would normally seek coverage at his premises, campus or industrial compound. However, regional licences would be based on the boundaries of local authorities or any other predefined rule. The private network user may see itself bidding against MFCN operators for a licence that covers a territory that it does not need – this is unlikely to result in the private operator gaining access to spectrum.

A2.3 INDIVIDUAL TRANSMITTER(S)

Advantages

- Suitable for private networks. Each user defines the geographical scope of the licence at the moment it applies for the licence, according to its business needs;
- Efficient spectrum use, as access rights are only awarded where and when there is demand.

Disadvantages

- Regulatory burden is high for deployment of MFCN networks, or more generally where ubiquitous coverage is expected. This approach requires that the regulator issues a licence every time a user wants to deploy and hence would result in a significant amount of overhead for both regulator and operator;
- Not suitable for locations with excess demand. If there are several users willing to deploy at a particular location, for instance a busy urban hotspot, then a first come first served mechanism may not result in efficient assignment, or may result in an insufficient amount of spectrum per licensee if the spectrum is divided. Furthermore, different users may have different needs regarding the precise geographic definition of the licence.

ANNEX 3: CASE STUDY – IRELAND'S 3.6 GHZ BAND SPECTRUM AWARD

A3.1 BACKGROUND

This annex details the approach taken by the Commission for Communications Regulation (ComReg) in Ireland for the release of spectrum rights of use in the 3.6 GHz Band (3400-3800 MHz).

In July 2016, ComReg, in its capacity as manager of Ireland's radio spectrum, published its decision¹⁷ to hold an Award Process for individual rights of use in the 3.6 GHz Band. ComReg subsequently published, following public consultation, an Information Memorandum¹⁸ which detailed the processes and procedures it would employ in the conduct of the Award.

A3.2 THE AWARD

Following an extensive public consultation process over approximately a 2 year period, the core decision arrived at by ComReg was to hold an open competitive selection process for the award of 350 MHz of spectrum rights of use on a regional basis in the 3.6 GHz band.

The award format consisted of a number of discrete stages including an application stage, a qualification stage, a main stage and an assignment stage. The qualification stage evaluated all valid applications and assessed the level of aggregate demand in order to determine whether an auction (main stage and/or assignment stage) is necessary, i.e. did demand exceed supply. The main stage determined how much spectrum in each region was won by each bidder. The assignment stage determined where in the band each bidder would be located¹⁹.

Some of the key features of the 3.6 GHz Award Process adopted by ComReg were:

- Spectrum rights of use were made available in nine discrete regions of Ireland (four rural and five urban). The award design took into consideration a number of factors, including rural and urban regions to allow flexibility and scalability for different types of bidders (large, small and new entrants) to compete for the appropriate geographic footprint suited to their business case, be it national, regional, rural based and/or city based;
- A CCA²⁰ award format which uses package bidding to allow for regional and/or national bids to be made, without aggregation risks;
- A combination of frequency-specific (A-Lots) and frequency-generic (B-Lots) lots to maximise the efficient assignment of the spectrum taking into account a non-ECS licensee using 40 MHz of the band;
- The Award design allowed the possibility of both regional and/or national operators to acquire spectrum rights of use for large contiguous blocks of TDD spectrum in multiples of 5 MHz²¹;
- Consortia bidding was facilitated prior to application to allow operators to come together to create larger economies of scale;

¹⁷ Response to Consultation & Decision on Proposed 3.6 GHz Band Spectrum Award (Document 16/57 and D04/16) - <https://www.comreg.ie/publication/response-to-consultation-decision-on-proposed-3-6-ghz-band-spectrum-award/>

¹⁸ 3.6 GHz Band Spectrum Award – Information Memorandum (Document 16/71) - <https://www.comreg.ie/publication/3-6-ghz-band-spectrum-award-information-memorandum/>

¹⁹ The assignment stage related only to the frequency generic B-Lots, the winner of the frequency specific A-Lot in each region was established in the main stage.

²⁰ The CCA is a price clock-based auction method used to sell multiple items in a single process. It provides bidders with the flexibility to bid on different combinations or packages of spectrum rights across the different regions in response to changes in prices without aggregation risk. The CCA format also creates good incentives for bidders to bid their full value for the spectrum and to compete over the amount of spectrum they acquire, leading to an efficient outcome;

²¹ Bidders could select the number of B lots they required in multiples of 5 MHz (subject to the competition cap) and be assured of their contiguity.

- The potential for winners of spectrum rights of use to (1) roll out services quickly, (2) maximise the use of the spectrum assigned to them and (3) ultimately provide better quality services to customers was facilitated by:
 - Setting out an Inter-Licensee Synchronisation Procedure that all Licensees are bound by;
 - Establishing a procedure for winning bidders to enter into “Alliances” in advance of the Assignment Round and jointly bid for their preferred spectrum assignment location in the band;
 - Establishing Assignment Options for bidders so that they obtain the same spectrum in each region to the maximum extent²²;
- A transition framework was established which manages the transition activities of both new and existing licensees, while providing a framework to minimise consumer disruption and ensure the most efficient use of the spectrum during the transition period;
- Given the potential for smaller and/or less experienced bidders, a comprehensive bidder training programme was facilitated that included workshops, webinars, access to an online auction “Playground” (where bidders could run and participate in their own simulated auctions) and formal mock auctions.

The above design elements, taken together, provided a flexible award accommodating a wide variety of different bidders with different business strategies, varying potential uses of the band and different technologies. After many days of bidding all 350 MHz of available spectrum, in all nine regions was competitively assigned²³.

A3.3 THE AUCTION

Taking account of a non-ECS licensee in the band the auction provided for:

- A single 25MHz frequency specific A-Lot in each region;
- Sixty five (65) 5 MHz frequency generic B-Lots in each region.

To safeguard competition in the Award no bidder could bid for more than 150 MHz of spectrum in any region. This ensured the possibility of at least three winners yet also ensured each winner could acquire sufficient amount to provide services.

To promote efficient spectrum use, fees were applied to lots based on a conservative estimate of the market value of spectrum in the 3.6 GHz band, as derived from an international benchmarking analysis²⁴.

In relation to setting minimum prices, the primary²⁵ aim was to:

- Set minimum prices at a sufficiently high level to avoid creating incentives for strategic demand reduction and/or collusion;
- Avoid the risk that the minimum price will be set too high, choking off efficient demand.

In this way, the conservative minimum price set by ComReg was projected to be below final prices with such prices determined by the interaction of bidders in the award. ComReg observes that these aims were achieved as the award was highly competitive with all packages of lots in all regions attracting bids significantly above the sum of the reserve price set for those lots.

²² This feature is expanded on below in “Additional Award Features”

²³ The results of the 3.6 GHz Award process is to be published as Document 17/38

²⁴ 3.6 GHz Award- Benchmarking Update ()

²⁵ Other issues in this award included concerns that a premature award of spectrum may inefficiently displace valuable future uses or lead to excessive speculative take up simply because the price is low

A3.4 ADDITIONAL AWARD FEATURES – THE GENERATION OF ASSIGNMENT OPTIONS

For the assignment round, and to ensure a more efficient assignment of spectrum, bidders were presented with a variety of assignment options based on the number of B-Lots awarded in the main stage. The assignment options presented to bidders ensured;

- The B-lots for every bidder would be contiguous within each region;
- Any bidder that won the same number of B-lots in each region (i.e. a national licence) would be assigned the same frequencies in every region;
- Subject to the previous requirements, were bidders won spectrum in multiple regions the options presented will be those which maximise the extent to which the same frequencies are assigned in each region;
- Subject to the previous requirements, the extent to which unassigned spectrum rights of use can be combined into the fewest number of contiguous blocks is maximised.

This allowed ComReg to release the spectrum on both a regional and national basis while providing certainty for bidders in relation to the contiguity of spectrum within and across regions that they could obtain.

A3.5 LICENCE CONDITIONS

The following are some of the main licence conditions that apply to all licences won in the award process:

- All Licence holders must attain and maintain the rollout of a minimum number of base stations per region within 3 years of Licence issue. A higher rollout obligation is imposed on licensees holding more than 100 MHz of spectrum rights in a region compared to those holding up to 100 MHz. In considering this obligation, ComReg assessed the experience of other Member States and noted the rollout of base stations in this band was more widely used rather than a coverage obligation;
- Minimum Quality of Service conditions require that network unavailability will be less than 35 minutes per 6 month period and a minimum voice call quality standard requires quality levels are ensured against blocked and dropped calls as well as ensuring appropriate standards of speech transmission;
- Compliance with the Inter Licensee Synchronisation procedure that builds on the technical conditions set out in the 3.6 GHz EC Decision to facilitate the co-existence of services in the 3.6 GHz band with services in the same band or in adjacent spectrum bands;
- Technical conditions required to ensure co-channel co-existence across regional borders and compliance with International Memoranda of Understanding ('MoUs') applicable to the 3.6 GHz band;
- Trading and leasing of spectrum rights attached to 3.6 GHz Band Licences will be permitted subject to the approval of ComReg.

ANNEX 4: LIST OF REFERENCES

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