



EUROPEAN COMMISSION

Directorate-General for Communications Networks, Content and Technology

Electronic Communications Networks and Services

Radio Spectrum Policy Group

RSPG Secretariat

Brussels, 11 June 2015

DG CNECT/B4/RSPG Secretariat

RSPG15-607

RADIO SPECTRUM POLICY GROUP

RSPG Report on Spectrum issues on Wireless Backhaul

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1 INTRODUCTION

Mobile networks are evolving to respond to an increased broadband usage. Mobile operators have always needed backhaul solutions to carry initially voice traffic, followed by text messages and then mobile data. The advent of LTE is expected to place even greater challenges on the mobile operators as they strive for more network capacity, latency reduction, and an enhanced user experience. Against this background, mobile operators are considering various forms of backhaul including wireless ones (point to point, non-line of sight). Small cells are under study by market players that could complement macro cells. The small cells intend to provide cellular coverage in a limited range. An increase in the number of wireless backhaul links required for the small cells could then be foreseen. Moreover, wireless backhaul solutions in frequency bands already licensed for Wireless Broadband (WBB) under harmonized technical conditions could be of interest to the current license holders.

Both wired and wireless solutions are able to meet this backhaul market demand. Various technical solutions could be considered by market players to facilitate roll out, reduce the backhaul cost, and to meet the traffic needs such as optical fibre or wireless and fixed links.

Wireless backhaul links are basically deployed through fixed links under the 'Fixed Service' defined in ITU's RR. Nevertheless wireless backhaul is only one application of the fixed service. A fixed service application in the core network should not be considered as wireless backhaul in the scope of this report. In this report, wireless backhaul should then be understood as the intermediate/last wireless link to connect various forms of base stations with either the core network or the backbone network.

Wireless backhaul to deliver higher broadband traffic within the mobile/cellular networks and to the mobile/cellular base stations will face strategic challenges due to mainly:

- Increased wireless backhaul capacity needs for existing macro-cellular sites
- Expected increasing number of wireless backhaul links required for the small cells

Various frequency bands for wireless backhauling are already subjected to ECC Recommendations which harmonize frequency plans. These deliverables are revised within CEPT if needed and where appropriate (i.e. to introduce new frequency channel plan for example). According to national demand and circumstances, the frequency bands together with the channel arrangements nationally available for fixed links vary from country to country even though a certain level of harmonisation exists through the implementation of ECC Recommendations published by CEPT.

New strategic spectrum challenges for wireless backhaul (non-line of sight wireless backhaul issues, capacity and number of links and their impact on spectrum management, the potential interest of WBB frequencies for wireless backhauling in the context of the service neutrality, etc.) and small cells issues are to be anticipated at national level and within the cooperation process in place at CEPT. These market trends that may impact the spectrum usage for the next 5 to 10 years are analysed in this report.

2 SCOPE

This Report intends to identify and analyse strategic spectrum issues relative to wireless backhaul for mobile networks (lessons learnt, various types of backhaul, trends, needs, etc.) due to:

- higher capacity needs for existing macro-cellular sites
- the densification of base stations and the small cells approach (trends, foreseen impact on spectrum management, non-line of sight wireless backhaul issues) in mobile networks infrastructures

This Report includes:

- a review of state-of-the-art developments and trends in new generation broadband mobile networks and wireless backhaul in public mobile cellular networks (including use of small cells and mesh networks);
- the identification of any relevant spectrum sharing and spectrum efficiency issues;
- a review of different kinds of backhaul topologies (outlining the advantages and disadvantages)
- different assignment methods that can be used in FS systems and coordination aspects
- a consideration of the applicability of the combination of access networks and wireless backhaul solutions (self-backhauling)
- frequency bands that could be used for wireless backhaul for new generation mobile networks
- and an assessment of any implications for spectrum management policies at the EU level.

3 LIST OF ABBREVIATIONS

Abbreviation	Explanation
3G	3rd Generation digital cellular network
4G	4th Generation digital cellular network
5G	5th Generation digital cellular network
3GPP	3rd Generation Partnership Program
5GPPP	5th Generation Infrastructure Public-Private Partnership
AM	Adaptive Modulation
ATPC	Automatic Transmit Power Control
BS	Base station
BSC	Base station Controller
BTS	Base Transceiver Station
CCDP	Co-Channel Dual-Polarization
	European Conference of Postal and Telecommunications
CEPT	Administrations
CoMP	Coordinated MultiPoint
CPRI	Common Public Radio Interface
C-RAN	Cloud Radio Access Network
DL	Downlink
ECA	European Common Allocation
ECC	Electronic Communications Committee
EFIS	ECO Frequency Information System
eICIC	Enhanced Inter-Cell Interference Coordination
EPC	Evolved Packet Core
EU	European Union
FDD	Frequency Division Duplex
FWS	Fixed Wireless System
GSM	Global System for Mobile Communications
ICT	Information and Communications Technology
IMT	International Mobile Telecommunications
IoT	Internet of Things
	International Telecommunications Union-
ITU-R	Radiocommunication Sector
LoS	Line of Sight
LSA	Licensed Shared Access
LTE	Long Term Evolution
M2M	Machine-to-Machine
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
MP-MP	Multipoint-to multipoint
MWA	Mobile Wireless Access
NLoS	Non Line of Sight
PDH	Plesiochronous Digital Hierarchy

P-MP	Point-to-Multipoint
P-P	Point-to-Point
ProSE	Proximity based Services
PSTN	Public Switched Telecommunication Network
QAM	Quadrature Amplitude Modulation
RAN	Radio Access Network
RF	Radio Frequency
RNC	Radio Network Controller
RRU	Remote Radio Unit
RSL	Received Signal Level
SDH	Synchronous Digital Hierarchy
TDD	Time Division Duplex
TDM	Time-Division Multiplexing
UHF	Ultra High Frequency
UL	Uplink
UMTS	Universal Mobile Telecommunications System
VCO	Voltage Controlled Oscillator
VoIP	Voice over Internet Protocol
WBB	Wireless Broadband
WRC	World Radiocommunications Conference
XPIC	Cross Polarization Interference Cancellation

4 BROADBAND MOBILE NETWORK AND BACKHAUL REQUIREMENTS

The increasing demand for mobile data raises challenges in terms of wireless access to the end user. Allocation to the mobile service, if necessary, and subsequent identification to IMT of new frequency bands is one of the possible answers to meet the increasing requirement, and is for instance addressed through Agenda item 1.1 of WRC-15. Refarming of frequency bands used for 2G and 3G services has also already started in some member states. Network densification is also already largely used by mobile operators which have been developing small cells in dedicated frequencies. This approach recently gained significant momentum with the standardization within 3GPP for UMTS and LTE of the reuse by small cells of the same frequency blocks as those of the macro-cell in which those small cells are deployed. Such network densification specifically implemented in urban and dense urban areas is a structural change for backhauling.

Even if optical fibre in most cases will be the preferred solution for backhaul in broadband mobile networks, it is expected that there will be situations where access to fibre will be problematic. Depending upon availability, cost and civil engineering difficulties, optical fibre may not be the only backhaul solution, especially for connecting small cells. Alternative technologies such as xDSL, cable based backhaul and wireless backhaul are expected to be viable alternatives. Depending on the requirements identified different technologies might be used for backhaul from macro base stations or small cells. The goal of this chapter is to identify requirements on backhaul in the mid and long term. Chapter 8 then contains an analysis on these requirements expected to be met with wireless backhaul for mobile networks in the targeted timeframe.

4.1 Requirements on backhaul in the mid term

The introduction of LTE has already changed the mobile broadband experience in many member states driving and facilitating a huge increase in mobile broadband consumption. Looking forward into the 2015 to 2020 timeframe there is a solid roadmap to cater for further capacity increases and support for higher end user bitrates. Within the LTE-Advanced framework a number of standard releases¹ have already been completed that introduce a toolbox of different solutions that can be used to increase the capacity and speed of the network. Several of these enhancements are expected to have implications on backhaul requirements. Ever increasing capacity needs, lower latency, tight synchronization and support for new physical network topologies will all have an influence on backhaul for mobile broadband.

Annex 1 of this report contains background information about how the expected mobile broadband developments up to 2020 might change the requirement on wireless backhaul. In the annex three main sets of requirements for wireless backhaul for mobile networks are identified. These are summarized in the sections below.

4.1.1 Backhaul requirements for dense urban areas

For macro base stations in these dense urban areas a substantial increase in the required capacity is expected, resulting in an expected **capacity requirement of one to a few Gbit/s per base station** at the end of the period. With further densification of rooftop macro base

¹ LTE release 10,11,12

station in these areas, hop lengths to reach an existing fibre connected point are expected to be short, in the **range of 200 meters to 1 km**.

In dense urban areas it is also expected that further macro cellular densification past a certain point will become problematic. There are already areas where the distance between nearby rooftop mounted macro base station belonging to the same operator is as low as 200-300m. It is thereby expected that further densification in these areas will be achieved through deployment of an increasing number of indoor and outdoor small cells within the coverage area of the macro base stations. In this timeframe indoor deployments are expected to be primarily connected with backhaul based on copper or fibre, indoor small cells are therefore not expected to bring new requirements. For outdoor small cells it is a different matter. Even if fibre is the preferred solution where available, it is expected that there will be numerous small cell sites where other backhaul technologies will be used. Most of these outdoor small cells are expected to be installed below rooftop on street furniture or the external walls of buildings. For wireless backhaul this means that finding Line of sight between the small cell and the fibre connection point could be problematic, so for outdoor small cells there is a need to handle **none line of sight environments**. For small cells, **capacity requirements from tens of Mbit/s up to several hundred of Mbit/s** could be expected and hop lengths to reach an existing fibre connected point are expected to be even shorter than for the macro base station case.

4.1.2 Backhaul requirements for rural areas

In these areas it is not expected that there will be such a high focus on network densification. Hop lengths are therefore still expected to be quite long in the **range a few km up to 15 km**. It is however also expected that the backhaul connecting these sites will have a substantially lower capacity requirement. In these areas **a capacity requirement from a few to several hundred of Mbit/s is deemed to be sufficient**.

It should be noted that the deployment realization of the majority of mobile sites will be between the two extreme (dense urban and rural) cases with moderate capacity requirements and hop lengths to reach a fibre connection point.

4.1.3 Requirements of wireless backhaul used for front haul links

A third set of requirements comes from the development of an alternative architecture for building the radio part of the mobile networks. Traditionally all the functionality of a base station has been situated at the site where the antennas are. An alternative is to split the operational functionalities of the base station and to divide the base station into a central unit, containing the control and digital signal processing functionality and a remote radio unit that only deals with the generation and reception of the radio signals. The remote radio unit would then be placed at the site where the antennas are and the central unit, containing the control and digital signal processing functionality can be placed elsewhere and even centralised so that it can support multiple antenna sites from the same central unit.

This architecture requires a high speed digital connection between the central unit and each remote radio unit, this connection is referred to as fronthaul. This can be seen as an application of wireless backhaul where it is a digital link connecting the more central parts of the access radio network with the antenna sites. You could either see it as wireless backhaul

used for fronthaul links or alternatively that the backhaul is replaced with fronthaul in the network.

In traditional backhaul link it is the end user data bits and system control information that are transmitted over the backhaul to and from the base station. Since front haul is then the connection between the central unit and the remote radio unit, in a front haul application the information sent and received over the front haul link is no longer the user data, but instead the digital samples representing the signal that is transmitted and received at the antenna. This normally increases the bitrate requirement for the front haul link a number of times compared to a traditional backhaul. Backhaul can also normally take advantage of statistical multiplexing to lower the capacity requirement for multi sector sites, this is no longer the case in a fronthaul application, here the capacity requirement will instead increase linearly with the number of sectors.

The possibility to centralize base station functionality also opens up the possibility for increased coordination of the signals transmitted from different remote radio units, something that can increase the capacity of the system. To be effective this coordination will however require that the front haul link has low latency and allows for tight synchronisation of the different remote radio units.

So for front haul over wireless (backhaul) links, **capacity requirements in the range of 1-10 Gbit/s** are foreseen for connecting a single remote radio unit in the timeframe of interest. It should be noted that for a multi sector site this requirement should be multiplied with the number of sectors. Some applications of this technology will also add additional requirements on low latency and tight synchronization to the front haul requirement set.

4.2 Backhaul requirements in the long term

From 2020^{2,3}-2022^{4,5} it is expected that the first iteration of fifth generation mobile network technology (5G) will be ready for market introduction. In the same way as described for 4G it is envisioned that 5G will then evolve over time and during the period 2020 to 2030 add more and more advanced capabilities on top of what is introduced in the first iteration.

Looking at a post 2020 scenario for mobile backhaul, it therefore becomes important to try to assess what kind of new issues and additional requirements could arise as a result of 5G introduction. Annex 2 and Chapter 8 of this report tries to give a description of the expected development in relation to 5G. It should be noted that the work on 5G is still at a relatively early stage. Discussions about the final requirement set for 5G are currently ongoing in ITU-R. This means that there is not yet an agreed detail description of 5G and its capabilities. Due to this the final requirement set for the long term must be seen as more uncertain.

One major requirement that has been identified is that 5G should support a substantial increase in uses and use cases. Future mobile systems are thereby expected to encompass more of the radio communication needs of current users but also support the needs of many completely new users and new industries. Use cases that have been mentioned are as diverse as low bit rate deep indoor M2M communication for the internet of things, industrial control

² Digital agenda for [Europe](#) towards 5G

³ ITU towards “IMT for 2020 [and](#) beyond”

⁴ Activities within the Digital agenda for Europe initiative, [Future internet, Towards 5G](#) [Europe](#) towards 5G

⁵ ITU towards “IMT for 2020 [IMT for 2020 and beyond](#)”

automation, tactile internet and home network communication used for the streaming of super high definition immersive 3D TV. To be able to accommodate all the use cases that can be envisaged today, as well as giving flexibility for future uses not yet conceived, a number of high level requirements have been proposed:

- User plane latency in the 1 ms range,
- Millions of simultaneous connections per square km,
- Peak data rates of tens of Gbit/s,
- Normal user data rates in the 1 Gbit/s range,
- Traffic volumes per square km in the tens of Tbytes/s range.

These are substantial increases in capabilities compared with present day mobile broadband systems. Comparing these preliminary requirements with an LTE-Advanced system the approximate change in requirements can be described as:

- Latency is expected to decrease a factor of 5-10 times,
- The number of simultaneous connections that can be supported per square km is expected to increase 10-100 times,
- Peak data rates are expected to increase 10-50 times,
- User data rates are expected to increase 10-100 times,
- Traffic volumes that can be supported per square km are expected to increase 100-1000 times.

There are also a number of other potential requirements that are equally important. Substantial reductions in cost per delivered bit and energy consumption per delivered bit will be a necessary requirement if the volume of data is going to increase in the order of 1000 times. Some of the new use cases, for example mission critical communication, will require improvements in robustness. And some Internet of Things (IoT) use cases would require better coverage, especially deep indoor coverage. Other IoT use cases would require long battery life, in the order of 10 years, which would require ultra-low power consumption for the radio communication. More background information on the predicted 5G development can be found in Chapter 8.

4.2.1 Mobile access in frequency bands above 6 GHz

It has been identified that to accommodate the targeted high user data rates and peak data rates described above, use of higher frequencies could be beneficial. As a consequence substantial research efforts are currently targeting use of frequencies in the range 6-100 GHz for 5G mobile access networks. Many of the frequency bands above 6 GHz are however currently used for fixed links, this might lead to a conflict if the same bands are targeted for both mobile access and fixed links. It could on the other hand also open up new possibilities for efficient sharing between mobile access and wireless backhaul in the same frequency band. Further information about this issue can be found in Chapter 8.

4.2.2 Ultra dense networks

The trend described for the midterm, with the densification of the radio access network is expected to continue in 5G. Small cell densification is expected to be one of the main means to reach the targeted traffic volume densities and ultra-dense small cell networks are a hot topic for 5G. This is expected to substantially increase the number of backhaul links that are

needed in the network. For urban outdoor use the number of small cells at street level mounted on street furniture and walls is thereby expected to increase substantially. These small cells are further expected to be able to deliver Gbit/s to the end users in the area, translating into a requirement of Gbit/s to tens of Gbit/s data rates for small cell backhaul. The increasing number of small cell sites will probably also drive the implementation towards less and less ideal infrastructure sites, where it could be difficult or too expensive to install the preferred fibre backhaul. This could increase the focus on high speed short haul wireless backhaul as a local aggregation solution to reach fibre access for the 5G small cell network layer. There is also a discussion on densification for the indoor component of the 5G network, with indoor small cells numbers potentially increasing to more than one in each room. Retrofitting existing buildings with wired Gbit/s backhaul to all indoor small cells could, in such cases, be problematic. Using local indoor wireless backhaul to reach small cells with a direct connection to wired backhaul could be an attractive proposition in such cases. For ultra dense networks a **capacity requirement in the range of Gbit/s to tens of Gbit/s** can be envisioned, **the hop length if wireless backhaul is used is expected to be short.**

4.2.3 Backhaul capacity requirements

With expected radio access peak data rates reaching tens of gigabit/s it is easy to see that there will be a need for backhaul that at least matches those data rates even in areas where ultra-dense networks will not be built. Even if fibre backhaul is the preferred solution, there will be situations where cost or practical problems will make wireless backhaul links an attractive alternative. In this case **capacity requirements up to tens of Gbit/s** can be envisaged and **hop lengths could be expected to be up to 15 km.**

4.2.4 Form factor for small cells

Small cells for 5G are expected to become physically small and low cost, this will of course also apply to the backhaul solutions for these small cells. Wireless backhaul equipment that targets this market will have to have similar properties, which are low cost and small physical size.

4.2.5 Latency requirements

With latency requirements in the ms range for some use cases the **latency budget for the backhaul links would need to be in the sub ms range.**

5 WIRELESS BACKHAUL FOR MOBILE INFRASTRUCTURE

The new requirements for mobile networks together with the technological evolution of fixed point-to-point radio systems used in the infrastructure (backhauling) networks will impact the current usage of fixed radio links. The advent of later generations of mobile systems (usually identified as LTE or 4G) where the amount of data traffic to/from the end user terminals is becoming larger and larger; will imply that the infrastructure (backhaul) networks also need to evolve towards higher capacity and performance, which implies that, for connecting a denser pattern of base stations, the fixed point-to-point links may also become shorter.

These very high capacity links can provide a viable alternative to deploying fibre optics, especially in rural areas, and equally in high-density urban areas where it would be not physically or economically feasible to deploy optical fibre or where there would be severe disruption caused, for example, by digging up roads to lay down fibre.

The network architecture has evolved in the past years, which could provide benefits with respect to the backhaul. Some detailed text on the network architecture evolution can be found in Annex 3.

The past and current use of Fixed Service frequency bands was analysed in the ECC Report 173 that shows a significant growth (based on data from 1997, 2001 and 2010) of FWS in the 10-38 GHz bands in Europe, and especially in the 23 GHz and 38 GHz bands -, which can be attributed to increased demand for mobile backhaul (23 GHz and 38 GHz bands are heavily used for mobile backhaul in several European countries). This trend will continue for the coming years with demands for higher capacity and more links due to the expected large scale deployment of wider bandwidth mobile technologies (e.g., UMTS/HSPA/HSPA+/LTE/IMT-Advanced).

The requirements defined in the previous chapter for new generation mobile networks pave the way for the new backhaul requirements.

New backhaul requirements

Foreseen changes in IMT-Advanced are driving required modifications in backhaul networks. According to the Working document towards a preliminary draft new Report ITU-R F.[FS.IMT/BB] being developed by WP5C within ITU-R a number of backhaul challenges must be overcome in order to support mobile broadband networks:

1. Backhaul must be able to transport more traffic to accommodate the increases in data throughput required by users.
2. Backhaul must also transport this traffic with low latency, in order to prevent a negative impact on the users' quality of experience (QoE).
In particular for small cell and small cell extensions.
3. Backhaul facilities should be cost effective, easy to install, and have a small footprint, as a large number of new small cells are expected to address the demand for mobile broadband growth.

4. To adapt to a challenging environment (lamp post, traffic light, etc.), the use of a new form factor antenna may be necessary.

These new backhaul requirements generated by the evolving mobile systems could be met by using wide channels in the frequency bands currently designated for fixed service systems or making new frequency bands available for such applications that could support fulfilling the increased data demand.

Using more spectrum efficient techniques could be a key element in meeting the high requirements. The trends show that the fixed service systems are also evolving together with the mobile systems. The following techniques could play a main role in increasing the spectrum efficiency (just mentioning a few):

- Automatic Transmit Power Control (ATPC)
- Modulation: using higher modulation formats; applying adaptive modulation technique
- Bandwidth adaptive systems
- Polarization: polarization multiplexing
- Multiple Input Multiple Output (MIMO): using multiple antennas at the transmitter and/or receiver
- Full duplex radios (echo cancellation)
- Asymmetrical point-to-point links

Detailed description of these techniques can be found in Annex 4.

Topology of the networks should also be discussed when finding the best solutions for wireless backhaul. Traditional point-to-point links, point-to-multipoint and also mesh topologies can be applied when deploying a network. It depends on the frequency band itself, the propagation and environmental conditions (LoS or NLoS deployment), the type of the base station of the mobile network to be served and the cost factor should be taken into consideration, as well. Certain frequency bands are more suitable for deploying point-to-multipoint networks than point-to-point links since those bands are harmonised for this kind of application. Each type of topology has its benefits and drawbacks that are discussed in this chapter.

5.1 Potential frequency bands to meet wide channel requirements

The lack of spectrum supporting wide channel bandwidths has been identified as a potential bottleneck for microwave backhaul. Many national regulators have recently adopted channel plans that allow for bandwidths of up to 112MHz in bands below 40GHz. These bands were originally made available at a time when there was limited need for wide bandwidths, and as a result, they are mainly populated with narrow channels. Since the rollout of mobile broadband, many of the narrowest channels have been abandoned because they are unsuitable for data traffic. This has given spectrum administrators the opportunity to introduce wider channels in these bands. An additional possibility is to open new, previously unused, frequency bands such as the 90 GHz band. According to the current relevant ECC Recommendations in the 42 GHz ($CB_{\max}=224$ MHz), 60 GHz ($CB_{\max}=2500$ MHz), 70/80GHz ($CB_{\max}=4500$ MHz) and 90 GHz ($CB_{\max}=400$ MHz) band, it is possible to use wide channels, which could support the small cell deployment by providing enough spectrum for the backhaul infrastructure to meet the demand for the increased data traffic generated by the high

speed mobile applications. Channel bandwidths like in the case of 70/80 GHz band could support multi gigabit transmission which is defined as a main criterion for the backhaul of the new generation mobile systems.

5.2 Increasing channel width

As described in ECC Report 173, channel arrangement recommendations have been developed within CEPT for all bands identified for FS bands between 1.4 and 71-76 / 81-86 GHz. In addition, early 2014, a similar ECC Recommendation was adopted for the 92-95 GHz band.

Before a specific activity was initiated within CEPT, the channel raster for most of the bands allocated to the FS above 20 GHz was based on channel separation not larger than 112 MHz. Notwithstanding other technical conditions, increasing the channel width allow for an automatic increase in the data rate and consequently the possibility to use the related links for wireless backhaul.

Channel aggregation can also be applied in order to increase the data throughput by using several channels combined but treated as a single channel. It can be achieved by aggregating non-contiguous channels, as well, which can provide an easier and more cost effective solution than deploying a new link to fulfil the increased data demand.

The list of the frequency bands for which higher channel widths have been recently introduced is given in Annex 5 together with the related ECC Recommendations.

A complete overview on all Fixed Service ECC Recommendations can be found in EFIS (ECO Frequency Information System). EFIS includes the possibility to provide accurate implementation information about the channelization arrangements for Fixed Services. CEPT-Administrations are in the process of updating the national implementation information for FS. Moreover, CEPT SE 19 is gathering information on fixed services applications within CEPT with the task of updating ECC Report 173, with a focus on spectrum requirements and technology trends for the Fixed Services in Europe related to frequencies higher than 50 GHz.

5.3 Topology of the networks

Fixed radio links provide a transmission path between two or more fixed points for provision of telecommunication services, such as voice, data or video transmission. In general we can say that typical user sectors for fixed links are telecom operators (mobile network infrastructure, fixed/mobile network backbone links), corporate users (private data networks, connection of remote premises, etc.) and private users (customer access to PSTN or other networks). With respect to mobile network infrastructure there are three kinds of network topology with which backhauling for macro and small cells can be realized: point-to-point, point-to-multipoint and multipoint-to-multipoint (mesh). Each topology has its benefits and drawbacks with regard to the deployment taking account of cost, environmental and propagation conditions, robustness, reliability, latency, interference sensitivity and installation properties.

Changes in network topology approaches to cope with network failure may also impact the spectrum requirement for wireless backhaul (see Annex 3 for further elements).

5.3.1 Point-to-point links

Point-to-point microwave is a cost-efficient technology for flexible and rapid backhaul deployment in most locations. It is the dominant backhaul medium for mobile networks, and is expected to maintain this position as mobile broadband evolves; with microwave technology that is capable of providing backhaul capacity of the order of several gigabits-per-second.

Complementing the macro cell layer by adding small cells to the RAN introduces new challenges for backhaul. Small cell outdoor sites tend to be mounted 3-6m above ground level on street fixtures and building facades, with an inter-site distance of 50-300m.

In the various options under study for suitably to respond to the small cells backhauling problem, it has to be considered that the design of P-P links deeply entering the street canyons in urban areas, even if still in LoS conditions, cannot ignore building and other forms of urban clutter.

As a large number of small cells are necessary to support a superior and uniform user experience across the RAN, small cell backhaul solutions need to be more cost-effective, scalable, and easy to install than traditional macro backhaul technologies.

Well-known backhaul technologies such as spectral-efficient LoS microwave, fibre and copper are being tailored to meet this need. However, owing to their position below roof height, a substantial number of small cells in urban settings do not have access to a wired backhaul, or clear line of sight to either a macro cell or a remote fibre backhaul point of presence.

5.3.1.1 LoS backhaul

Line of sight (LoS) backhaul, in particular at millimetre waves, allows the reuse of the same frequencies for two or more PP links at the same location or at very close locations due to the very high antenna gain.

However, such a link is then very sensitive to any mis-pointing due to small movements of urban installations (such as lampposts) that are not designed to avoid such movements (due to wind or vibrations).

Due to these circumstances in the 70 GHz and 90 GHz frequency bands (which have similar atmospheric attenuation) a LoS connection can be made avoiding significant mis-pointing by precise adjustment of the high gain antenna mounted on a robust console.

The 60 GHz frequency band could be an outstanding solution for street level installation due to the high oxygen absorption and smaller antenna gain requirements. The available contiguous spectrum in this band can support the data throughput demand towards the base stations. Furthermore the band is a natural fit for TDD rather than FDD resulting in some advantages⁶:

- As the transport payload of cellular backhaul is typically asymmetric – better efficiency can be achieved (upload/download ratio is flexible)
- More available channels – improving capability for frequency re-use in dense deployments

⁶ : ATTM TM4: Considerations for Small Cell Backhaul

LoS Advantages

A LoS wireless small cell backhaul solution, such as microwave, 60 GHz, and E-band, require, as the name implies, direct, unobstructed visibility between the transceivers at each end of the link. A highly directional beam transmits data between two transceivers and transports the data in a straight line with little or no fading or multipath radio interference. This is a highly efficient use of spectrum, as multiple microwave transceivers can function within a few feet of each other and reuse the frequency band for transmitting separate data streams.

Mainly used for high-bandwidth applications for outdoor small cell deployments rather than indoor femtocells or picocells, LoS links can allow a single small cell with integrated backhaul, such as a lamppost femtocell, to communicate with the next point of aggregation. Since microwave is best used as a highly directive beam, spectrum is not much of an issue; two microwave transceivers can be used at very close range compared to NLoS technologies. This setup is useful in areas with a high concentration of cells.

LoS Disadvantages

LoS applications are more effective in some situations than others. For example, a park where many trees could block LoS is an impractical location for small cells backhauled through LoS technology. Pole tilt and sway are also a concern for small cell backhaul, and this becomes increasingly important for frequencies above 18 GHz where the antenna beam width is narrower. This is a concern for operators wishing to deploy small cell backhaul on structures like utility, lighting, and traffic poles, which were not originally designed to resist sway to the extent required by microwave backhaul.

5.3.1.2 NLoS backhaul

The evolution to denser radio-access networks with small cells in cluttered urban environments has introduced new challenges for microwave backhaul. A direct line of sight does not always exist between nodes, and this creates a need for near- and non-line-of-sight microwave backhaul.

Using non-line-of-sight (NLoS) propagation is a proven approach when it comes to building radio access networks, and more generally speaking in high-density urban environments, due to the propagation characteristics of waves at these frequencies (building penetration, diffraction). In lower frequency bands NLoS does not require antenna alignment, which may ease backhaul equipment installation, which can in particular be an advantage in a P-MP topology.

One drawback of NLoS is related to the frequency band and size of the latter available for such deployment. The 6 GHz band is inherently limited in terms of capacity and this is for the time being the only NLoS band available in Europe for which there is no plan for the introduction of broadband mobile systems on a large scale.

Non-line of Sight (NLoS) links generally operate up to the 6 GHz frequency ranges. “Near” Line of Sight can operate up to around 10 GHz. These backhaul links make use of these signals’ ability to penetrate or diffract around obstacles. Unlike LoS, these systems do not require alignment at set up. NLoS systems can potentially offer better coverage in dense urban

environments provided the links support the bandwidth, synchronization, and latency requirements of the RAN.

In the Working document towards a preliminary draft new Report ITU-R F.[FS.IMT/BB] it is stated that microwave backhaul using frequency bands above 20 GHz can, under certain conditions, perform in a way similar to those using bands below 6 GHz – even in locations with no direct line of sight. Indeed, in traditional LoS solutions, high system gain is used to support targeted link distance and to mitigate any fading factor, such as rain. For short-distance solutions, this gain may be used to compensate for NLoS propagation losses instead.

The key system parameter enabling the use of high-frequency bands is the much higher antenna gain for the same antenna size. With just a few simple engineering guidelines, it is possible to plan NLoS backhaul deployments that provide high network performance. And so, in the vast amount of dedicated spectrum available above 20 GHz, microwave backhaul is not only capable of providing fibre-like multi-gigabit capacity, but is also capable of supporting high performance backhaul for small cells, even in locations where there is no direct line of sight.

5.3.2 Point-to-multipoint networks

P-MP networks are usually deployed in a dense manner employing the star configuration for their networking topology. It is necessary to ensure the transmission of high data rates between the base and terminal stations, and, at the same time, minimise the possible intra-system interference between different cells/sectors of the network.

P-MP networks are finding application for providing last mile connections for mobile broadband networks. P-MP is suited to carrying the data traffic that is becoming the predominant type of information carried over mobile networks.

P-MP equipment is based on the observation that mobile data has one characteristic that makes it particularly challenging for FS link networks. Because packet data volume is based on the nature of the data usage characteristics of the users on the network, the traffic presented to the link has a distinct ‘shape’ – transient, unsynchronised peaks when users or applications are consuming data and troughs when users are idle. Such peaks and troughs are no longer correlated with a specific ‘busy hour’ that is common across the whole network (although an overall diurnal ‘swell’ may still be observed). The unpredictable nature of this data traffic makes it difficult for operators to design their network backhaul connections.

P-MP networks can address this challenge by statistically multiplexing the traffic from multiple sites to improve the efficiency of the network. That allows the traffic to be merged so that the peaks from one mast ‘cancel out’ the troughs of another which improves system efficiency.

Point-to-multipoint network as backhaul

With respect to the small cell backhauling it should be noted that as the radius of a small cell decreases, the cost savings using P-MP NLoS increases. Also, as the traffic load increases, there can be additional savings offered due to the ability of P-MP NLoS to support denser traffic configurations.

In addition to the cost savings, the NLoS capability of the P-MP solutions makes design and implementation of the backhaul easier and faster as the network expands.

The topology is based on a hub and remote concept where the backhaul hub supports several small cells with a small remote located at each small cell. The hub and remotes operate NLoS allowing operators great flexibility in placing the small cell at an ideal location.

On the other hand it should be noted that there are only a few frequency bands that can be used for P-MP application, but self backhauling might be an option where mobile network and its backhaul can be realized in the same band (technology and service neutral bands).

5.3.3 Multipoint-to-multipoint networks

Multipoint-to-multipoint networks (MP-MP), also known as meshed networks, are intended to serve a large number of densely located fixed terminal stations. Meshed networks would therefore provide an alternative for P-MP networks. Meshed networks do not require central (base) stations for communications between terminal stations. Instead, each and every terminal station may act as a repeater and pass on the traffic to/from the next terminal station. Such networks would have only one or a few drop nodes, which would provide interconnection of the meshed access network to the core transport network. Usually, all the nodes of the meshed network are located on the customer's premises and act as both customer access and network repeater. In such a way traffic is routed to the addressed customer via one or many repeaters. Nodes located at the edge of the network initially act as terminating points, however they may be later converted into repeaters with the further growth of the network.

Wireless mesh network as backhaul

As data rates increase, the range of wireless network coverage is reduced, raising investment costs for building infrastructure with access points to cover service areas. Mesh networks are unique enablers that can reduce this cost due to their flexible architecture.

With mesh networking, access points are connected wirelessly and exchange data frames with each other to forward to/from a gateway point. Since a mesh requires no costly cable constructions for its backhaul network, it reduces total investment cost. Mesh technology's capabilities can boost extending coverage of service areas easily and flexibly.

For outdoor deployments, the forwarding capabilities of a mesh architecture allow the wireless network to switch traffic around large physical objects, such as buildings and trees. Instead of attempting to radiate through impeding objects, a wireless mesh network can easily forward packets around an object via intermediate relay nodes. This approach is very useful in dense urban environments that contain many obstructions, or in rural areas where hills or mountains become an obstacle to conventional wireless networks.

On the other hand it is intrinsic to all mesh networks that user traffic must travel through several nodes before exiting the network. The number of hops that user traffic must make to reach its destination will depend on the network design, the length of the links, the technology used, and other variables. Due to the multiple traffic hops within the wireless mesh network bandwidth degradation, radio interface and network latency problems can occur.

5.4 Self-backhauling in mobile frequency bands

The general idea with self backhauling in mobile frequency bands is to reuse frequencies and radio interfaces/radio technology normally used for the mobile access also for the backhaul and can be realized in any of the above-mentioned topology types. This can be done either in band in the same frequencies that are used for connecting the mobile end users in the area, or out of band using a mobile frequency band that is not used for end user access in the area. For in-band use the backhaul and the mobile end users will share the same radio interface and also share the available capacity on that radio interface.

However, the in-band use sometimes conflicts with the national licensing/auctioning rules (e.g. requiring “access only”) or, in any case, imply that the backhaul capacity would reduce the access capability and that, given the limited block bandwidth, there will be strong limitation to the planning of P-P links (in term of capacity and availability of channels for interference reduction purpose).

For the out of band case a new dedicated radio interface at another mobile frequency band will be used for the backhaul, using a standard mobile broadband technology such as LTE. An example of self backhaul is relaying and relay nodes as defined in 3GPP release 10 of LTE. This functionality is mainly targeting heterogeneous network deployment and allows new small cells to connect to the base station through the standard base station LTE air interface, allowing for a low cost backhaul solution

5.5 Wireless broadband spectrum used for backhaul

Characteristics of FS bands

The characteristics of FS bands are described in following documents: Working document towards a preliminary draft new Report ITU-R F. [FS.IMT/BB] and Draft new Report ITU-R F.[FS USE-TRENDS] being developed by WP5C. In general, all frequency bands available for the fixed service could be used in the transport networks. First and foremost, the increase in traffic requirements for IMT and other terrestrial mobile broadband systems requires a minimal transmission capacity. Backhaul links with too small capacity would become a bottleneck, impacting the operations of the mobile broadband system.

The transmission capacity should be appropriate to the requirement of the mobile system, which depends upon the number of base stations for which the fixed link will provide backhaul.

With this capacity requirement, many fixed service bands are capable of supporting deployment of IMT and other terrestrial mobile broadband systems. These cover short hops, in the range of less than a kilometre up to tens of kilometres. Fixed service bands can be divided into three broad categories, each fulfilling specific traffic requirements: Low frequency bands, mid-range frequency bands and high frequency bands.

- Low frequency bands (below 11 GHz)

Due to their good propagation characteristics, the main application of these bands for backhaul is to support long-haul hops (typically from 10 kilometres to 50 km). This is very important for mobile broadband services deployment in communities outside urban

areas, as well as along corridors between population centres, where wired transport mediums (such as fibre) are not technically or economically feasible. It should also be recognized that the long-hop lengths achievable by these fixed services' bands allow minimizing the number of sites; this is an important aspect in providing economical access to mobile broadband services in remote areas. Another application could be for shorter hops without line-of-sight. In such cases, the low frequency bands could be used as their better propagation characteristics can compensate for losses due to obstacles between the two fixed stations.

- Mid-range frequency bands (11 to 23 GHz)

Fixed service frequency bands in this range provide transport networks and mobile backhaul applications supporting medium-haul links (typically between about 8 and 20 km). In this range, larger RF channel bandwidths are possible, allowing traffic requirements for IMT and other terrestrial mobile broadband systems in populated areas outside dense city centres, such as suburbs and industrial parks to be better addressed.

- High frequency bands (above 23 GHz)

Wireless backhaul applications in these fixed service frequency bands are used for short-haul links (typically less than about 8 kilometres). However, they offer very large transmission capacity, which is well suited to fulfil the high traffic requirements and small distance between cells in IMT and similar mobile broadband systems deployed in dense urban areas. Another increasingly important application is to backhaul traffic from small cells, as the location of small cells often could make fibre use impractical.

The frequency band 59 to 64 GHz is gathering interest in particular due to a high atmospheric absorption which provides an opportunity for small cell backhauling. Also the 64-66 GHz range, where atmospheric absorption drops down significantly, has growing interest for similar applications where longer hops are foreseen. The air absorption around 60 GHz (i.e. from 58 to 64 GHz) is over 10 dB/km. This restricts the hop length; but on the other hand, the spectrum reuse efficiency is high. Thus spectrum reuse efficiency makes the band suitable for small cell mobile backhaul.

In the 71-76/81-86 GHz bands, wide bandwidth can be used and the attenuation due to gas absorption is relatively small compared with the 60 GHz band and, in practice negligible. Therefore, this band is suitable for high-capacity transmission. Most applications are foreseen for FWS links used for fixed and mobile infrastructure. Applications within the frequency band 92 to 95 GHz (92.0-94.0/94.1-95 GHz) are almost the same as those within 71-76 and /81-86 GHz bands. However, the total bandwidth of the 92 to 95 GHz band is 2.9 GHz, and thus the data rate of FWS in this band is less than can be provided in 71-76 and /81-86 GHz bands.

6 FIXED SERVICE ASSIGNMENT METHODS

When discussing the use of Fixed Service frequency bands for backhaul in new generation mobile networks, taking into account the cell densification and the fact that cells are becoming smaller and smaller, the choice of assignment method may be important and should be addressed. It will be challenging to use the traditional point-to-point assignment methods in certain frequency bands that could be used for small cell backhauling. Considering this issue different kinds of assignment methods should be taken into account when seeking the best solution. In this chapter a list of these methods can be found and in Chapter 8 an assessment is given based on these options.

The assignment methods currently present in the Fixed Service regulatory framework of most CEPT countries are summarized in ECC Report 173 in the following four categories:

Individual licensing: this is the conventional link-by-link coordination, usually made under an administration's responsibility; however sometimes, the administration delegates this task to the operators, but it keeps control of the national and cross-border interference situation. This is currently assumed to be the most efficient method of spectrum usage for P-P links networks.

Light licensing: even if the terminology itself is not completely agreed among CEPT administrations (see ECC Report 132), the common understanding, where fixed P-P links are concerned, refers to a link-by-link coordination, under users responsibility, reflected in the definition given by ECC Report 80. From the spectrum usage point of view, this method is, in principle, equivalent to individual licensing; only the potential risk of "errors" or "misuses" in the coordination process might be higher because of the number of actors involved, some of them also inadequately prepared technically.

Block assignment: the assignment might be made through licensing (renewable, but not permanent) or through public auction (permanent). This is most common when FWA (P-MP) is concerned where the user is usually free to use the block to best effect in the deployment of its network; in some cases, there might even be no limitation to the wireless communications methods used in the block (e.g. P-P and/or P-MP, terrestrial and/or satellite or any other innovative technology or architecture). In the most popular bands for this method, ECC recommendations exist suggesting intra-block protection guidelines in terms of guard bands or block-edge masks (BEM). For some frequency bands this method is considered the best compromise between efficient spectrum usage and flexibility for the user.

License exempt: this method offers the most flexible and cheap usage, but does not guarantee any interference protection. It is most popular in specific bands (e.g. 2.4 and 5 GHz) where SRD are allocated, but FS applications may also be accommodated; in addition, it is often used in bands between 57 GHz and 64 GHz where oxygen absorption is significant, reducing the risk of interference.

For completeness it has to be mentioned in this report, that the RSPG published in November 2013 an "Opinion on Licensed Shared Access" (RSPG13-538). The RSPG defines the LSA concept as follows:

"A regulatory approach aiming to facilitate the introduction of radiocommunication systems operated by a limited number of licensees under an individual licensing regime in a frequency band already assigned or expected to be assigned to one or more

incumbent users. Under the Licensed Shared Access (LSA) approach, the additional users are authorised to use the spectrum (or part of the spectrum) in accordance with sharing rules included in their rights of use of spectrum, thereby allowing all the authorized users, including incumbents, to provide a certain Quality of Service (QoS)”.

The RSPG recommends that Administrations/NRAs should actively promote discussions and define the possibilities for LSA. It should be noted that within ITU-R, WP5C is currently developing a Working document towards a preliminary Draft new report ITU-R F.[FS.IMT/BB] for the use of fixed service for backhaul for IMT and other terrestrial mobile broadband systems. Within CEPT, there is some work on-going within SE19 that could be linked to a certain extent to wireless backhaul⁷. The use of LSA with fixed service (either as incumbent or licensee) would require studies to assess the overall benefit of such an approach.

The decision of an Administration to use a particular assignment procedure for a particular band or an application can be influenced by a number of factors, which could have different backgrounds such as regulatory, administrative, technology/application or market driven.

Individual licensing (frequency assignment of each individual link assignment method) continues to be the predominant method in making assignments in the majority of bands.

The impact of future developments in wireless backhaul on the assignment method is analysed in Chapter 8.

⁷ WI35: To study and gather up to date information related to developments in the FS in the millimetre waves bands (frequency bands higher than 50 GHz) in CEPT.
WI36: Guideline on how to plan MIMO Fixed Service Link.

7 CROSS-BORDER FREQUENCY COORDINATION

Efficient and interference-free frequency utilization has also to be ensured in the border area. Therefore, aspects of cross-border frequency coordination have to be taken into account. Various bilateral and multilateral frequency coordination agreements are in force for point-to-point as well as point-to-multipoint applications of the Fixed Service.

The HCM-Agreement⁸ is a well-known example that sets the terms for the frequency coordination of the fixed service up to 43.5 GHz. The agreement contains provisions for the exchange of data between administrations, prediction methods to determine the interference situation (based on ITU-R Recommendations) and triggers for coordination. All these provisions have proven to be successful for "classical" applications of the fixed service.

The considerably larger number of small cells in rural and urban areas that require wireless backhaul and their operational conditions might have an impact on frequency coordination in the border area. In Draft new report ITU-R F.[FS USE-TRENDS]⁹ being developed by WP5C for example the following challenges with respect to radio wave propagation are identified;

Urban LoS, near LoS and NLoS links for small cell backhaul represent a challenging deployment from the point of view of FS performance prediction and related propagation scenarios. Presently ITU-R propagation recommendations have not yet considered in detail these specific deployment scenarios e.g.:

- a) FS NLoS links normally use relatively high gain antennas, which are generally not considered in recommendations developed for mobile deployment scenarios.
- b) Even LoS links in the expected cases of street-to-street and roof-to-street deployment will be affected by multipath interference due to reflections on buildings and clutter elements; therefore, while the "main path" could still be planned with the conventional link-by-link methodology, the expected interference might be addressed with a statistical approach.

⁸ AGREEMENT between the Administrations of Austria, Belgium, the Czech Republic, Germany, France, Hungary, the Netherlands, Croatia, Italy, Liechtenstein, Lithuania, Luxembourg, Poland, Romania, the Slovak Republic, Slovenia and Switzerland on the co-ordination of frequencies between 29.7 MHz and 43.5 GHz for the fixed service and the land mobile service (HCM Agreement)

⁹ ITU-R Document 5/167, specifically chapter 5.1.1 (small cell backhauling) and 5.1.2 (urban links scenario)

8 ANALYSIS AND CONCLUSION

8.1 Wireless backhaul for 4G mobile networks

As mentioned in the previous chapters densification of the base stations can be foreseen in the mid-term, due to the enhanced need for big data rates, which means that more and more small cells will be deployed beside the current macrocells. In order to fulfil the requirements (data traffic rate, latency, etc.) defined for 4G it is important to provide backhaul solutions that could meet these criteria. This can be achieved in various ways, one of which would be wireless backhaul. As mentioned earlier it can be a supplementary solution alongside the optical fibre and under some circumstances the only solution for backhaul for mobile cells, especially for small cells.

Harmonised fixed service bands currently used can support the needs in the mid-term due to the improved spectrum efficiency of technologies currently available in fixed service systems. Some examples of efficient use are:

- Flexibility in applying higher modulation orders to achieve higher throughput in a given channel bandwidth which may allow operators to solve capacity problems when there is spectrum scarcity in a particular frequency band.
- Polarization multiplexing, which is a method for doubling spectral efficiency on a single channel.
- MIMO technology, which could increase capacity (Spatial Multiplexing) and/or link availability (Space Coding).
- Self-backhauling which could also be a solution in those bands where technology and service neutrality should be applied when spectrum is available.

There are some relatively new high frequency bands (60, 70/80 and 90 GHz) that support the use of wide channels and due to the propagation characteristics are especially suitable for small cell backhauling.

In conclusion it can be stated that the requirements defined for 4G mobile networks can be fulfilled in the mid-term taking into account the above-mentioned factors.

8.2 Wireless backhaul for 5G mobile networks

8.2.1 Spectrum aspects of requirements for 5G

There are requirements that will be challenging to address within the spectrum resources that are expected to be available to mobile operators in 2020. The most important one with respect to mobile backhaul is the requirement to support Gbit/s end customer access in areas with high user densities. This is expected to translate into a need for extremely high peak data rates, in the range 10 to 50 Gbit/s. To achieve these kinds of data rates, it would be beneficial to use wide frequency channels in the order of several hundreds of MHz to a few GHz. There will also be a need to support a multi-operator environment, something that could further increase the required frequency bandwidth for such new radio access interfaces. Finding these kinds of continuous frequency bandwidths below 6 GHz is unlikely to be possible. Instead the research effort for these ultra-high speed radio access interfaces has been targeting the frequency range 10-100 GHz where it could be easier to get access to suitable bandwidths.

However, as the only true LoS frequency band, the 6 GHz band should not be disregarded and is still beneficial in some circumstances for wireless backhaul.

8.2.2 Mobile access networks above 10 GHz

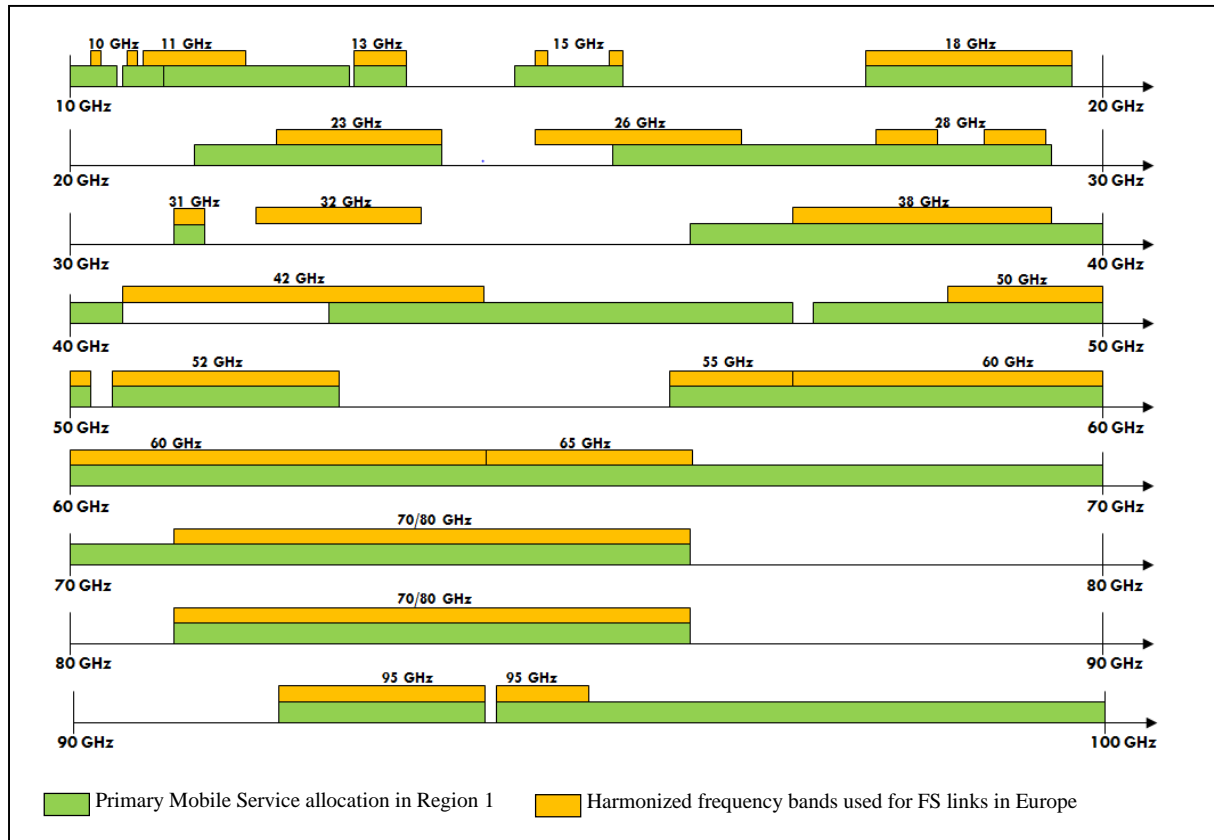


Figure 1: Primary MS allocations and harmonized frequency bands used for FS links

The picture above illustrates the potential conflict between frequency bands used for wireless backhaul in different member states and those bands that might be of interest for 5G mobile systems in the range 10 to 100 GHz. The green areas indicate the frequency regions that already have a primary mobile allocation in ITU Region 1 according to the Radio Regulations. While the yellow areas indicate harmonized frequency bands used for fixed links in Europe. The text above each yellow area indicates the name normally used to identify the fixed link frequency band. It should be noticed that not all fixed link frequency bands are used in all member countries, normally only a subset is used in each country.

As most frequency bands that might be potential candidate bands for 5G are used by fixed service applications sharing could be a way for co-existence. Mobile operators are, in most countries, the dominant users of fixed links. This could open the way up for creative solutions when it comes to internal sharing between a mobile operator's backhaul and end customer access networks within the same frequency band. There might also be room for sharing based on geographical separation especially in higher frequency bands where mobile coverage would be expected to be limited to urban areas.

In some of the Member States there could however be a number of other users that may have to move out of the band, in this case these users would need to move to other fixed services frequency bands.

8.2.3 Spectrum aspects and requirements for FS

The technology trends in the fixed service described in this report have an impact on the future spectrum requirements. Detailed studies on this issue can be found in documents of ITU-R Study Group 5, especially in the following documents:

- Annex 8 to Document 5C/358 (Working document towards a Preliminary Draft new report ITU-R F.[FS.IMT/BB]: Use of fixed service for backhaul for IMT and other terrestrial mobile broadband systems
- Document 5/167 (Draft new report ITU-R F.[FS USE-TRENDS]: Fixed service use and future trends

The main temporary conclusions of ITU-R are as follows:

Although there has been an order of magnitude increase in mobile capacity requirements and new spectrum being sought for mobile broadband applications over the last decade, **it is currently too early to tell definitively by which order of magnitude the overall corresponding fixed service spectrum requirements are likely to change in the future.** These areas require further study in order to better quantify the changing spectrum requirements for the future.

In addition the other aspect to the spectrum question is the corresponding current spectrum supply for the fixed service. Whilst currently spanning a wide range of bands from the UHF frequencies up to the higher millimetre wave bands this could also change in the future depending on the new applications or services that are looking for access in the higher bands, currently used by fixed service systems. For example mobile broadband systems are currently being considered in a range of bands above 6 GHz which may impact on the availability of the spectrum for the FS in the future.

This may be partly mitigated by advances in technology, enabling fixed links to have a corresponding increase in throughput and reliability and the addition of new fibre connections that enable improved access to fixed stations, in urban and suburban locations, removing the need for previous fixed wireless backhaul from those locations.

Further uncertainty is added to the determination of spectrum requirements as not all of the spectrum allocated to the Fixed Service in the Radio Regulations may be practical or available for such use on a national basis for a number of different reasons; for example, the spectrum may already be used by other services or may not be suitable for a variety of technical and/or spectrum management reasons.

Exploration of higher frequency bands, such as over 100 GHz, is important in preparation for the future shortage of millimetre-wave band resources. To make practical use of these frequency bands, it is necessary to develop inexpensive RF devices, propagation models and antenna pattern models that cover the frequency region over 100 GHz.

Also from the perspective of CEPT, the growth in the number of FS links is likely to continue for the foreseeable future according to CEPT Report 173 (Fixed Service in Europe: Current use and future trends post 2011). CEPT has already made several successful moves towards ensuring favourable conditions for such growth, by developing ERC and ECC Decisions and Recommendations with relevant channel arrangements and by identifying additional bands for

high density applications in the FS, including FWA and infrastructure support. Studies, including studies on MIMO and mmW-frequencies, are still ongoing in CEPT SE 19.

In conclusion, technical studies in ITU-R and CEPT have to continue in order to identify and solve the various challenges with respect to spectrum requirements.

8.2.4 Assignment methods and cross-border frequency coordination

Most of the Fixed Services bands below 50 GHz are already intensively used by the public mobile operators for wireless backhaul. Although the predominant utilization of the fixed services bands is by public mobile operators, various other users also deploy fixed services, e. g. emergency services, energy utilities, universities and hospitals, to name just a few. In some countries all users share the same frequency bands. Moreover, in many bands, the Fixed and Fixed Satellite Services are co-primary in the Radio Regulations. In those bands where administrations authorize the operation of both services, two situations may occur depending of the type of FSS Earth stations (coordinated or uncoordinated). In some fixed services frequency bands other radio services have also to be taken into account (e. g. radio astronomy service in some countries).

Due to these various and intensive utilizations, individual licensing continues to be the predominant method of making assignments in the majority of the concerned bands.

The previous chapters and the annexes describe in detail technological developments for wireless backhaul taking into account the developments of the Mobile Service from 4G to 5G networks. Deployment scenarios for the networks were also considered. For the time being, it is unclear which technological developments of the Fixed Service will be implemented to what extent in which frequency bands (e.g. asymmetrical point-to-point links, MIMO-techniques and self-backhauling).

Moreover, the work on harmonising 5G is still at a relatively early stage. Discussions about the final requirements set for 5G are currently ongoing in ITU-R. In the case of wireless backhaul, information on the technical parameters and deployment scenarios is not sufficient today to start detailed discussions.

Nevertheless, the following general conclusions can be drawn with respect to frequency assignments for wireless backhaul.

It is clear that the channel bandwidth utilized for wireless backhaul for small cells will increase in the future as described in previous chapters. ECC Recommendations on the Fixed Service already enable the possibility to use bandwidths of up to 224 MHz in those bands where only narrower channels could be used previously. It will be a challenge for national frequency management to find solutions to accommodate these higher bandwidth systems in frequency bands that are already occupied by systems with smaller bandwidths. Thus the authorization process in cases of link-by-link assignment will be more complex in the future but could be handled with the appropriate software.

In the coming years (until the introduction of 5G) the current assignment methods in the various fixed service frequency bands will continue and will pose no major problem with the expansion of 4G networks.

In the long run (after the introduction of 5G) the number of small cells will increase significantly due to the continued densification of the mobile networks. Light licensing or technology-neutral block licensing seem to be attractive alternatives, compared to other approaches such as individual licensing, to cope with very high numbers of short links as they provide flexibility. Furthermore using license exempted frequency bands can be a tempting option, but that may result in unpredictable interference and degraded network performance. Using these bands (e.g. 2.4 GHz and 5 GHz), provided that current e.i.r.p. limitations are enforced, would permit practical P-P applications but could be limited by their extensive use for “urban” RLAN applications and significant technical limitations (DFS for primary radars protection); nevertheless, it still deserves careful analysis. Eventually, other regulatory approaches such as refarming of frequency bands or LSA could be taken into account.

It is vital, that detailed information on the technical parameters and deployment scenarios for wireless backhaul is available to support discussions on the appropriate frequency assignment methods. These technical studies have already begun in ITU-R in order to identify and solve the various challenges with respect to small cell backhauling. The (preliminary) results of these studies are mentioned in the previous chapters. Furthermore CEPT has started work on some of the issues in relation to wireless backhaul (e. g. studying and gathering up to date information related to developments in the FS in the millimetre waves bands and developing guidelines on how to plan MIMO Fixed Service Links). It is expected that further work will be done in CEPT SE 19 on wireless backhaul.

After completing the technical studies and when the deployment scenarios for wireless backhaul are clearer, further work might be necessary in the field of cross-border frequency coordination for those cases where conventional methods might no longer be appropriate. These issues will be closely monitored and dealt with by the HCM Subworking Group Fixed Service.

Concerning frequency assignment procedures for future wireless backhaul services, each administration can find a suitable solution taking into account the national situation.

9 SUMMARY

As mobile networks are evolving new forms of cell deployment and increased data demand are envisaged in the future. New requirements have been set for the mobile access network and also for the backhaul network. This report contains information on these requirements and the spectrum (and related) aspects that should be taken into account by administrations when defining those elements that could be relevant with regard to wireless backhaul. Different requirements can be defined for the mid- and long-term, which are analysed in detail in the report.

Ever increasing capacity needs, lower latency, tight synchronization and support for new physical network topologies will all have an influence on backhaul for mobile broadband. Cell densification is a key element that should be considered in the mid-term, and increasingly in the long-term.

For macro base stations in these dense urban areas a substantial increase in the required capacity is expected, resulting in an expected capacity requirement of one to a few Gbit/s per base station. With further densification of rooftop macro base station in these areas, hop lengths to reach an existing fibre connected point are expected to be short, in the range 200 meters to 1 km. For small cells, capacity requirements from tens of Mbit/s up to several hundred of Mbit/s could be expected and hop lengths to reach an existing fibre connected point are expected to be even shorter than for the macro base station case.

In the long-term the deployment of ultra dense networks is foreseen. Small cells are further expected to be able to deliver Gbit/s to the end users in the area, translating into a requirement of Gbit/s to tens of Gbit/s data rates for small cell backhaul.

Discussions about the final requirement set for 5G is currently ongoing in ITU-R. This means that there is not yet an agreed detailed description of 5G and its capabilities.

Use cases in 5G systems are diverse but some requirements can be mentioned that have to be met: latency should be in the 1 ms range, millions of simultaneous connections and traffic volumes in the tens of Tbytes/s range per square km are expected, peak data rates of tens of Gbit/s and normal user data rates in the 1 Gbit/s range are foreseen.

It has been identified that due to the high user data rates the use of higher frequencies are required (6-100 GHz) These frequency bands are however currently used for fixed links, this might lead to a conflict if the same bands are targeted for both mobile access and fixed links. It could on the other hand also open up new possibilities for efficient sharing between mobile access and wireless backhaul in the same frequency band.

Since the rollout of mobile broadband, in the Fixed Service bands many of the narrowest channels have been abandoned because they are unsuitable for data traffic. This has given spectrum administrators the opportunity to introduce wider channels in these bands. An additional possibility is to open new, previously unused, frequency bands such as the 90 GHz band.

It is possible to use wide channels (including channel aggregation), which could support small cell deployment by providing enough spectrum for the backhaul infrastructure to meet the demand for the increased data traffic generated by the high speed mobile applications in the mid-term.

With respect to mobile network infrastructure, there are three kinds of network topology with which backhauling for macro and small cells can be realized: point-to-point, point-to-multipoint and multipoint-to-multipoint (mesh). Each topology has its benefits and drawbacks with regard to its deployment, taking account of cost, environmental and propagation conditions, robustness, reliability, latency, interference sensitivity and installation properties.

The general idea with self backhauling in mobile frequency bands is to reuse frequencies and radio interfaces/radio technology normally used for the mobile access for the backhaul link and can be realized in any of the above-mentioned topology types. As some higher frequency bands (above 6 GHz) will probably be identified for IMT self backhauling could be a solution.

With regard to the Fixed Service frequency bands three categories can be defined. Low frequency bands (below 11 GHz) can be used for long-haul backhaul links due to the good propagation characteristics – this could provide economical access to mobile broadband services in remote areas. Another application could be NLoS links for shorter hops. Mid-range frequency bands (11 to 23 GHz) can be used for medium-haul links especially in populated areas outside dense city centres (suburbs, industrial parks). In high frequency bands (above 23 GHz) short-haul links can be applied. These bands are well suited to satisfy the high traffic requirements of small cells in broadband mobile systems. (e.g. 60 GHz and 70/80 GHz bands - further advantage could be the high frequency reuse factor with regard to the 60 GHz band).

ECC Recommendations allow the possibility to use bandwidths of up to 224 MHz in Fixed Service bands in which only narrower channels could be used previously. It will raise new challenges for national frequency management to find solutions to accommodate these higher bandwidth systems in frequency bands that are already occupied by systems with smaller bandwidths. Thus the authorisation process in cases of link-by-link assignments will be more complex in the future but could be handled with the appropriate software. Current process of cooperation between administrations will ensure that these issues will be addressed at the right time schedule.

In the long run (after the introduction of 5G) the number of small cells will increase significantly due to the continued densification of the mobile networks. Light licensing or technology-neutral block licensing seem to be attractive alternatives to cope with the very high number of short links, compared to other approaches such as individual licensing, as they provide flexibility. Also using license exempt frequency bands can be a tempting option, but may result in unpredictable interference.

In conclusion it can be stated that the backhaul requirements determined for mobile networks can be fulfilled in the mid-term by backhaul networks which use the current CEPT harmonised Fixed Service frequency bands and apply the currently available spectrum efficient techniques.

In the long term, according to evolution of market demand, new frequency bands might need to be designated for Fixed Service applications and channel plans that could support the use of wideband systems in the current CEPT harmonised Fixed Service frequency bands might need to be introduced. Furthermore different kinds of licensing approaches might need to be considered and the feasibility of sharing between mobile and fixed service networks in the same frequency band might need to be assessed. These elements will be addressed by current process already in place.

ANNEX 1

BROADBAND MOBILE NETWORK**Mobile architecture development in the mid term**

The introduction of LTE has already changed the mobile broadband experience in many countries driving and facilitating a huge increase in mobile broadband consumption. Looking forward into the 2015 to 2020 timeframe there is a solid roadmap to cater for further capacity increases and support for higher end user bitrates. Within the LTE-Advanced framework a number of standard releases¹⁰ have already been completed that introduces a toolbox of different solutions that can be used to increase the capacity and speed of the network. Technologies and solution such as Carrier Aggregation, Heterogeneous Networks (Hetnets,), Multi User MIMO, eICIC and CoMP¹¹, just to mention a few, can all be used to increase the capacity of the mobile broadband system. Future releases of the LTE standard are expected to bring even further enhancements. Several of these enhancements are expected to have implications on backhaul requirements. Ever increasing capacity needs, lower latency, tight synchronization and support for new physical network topologies will all have an influence for different parts of the backhaul for mobile broadband. In the following sections the developments in a number of areas which are expected to drive backhaul requirements are summarized.

Frequency usage for mobile broadband in 2015 to 2020

The amount of spectrum in use by an operator will have a direct implication on the required backhaul capacity to a site. Modern base stations normally support the use of multiple radio access technologies and concurrent usage in multiple frequency bands. This means that it is possible to support GSM, UMTS, LTE and LTE-Advanced in multiple frequency bands from the same base station (if needed). The backhaul for connecting such a base station should obviously support the aggregate capacity needed by all those radio interfaces.

Going forward LTE-Advanced has been designed to optimize the performance in an environment where the operator has frequency allocations in several different frequency bands. The carrier aggregation feature allows the network to combine channels in different frequency bands into one wide common logical capacity pipe. This way an operator will be able to combine its frequency holding in different bands to create higher bandwidth channel. The capability to combine channels in this way has also been introduced in the UMTS standard.

Many countries plan for additional assignments of frequencies suitable for mobile broadband use. Some countries still have unassigned blocks of frequencies in the 800, 900, 1800 MHz, 2.1 and 2.6 GHz frequency bands already harmonised by the EC. There are also new spectrum such as 700 MHz, 1452-1492 MHz and 2.3 GHz bands for which authorisations are expected to be delivered as soon as 2015 in some EU Member States for some of these bands. Some operators have already started to refarm frequencies in the GSM bands and the amount of

¹⁰ LTE release 10,11,12

¹¹ These are technologies and solution used for enhancing the capabilities of mobile broadband systems. Some of these are further explained later in the this chapter, more extensive explanations of each technology component can be found at the 3GPP website for example in their [Keywords & Acronyms](#) page.

frequencies refarmed can be expected to increase during the target period. In some countries the harmonized 3.4-3.8 GHz band could also be expected to provide a substantial contribution to spectrum for mobile broadband. This means that many operators can potentially have access to more than 100 MHz of downstream spectrum for mobile broadband in 2020 allowing for substantial increases in speed and capacity in the mobile broadband network. As a result the mobile backhaul capacity requirement is also expected to increase in a substantial way during the period.

Heterogeneous networks, Het Net

Heterogeneous networks, Het nets are designed to allow macro cells and small cells use the same frequency channels thereby increasing the combined spectrum efficiency. It is therefore expected that the introduction of a Het net architecture could facilitate a massive capacity increase in the network. Although the Het Net concept has been around for several years the implementation in live networks has thus far been limited. Further densification of rooftop or mast sited macro cellular networks might not be practical or economically viable beyond a certain point. This could depend on scarcity of new available sites or due to the fact that the macro cellular network is already very dense. In these situations introducing small cells as a complement can be an attractive proposition. But covering whole areas with a new layer of small cells could be both costly and challenging. A midway in between would be to reuse the macro cellular network for continuous coverage and place small cells giving local capacity boosts only in areas of high usage for example at a city square, outside the train station or at a café or in areas with poor coverage.

With a number of small cells within the coverage area of each macro base station efficient solutions for backhaul becomes even more important. In some cases it will be possible to connect the small cells directly to a fibre backhaul but it is expected that all available backhaul technologies will be used including wireless backhaul.

The standards also supports another type of small cell base station, the relay node that uses the LTE interface on an adjacent Macro base station as backhaul, this will of course consume capacity from the macro base station but might be an interesting alternative in certain situations.

Technology enhancements

The LTE advanced roadmap contains several technology concepts targeted at either increasing the peak data rate and/or the spectrum efficiency of mobile networks.

Carrier Aggregation:

LTE systems today normally use a dual antenna configuration allowing for 2x2 MIMO. With this configuration the theoretical peak data rate of a 20 MHz channel is approximately 150 Mbit/s. By using carrier aggregation to combine several 20 MHz channels in the same or different frequency bands it is possible to multiply the peak data rate. Terminals combining two 20 MHz channels with a peak data rate of 300 Mbit/s are already on the market¹² and terminals combining three 20 MHz channels with a peak data rate of 450 Mbit/s are expected

¹² Support for LTE category 6

in 2015¹³. Proposals for combining four and five 20 MHz channels are expected going forward.

Advancements in MIMO configuration:

Introducing higher order MIMO support on the base station going to a 4 or 8 antenna configuration would allow a further capacity increase of two or four times, the introduction of Multi User MIMO that allows the scheduling of multiple spatially separated terminals at the same time, would also allow this increase to be realized with terminals that only have two receive antennas.

Spectrum efficiency improving technologies:

While LTE and LTE-Advanced are technologies with a frequency reuse one, there is a risk of self interference from nearby sectors and base stations in the down link direction. Different technologies that either improve the signal quality or reduce the noise at the terminals have already been standardized, such as for example downlink CoMP and eICIC. Some of these technologies require an increased cooperation between base stations and will have implications on the backhaul in the form of requirements for low latency and possibilities to support tight time synchronization.

Fronthaul and Cloud RAN (CRAN)

For a number of years it has been possible to buy base stations with the operational functionalities of the base station split into a central unit, containing the control and digital signal processing functionality, and a remote radio unit that only deals with the generation and reception of the radio signals that are to be transmitted and received by the IMT antennas. This allows the remote radio unit that transmits and receives the IMT radio frequency signals to be installed close to the antenna thereby minimising the attenuation of the radio frequency cables that connect the antennas and the remote radio unit. This functional split also allows for a greater freedom when it comes to the placement of the rest of the base station. Previously the need to connect the base station to the antenna with radio frequency feeder cables had been a limitation. With this architecture in practice most of the radio frequency feeder cables can be replaced by a high speed digital interface most often implemented through an optical fibre connection. This connection is called a front haul link. While a front haul link can be quite long, this architecture opens up the possibility for co-location of the part containing the control and digital signal processing functionality belonging to several base stations. In this case some of the traditional backhaul that had been used to reach each site can be replaced by front haul to reach the same sites.

The possibility to centralize base station functionality also opens up the possibility for increased coordination of the signals transmitted from different remote radio units that would normally have belonged to different base stations, something that can increase the capacity of the system. With the introduction of the Cloud RAN concept (C-RAN) this is taken even further. In a C-RAN based network the control and digital signal processing functionality of all base stations in an area is centralised into the equivalent of a data centre. This can have several advantages but it has some specific implications when it comes to backhaul requirements.

¹³ Support for LTE category 9

The introduction of a **C-RAN based network would in practice eliminate the need for local backhaul** by which all the end user data traffic is usually delivered to and from the centralised location. **The sites in the radio network are instead connected by even higher speed front haul** links running between the centralised location and each remote radio unit.

With access to all information about the radio network and the end users at the same point it would also be possible to optimise the network in new ways, for example coordination of the signals transmitted from different remote radio units to minimise internal interference or cooperatively transmitting data to the same user from antennas in different locations. It could also have advantages when coordinating the operation of the macro cellular and the small cell layer of a het net while both layers would be implemented by the same C-RAN.

To be effective all this coordination will however require that the front haul link has low latency and allows for tight synchronisation of the different remote radio units.

Dense urban areas

In dense urban areas it would normally be possible to utilize all frequency bands that are licensed to the mobile operators. Frequency bands below 1 GHz are good to achieve deep indoor coverage while higher frequency bands can be used for increasing the network capacity. Most operators will in the time frame 2015 to 2020 have access to a mix of frequency bands that they will be able to utilize in this environment. This, in combination with technology enhancements, is expected to drive up backhaul requirements.

Upgrades of the rooftop macro cellular network and macro cell densification:

Applying LTE Advanced carrier aggregation, adding new frequency channels and increases in the MIMO configuration of the current rooftop macro cellular could substantially increase capacity of the network. Combining three 20 MHz downstream channels and 4x4 MIMO would allow for a theoretical 900 Mbit/s peak data rate on a single cell/radio interface.

For a normal three sector site and taking account of the statistical variation of the aggregated real user speeds¹⁴ this could translate into a 1 Gbit/s requirement on the backhaul.

Looking forward towards 2020 introduction of 8x8 MIMO could yet again double the theoretical peak data rate compared with a 4x4 based system. Using three 20 MHz downstream channels and 8x8 MIMO would result in a theoretical 1800 Mbit/s peak data rate. Aggregating more than 3 channels could also further enhance the speed and capacity of the network, by aggregating five 20 MHz channels instead of three, theoretical peak data rates of 1500 Mbit/s for a 4x4 MIMO configuration and 3000 Mbit/s for a 8x8 MIMO configuration could be envisioned. Base stations with maximum configuration could therefore in the end of the period push the requirement towards the 2 Gbit/s for such high capacity sites. In case of dense urban deployment the expected hop length can be expected to be quite short in the range of 1 km or below.

Another way to increase the capacity is further densification of the macro cellular rooftop network, making the coverage area for each base station even smaller. There are already high density areas where the inter site distance is in the 200-300 m range¹⁵. If fibre backhaul is not

¹⁴ The theoretical peak data rate is normally only achievable in a low percentage of locations within the coverage area and is therefore not representative of the capacity of the system or the normal average bitrates experienced by an end user. But to maximise the throughput and minimise the latency of the system it is normally required that the backhaul should at least be able to deliver data at the same rate as the peak data rate of one sector can transmit the bits to an end user. Taking account of statistical averaging between the different sectors of a site with more than one sector means that the increase beyond the requirement for a one sector site can be kept low.

¹⁵ For example: downtown Stockholm

readily available in such an area a short haul high capacity wireless link to a nearby base station with a fibre connection could be an attractive solution.

Het net, in cell densification

As mentioned above further densification might not be practical or economically viable past a certain point due to a scarcity of new available rooftop sites or due to the fact that the macro cellular network is already very dense.

While many of the macro sites will have a fibre connection, one possibility for sites without fibre will be to connect these small cells in dense urban areas with short haul wireless backhaul. With the small cells at or near street level and the macro cell sites on rooftops, achieving line of sight could however be problematic. NLOS or multi hop solutions might be required. Small cells are normally expected to be single sector implementations but could support multiple bands and integrated carrier WiFi support. This means that small cells can be expected to require a backhaul capacity of several hundred of Mbit/s at the end of the targeted period.

As mentioned above there are also a number of supporting technologies targeted at increasing the spectral and cell edge efficiency of the network, some of these technologies require low latency and/or tight time synchronization of the base stations adding more requirements on the backhaul.

Rural areas

In rural areas with low population densities inter site distances are normally much larger. Normal inter site distances in such areas range from a few km (in more densely populated countries) up to 15 km (e.g. in the Nordic countries). A major difference compared with non-rural areas is the relative lack of infrastructure and base stations are normally sited on a dedicated mast. Macro cell densification can therefore be a more expensive strategy in these areas since in many cases it would require the construction of new masts. To achieve good coverage with relatively large inter site distances sub 1 GHz frequency bands are normally utilized.

In most countries the 800 MHz and some parts of the 900 MHz bands can be expected to be available for mobile broadband in 2015 and beyond. The amount of spectrum available for mobile broadband will depend on to which extent refarming can be achieved by different operators. In some countries there will also be the possibility to use the 700 MHz band.

An operator upgrading to LTE-Advanced in the 2015-2020 period could decide to combine frequency channels in multiple sub 1 GHz bands making it possible to support 15-30 MHz aggregated channel bandwidths. If there are margins when it comes to load and wind load of the mast, adding more antennas could facilitate a number of different capacity enhancing solutions. With a 4x4 MIMO configuration this would allow for a theoretical 225-500 Mbit/s peak data rate on a single cell/radio interface. For a normal three sector site and taking account of the statistical variation of the aggregated real user speeds this could translate into a 200-500 Mbit/s requirement on the backhaul at the end of the period.

Requirements on wireless backhauling up until 2020

One extreme for backhaul the requirements would be the dense urban case. For macro base stations in dense urban areas a substantial increase in the required capacity can be expected running from about one Gbit/s to a few Gbit/s at the end of the period. Hop lengths to reach a fibre connected point are expected to be short.

For small cells, capacity requirements from tens of Mbit/s up to several hundreds of Mbit/s could be expected. These requirements might also in some cases be combined with low latency requirements and/or requirements to support tight time synchronization.

The other extreme for requirement would be in rural areas where hop lengths are still expected to be quite long in the range a few km up to 15 km. It is however expected that the backhaul connecting these sites will have a substantially lower capacity requirement in the range of several hundreds of Mbit/s.

It should also be noted that the majority of mobile sites will have backhaul requirement which lie between these two extreme cases. In these cases the capacity requirement is expected to be more moderate and the hop lengths in the low km range which is expected to be easier to handle.

ANNEX 2

HIGH LEVEL DESCRIPTION OF 5G

It would be difficult to effectively address all the different requirements with one single radio access technology. Due to this 5G may not be based on a single new radio access technology but rather make use of a combination of different radio access technologies connected to a common core network. These different radio access technologies are expected to be both further evolutions of current available technologies such as UMTS, LTE, LTE-Advanced and WiFi, but might include new radio access technologies especially targeted to address requirements that would be difficult to fulfil with the development of current radio access technologies.

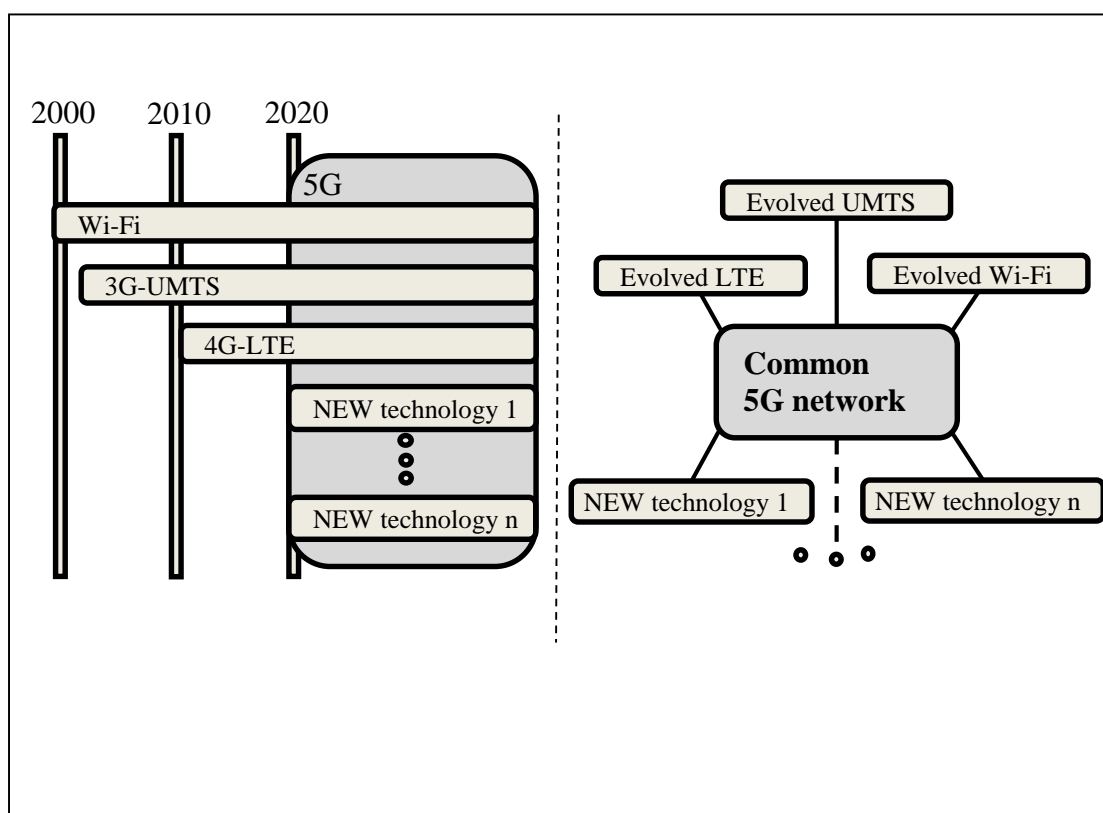


Figure 2: High level concept of 5G

5G is expected to be reusing all the current and planned frequency bands up to 6 GHz that will be available for mobile operators in 2020, in most cases using future developments of 3G/4G. It is also expected that some WiFi bands (60 GHz band) may be used by 5G networks.

ANNEX 3

NETWORK EVOLUTION

Network architecture evolution

Wireless backhaul is evolving as the existing 2G and 3G network's base stations (BTS and NodeB) were originally connected to controllers (BSC and RNC) via multiple 2Mbit/s transmission links (E1s) provided in both Plesiochronous & Synchronous Digital Hierarchies (PDH and SDH)variants by both fixed and wireless transmission networks.

These new mobile systems will no longer generate TDM traffic (e.g. building up PDH and SDH hierarchies) as mostly used in current mobile systems (GSM and 3G) but will directly use Packet data traffic (e.g. IP/Ethernet).

Also the fixed transport infrastructure is migrating to Ethernet traffic transport, with the consequence of having the actual payload capacity that varies continuously according to the load.

The move to a flatter network architecture in 4G with an Evolved base station (eNode B) connecting directly to a Mobility Management Entity/Evolved Packet Core MME/EPC together with increased speed and latency demands, requires a multi service backhaul network to a macro site supporting both the legacy E1 and new Ethernet services (100 Base T, 100 Base FX and Gig- E).

Finally, Cloud RAN services are also being deployed making use of the X2 interface linking eNB plus (CPRI) Common Public Radio Interface or Radio over Glass solution both requiring tight controls over timing, latency and jitter control. This combination of high speed and tightperformance characteristics is largely met today with dark fibre.

Microwave network topology evolution¹⁶

Microwave networks have historically relied on daisy chain and tree backhaul topologies, as shown in the top portion of the following figure, even though the benefits of rings over these linear topologies were well known:

- Since traffic can be sent in two directions around a ring, the load capacity of the ring is effectively doubled when no failures exist.
- Rings offer a reduction in protection CAPEX spend since each ring site has two paths around a ring, this eliminates the need for fully protected aggregation sites that have only one path to the broader network.

The main reason for the reluctance to deploy ring architectures in the past was due to bandwidth inefficiencies. Specifically protection bandwidth had to be reserved, bandwidth that could not be optimally used when no failures in the network were present. This wasn't a limitation in higher capacity fibre networks, but it was a severe limitation when trying to

¹⁶ Draft new Report ITU-R F.[FS USE-TRENDS]

leverage scarce microwave spectrum. Hence, rings never emerged as a widely deployed microwave network topology.

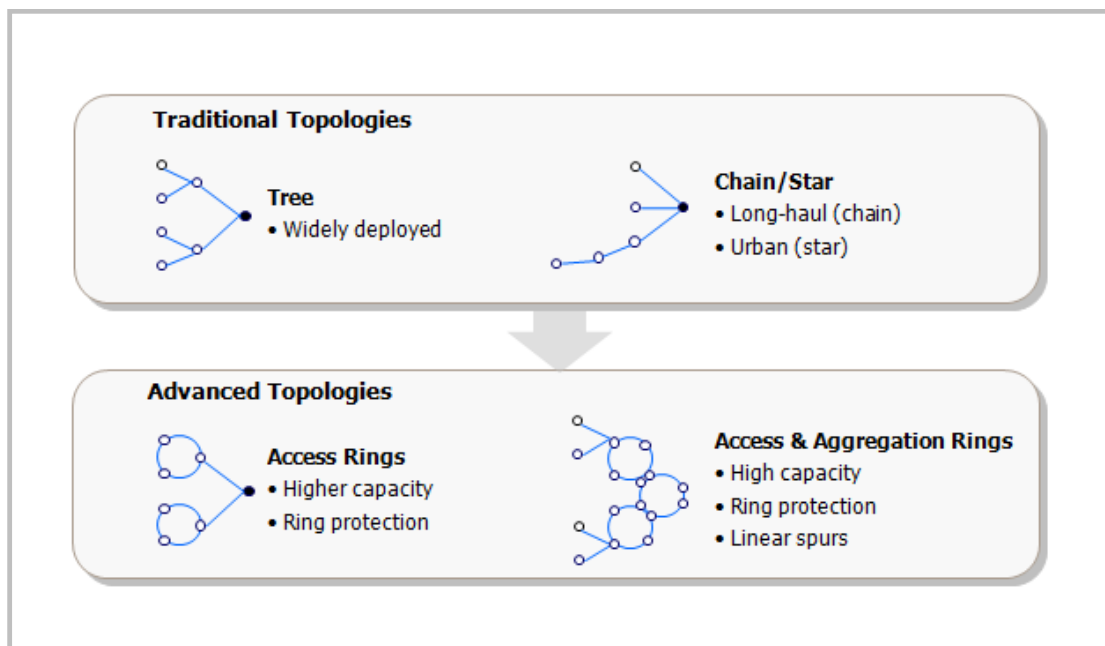


Figure 3 Microwave network topology evolution

ANNEX 4

TECHNOLOGY TRENDS AND SPECTRUM EFFICIENCY IN FS SYSTEMS

Draft new Report ITU-R F.[FS USE-TRENDS] and ECC Report 173 contains relevant information with regard to the techniques applied in FS systems to improve spectrum efficiency listed below. Beside these two documents further technical details can be found in ECC Report 198 and ECC Report 211 on adaptive modulation and asymmetric P-P links, respectively.

I. Modulation

Advances in the area of modulation and coding (error correction) technology, are having a profound effect on the increase of capacities of P-P links. Today modulation schemes of as high as 128-QAM are used widely for trunk/infrastructure networks and modulation as high as 16-QAM is increasingly used for access links. New equipment can cope with modulation formats up to 512-QAM and the introduction in the market of 1024-QAM systems is expected shortly.

It should be noted however that according to some industry players, the use of modulation formats above 256 / 512 QAM will not bring any spectrum efficiency benefit. Indeed:

- The relation between modulation format and capacity, expressed in bits per symbol shows that the theoretical capacity increase reduces significantly above 256 / 512 QAM. For instance, transmission capacity at 16 QAM is twice that at 4 QAM while to double the capacity of a 256 QAM modulation would require a modulation format of 65 536 QAM, which is unrealistic. From a 256 QAM modulation to a 1024 QAM modulation, the increase is only of about 15%.
- Very high modulation format systems are very sensitive to equipment imperfections (e.g., phase noise of local oscillators, which is then costly in terms of redundancy which in turn decreases the actual data transmission).

Adaptive modulation

Adaptive modulation is a technology in which the modulation formats are dynamically changed (errorless for the relevant payload fraction) according to the propagation conditions; this permits to design a link with a defined availability for a uniquely predefined modulation format (the “reference mode”) and having the payload capacity enhanced during good propagation time and, if desired, further reduced, but with even higher availability, during abnormally adverse propagation.

The new services offered to the end-user, over IP based platforms, are going to evolve with different degrees of quality (pay for quality) from the simplest “best effort” to different increasing degrees of guaranteed traffic availabilities. Adaptive modulation algorithm perfectly fits the quality requirement and allows the use of high modulation schemes even in access links. AM is used to dynamically increase radio throughput by scaling modulation schemes (e.g. 4-QAM → 64-QAM → 256-QAM) according to the current propagation condition.

In case of high capacity links adaptive modulation can be used to further increase link availability, for the high priority fraction of the payload, by means of scaling down to lower modulation formats (e.g. 256-QAM \rightarrow 64-QAM \rightarrow 4-QAM) during fading condition.

II. ATPC

Systems employing Automatic Transmit Power Control have a range of transmit attenuation dynamically variable with the propagation effects. Total range(s), activation threshold(s) and attenuation dynamics may also be software programmable.

The possible introduction of ATPC can be a method for enhancing the spectrum usage

III. Bandwidth adaptive systems

Bandwidth adaptive systems can dynamically (on the basis of RSL and other built-in quality parameters) smoothly switch between different bandwidth with the same modulation formats, increasing/decreasing the payload capacity accordingly. In principle, the output power is kept constant because there is no change in equipment linearity; therefore, in contrast to adaptive modulation systems, bandwidth adaptive systems might not have ATPC built-in functions.

These systems are mainly used for high capacity systems in EHF bands (e.g. 60 and 70/80 GHz) where the radio frequency technology does not (yet) permit the use of high level modulation formats (only the simplest 2 or 4 levels would be practical).

In principle, this technology might be combined with adaptive modulation functionality (e.g. switching also between PSK and QPSK). Still in principle, this technology might also be added to (full) adaptive modulation systems for further enhancing the link availability for a very limited portion of payload (beyond the minimum modulation format).

IV. Polarization

The use of Cross-Polarization Interference Cancellation (XPIC) to double capacity in Co-Channel Dual-Polarization (CCDP) applications is already a well consolidated technique and should also be more and more utilised.

Polarization multiplexing

This method has been commercially available for point-to-point microwave links in the access network since mid-2000. It involves two single-carrier radios transmitting on the same frequency channel but with orthogonal polarizations (horizontal and vertical). Because the radios share the same carrier frequency, they can use a single dual polarised antenna. Ideally, the two polarizations are completely isolated from each other. Signal leakage can occur due to rotational misalignment between the antennas. In practice, it is difficult to achieve better isolation between the two polarizations than 25dB. Certain weather conditions, such as heavy rain, may further reduce the level of isolation that can reasonably be achieved. However, by sharing the received signal between the two modems, it is possible to cancel the interfering polarization using digital signal processing. This technique is referred to as cross-polarization interference cancellation (XPIC).

V. MIMO

This is a technology currently looked at for MWA systems; however, it can be effectively applied for P-P links in higher bands, e.g. above 15 GHz, where the required spatial distance of the various antennas becomes practical.

Line-of-sight MIMO

MIMO is a well-known technology for increasing spectral efficiency in WiFi and RANs. An $N \times N$ MIMO system comprises N transmitters and N receivers with the potential to simultaneously transmit N independent signals. For example, a 2×2 MIMO system contains two transmitters and two receivers, and can transport two independent signals, thus doubling the link's capacity. The basic principle of MIMO is that a signal will use different paths between transmitters and receivers. In conventional MIMO systems, the difference in path is achieved through reflexes in the environment. For microwave links, it is not possible to take advantage of objects in the environment because these links, by definition, are operated in LoS mode with highly directional antennas. In contrast, because the carrier frequencies for microwave links are high, it is possible to design a 2×2 MIMO channel with a phase difference of 90 degrees between short and long paths by spatially separating the radio antennas. This is commonly referred to as a LoS MIMO system.

VI. Adaptive antenna systems

Near future evolution in the antenna technology may be related to the deployment of new mobile access networks, LTE and 4G, which will use smaller size cell footprint, especially in urban areas, the backhauling will require denser and shorter link networks. In addition equipment may be installed on light poles at street level and shall not have a large visual impact. This will drive the use of smaller antenna which would likely be integral to the equipment itself.

Adaptive antenna systems could help greatly in link activation and compensate for slight modifications in pointing due to pole vibrations and bending for various unpredictable reasons (road works, car accidents, etc.); it could possibly help in reducing effect of multipath reflections from nearby buildings.

The consequent loss of directivity might be compensated using steering antenna, which can keep pointing in an adaptive way even in an urban and changing environment where poles can be bent causing pointing misalignment.

Furthermore, active antennas may also be driven by "beam-forming" algorithms in order to minimise interference, i.e. minimizing the gain in the direction of the main interferer. This might be of major interest in dense urban environment for street level base station backhauling where reflection/diffraction phenomena become important.

VII. Full duplex radios (echo cancellation)

Traditionally radio systems used for bidirectional communication have used Frequency or Time Division Duplexing to handle the fact that some of the transmitted signal will leak back into the receive path of the transceiver. In the FDD case this is handled by attenuating the signal that leaks into the duplex band that is used for reception with steep filters. In the TDD case you avoid transmitting and receiving at the same time thereby eliminating the risk that the transmitted signal could interfere with the received signal.

This means that for the FDD case only one of the two available frequency channels will be used to transmit data in a certain direction. And for TDD it means that only a part of the available time will be used to transmit data in a certain direction. For a symmetrical point to point link this would translate into that about half of the occupied frequencies would be used to transfer data in one direction for FDD and about half of the time would be used transfer data in one direction for TDD.

This is however not an inherent limitation in radio communication, but this self-interference is an imperfection in the design of radio transceivers and antenna systems. If you could eliminate the signal leakage from the transmitter into the receiver, you could transmit and receive at the same time on the same frequencies.

The theoretical method of using Echo cancellation techniques to solve this problem has been known for a long time. But the technical problem in relation to achieving the necessary suppression of the transmitted signal has been too difficult to handle in real life implementations.

This might however change as recent research results have been able to demonstrate real life implementations that achieves suppression levels that would allow for full duplex operation in certain applications¹⁷. Continued research is expected to bring yet further improvements. WLAN, point to point links and 5G are areas that have been mentioned as suitable targets for future full duplex operation¹⁸.

Full duplex operation could in theory double the spectrum efficiency thereby cutting the required frequency need for wireless backhaul in half. Full duplex operation would however have implications on the radio planning that could lower the real gain. Packing more transmitters into the same frequency space could lead to an increased risk of interference something that in high density environments might lead to restrictions on which site could be used thereby decreasing the real life gain.

It should also be noted that using the same cancelation/suppression technologies between two adjacent radio interfaces could allow for frequency reuse in the same place as long as the antennas can maintain enough separation. Possible use cases could be frequency reuse 1 for multiple full duplex point to point links at the same site and full duplex backhaul in the same frequency band that is used for mobile access especially for small cell deployments.

¹⁷ Full duplex radios, <http://web.stanford.edu/~skatti/pubs/sigcomm13-fullduplex.pdf>

¹⁸ Possible use cases for full duplex radio, <http://kumunetworks.com>

VIII. Asymmetrical point-to-point links

It is recognised that with the move to more data intensive applications by mobile users the consequent traffic in the access network has become asymmetric in nature, with more data being downloaded than uploaded. Whilst it is agreed that the amounts of data are application dependant and that new applications such as cloud computing, instant messaging, VoIP and social networking, might still change this trend, the impact of current asymmetry trends in the access network on the backhaul network is an important issue that has to be dealt with. It should be noted that whilst the presence of asymmetry in the access network is agreed, the degree of this asymmetry differs from operator to operator based on the services offered.

All sources recognize that a certain degree of asymmetry is always present, but actual figures are significantly different. Therefore, a unique asymmetry definition seems not possible to be determined; however, this can be done on a case-by-case basis, if the operator wish to pre-define the asymmetry degree expected in his network.

As described in ECC Report 211 one of the prime motivators in allocating spectrum for bi-directional links in an asymmetric manner is a potential saving of spectrum. This saved spectrum must be available for re-use, ideally also for other symmetric point-to-point applications, and not left orphaned.

With existing tools and processes, with fixed duplex spacing, the ability to re-use the saved spectrum appears to be limited. On the other hand, fully flexible duplex spacing that can be configured to any required size is impractical from a radio design perspective, therefore a compromise situation needed to be found.

It should be noted that even if the asymmetry of the traffic may justify the use of asymmetrical links in mobile backhauling, symmetric links will continue to be needed in networks and other point-to-point applications.

An important factor that should be taken into account with regard to the asymmetry deployment is the co-existence of symmetrical links with asymmetrical links within the same band and thus the same band plan.

In principle, channel arrangements could be completely redesigned in order to maximise the flexibility of the asymmetric deployment; however, the following considerations should be taken into account:

- All bands available for P-P licensed links are regulated by current channel arrangements and a large number of existing symmetric links are in place;
- Therefore, the new channel arrangement should in any case also provide symmetric channels of various sizes;
- That asymmetric channels would still need a set of various channel sizes and of different degrees of go/return asymmetry.

The approach of completely new channel arrangement might be considered only for newly opened (or emptied) bands. In addition a suitably flexible design seems very complex and possibly resulting with small or no benefit with respect of the “compatible” use of current arrangement.

ANNEX 5

FREQUENCY BANDS WHERE HIGHER CHANNEL WIDTHS HAVE RECENTLY BEEN INTRODUCED

Reference	Date	Frequency band	Channels <u>before</u> ECC REC revision	Channels <u>after</u> ECC REC revision	Remarks
ECC/REC(01)04	May 2014	40.5 - 43.5 GHz (42 GHz)	112 MHz, 56 MHz, 28 MHz, 14 MHz and 7 MHz	224, 112 MHz, 56 MHz, 28 MHz, 14 MHz and 7 MHz	
ECC/REC 12-11	January 2015	48.5 – 50.2 GHz (50 GHz) 51.4 - 52.6 GHz (52 GHz)	56 MHz, 28 MHz, 14 MHz, 7 MHz and 3.5 MHz	112 MHz, 56 MHz, 28 MHz, 14 MHz, 7 MHz and 3.5 MHz	This January 2015 update of ERC/REC 12-11 includes a possible pairing of the 50 GHz and 52 GHz bands providing inter alia 7 channels of 224 MHz and 14 channels of 112 MHz
ECC/REC 12-12	January 2015	55.78 – 57.0 GHz (56 GHz)	56 MHz, 28 MHz, 14 MHz, 7 MHz and 3.5 MHz	112 MHz, 56 MHz, 28 MHz and 14 MHz	