International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Report ITU-R F.2393-0

(11/2016)

Use of fixed service for transport of traffic, including backhaul, for IMT and other terrestrial mobile broadband systems

F Series

Fixed service

International Telecommunication Union

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from http://www.itu.int/ITU-R/go/patents/en where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

Series of ITU-R Reports

(Also available online at http://www.itu.int/publ/R-REP/en)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	Broadcasting service (television)
F	**Fixed service**
M	Mobile, radiodetermination, amateur and related satellite services
P	Radiowave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management

***Note**: This ITU-R Report was approved in English by the Study Group under the procedure detailed in Resolution ITU-R 1.*

Electronic Publication
Geneva, 2017

REPORT ITU-R F.2393-0

Use of fixed service for transport of traffic, including backhaul, for IMT and other terrestrial mobile broadband systems

(Question ITU-R 247/5 and Question ITU-R 253/5)

(2016)

1 Scope

The aim of this Report is to show how the FS can be used in support of IMT and other mobile broadband systems, in order to ensure the fixed service links at the base-station level, and between base stations and higher-level nodes within the transport network, as well as between nodes in the core network requiring similar connection capabilities.

2 Introduction

As traffic demands for mobile broadband communications, represented in particular by International Mobile Telecommunications (IMT), including both IMT-2000 and IMT-Advanced as defined in Resolution ITU-R 56[1], are increasing, fixed service (FS) use in the transport network in the mobile infrastructure is becoming an important application that requires special consideration.

The fixed service transport network supports the connections between the different base stations of the mobile broadband network, as well as the connections of one base station to other network elements of the mobile infrastructure.

Even though ever-increasing traffic requirements are generally best addressed by using fibre for backhaul, it may not be technically and/or economically feasible in every case. For example fixed wireless transport is predominantly used in urban areas (for small cells), and in semi-rural and rural areas, as well as along highway corridors where fibre is not readily available. In such cases, fixed wireless systems can be used and serve equivalently as fibres.

FS use is necessary to support the operation of IMT and other terrestrial mobile broadband networks in the transport network. Depending on the evolution of IMT and the required transmission capacities at different levels of the transport network, different FS frequency bands are needed.

This Report gives possible structures of point-to-point (P-P) FS transport networks including an outline of the needs of IMT-2000 and IMT-Advanced. The Report also examines the possible use of already allocated FS spectrum. Regardless of the transmission network capacity, the choice of frequency bands depends on the local situation of the various countries (existing deployment of the frequency bands, number of mobile (IMT) operators, traffic, etc.).

3 References

The reader will find additional guidance in the references listed below:

Recommendation ITU-R F.382:	Radio-frequency channel arrangements for fixed wireless – systems operating in the 2 and 4 GHz band

1 Resolution ITU-R 56, "Naming for International Mobile Telecommunications."

Recommendation ITU-R F.383:	Radio-frequency channel arrangements for high-capacity fixed wireless systems operating in the lower 6 GHz (5 925-6 425 MHz) band
Recommendation ITU-R F.384:	Radio-frequency channel arrangements for medium- and high- capacity digital fixed wireless systems operating in the 6 425-7 125 MHz band
Recommendation ITU-R F.385:	Radio-frequency channel arrangements for fixed wireless systems operating in the 7 110-7 900 MHz band
Recommendation ITU-R F.386:	Radio-frequency channel arrangements for fixed wireless systems operating in the 8 GHz (7 725 to 8 500 MHz) band
Recommendation ITU-R F.387:	Radio-frequency channel arrangements for fixed wireless systems operating in the 10.7-11.7 GHz band
Recommendation ITU-R F.497:	Radio-frequency arrangements for fixed wireless systems operating in the 13 GHz (12.75-13.25 GHz) frequency band
Recommendation ITU-R F.595:	Radio-frequency arrangements for fixed wireless systems operating in the 17.7-19.7 GHz frequency band
Recommendation ITU-R F.635:	Radio-frequency arrangements based on a homogeneous pattern for fixed wireless systems operating in the 4 GHz (3 400-4 200 MHz) band
Recommendation ITU-R F.636:	Radio-frequency arrangements for fixed wireless systems operating in the 14.4-15.35 GHz band
Recommendation ITU-R F.637:	Radio-frequency arrangements for fixed wireless systems operating in the 21.2-23.6 GHz band
Recommendation ITU-R F.746:	Radio-frequency arrangements for fixed service systems
Recommendation ITU-R F.747:	Radio-frequency arrangements for fixed wireless system operating in the 10.0-10.68 GHz band
Recommendation ITU-R F.748:	Radio-frequency arrangements for systems of the fixed service operating in the 25, 26 and 28 GHz bands
Recommendation ITU-R F.749:	Radio-frequency arrangements for systems of the fixed service operating in sub-bands in the 36-40.5 GHz band
Recommendation ITU-R F.758:	Considerations in the development of criteria for sharing between the terrestrial fixed service and other services
Recommendation ITU-R F.1099:	Radio-frequency arrangements for high- and medium-capacity digital fixed wireless systems in the upper 4 GHz (4 400-5 000 MHz) band
Recommendation ITU-R F.1245:	Mathematical model of average radiation patterns for line-of-sight point-to-point radio-relay system antennas for use in certain coordination studies and interference assessment in the frequency range from 1 to about 70 GHz
Recommendation ITU-R F.1399:	Vocabulary of terms for wireless access
Recommendation ITU-R F.1496:	Radio-frequency channel arrangements for fixed wireless systems operating in the band 51.4-52.6 GHz
Recommendation ITU-R F.1497:	Radio-frequency channel arrangements for fixed wireless systems operating in the band 55.78-66 GHz

Recommendation ITU-R F.1520: Radio-frequency arrangements for systems in the fixed service operating in the band 31.8-33.4 GHz

Recommendation ITU-R F.1568: Radio-frequency arrangements for fixed wireless access systems in the range 10.15-10.3/10.5-10.65 GHz

Recommendation ITU-R F.2004: Radio-frequency channel arrangements for fixed service systems operating in the 92-95 GHz range

Recommendation ITU-R F.2005: Radio-frequency channel and block arrangements for fixed wireless systems operating in the 42 GHz (40.5 to 43.5 GHz) band

Recommendation ITU-R F.2006: Radio-frequency channel and block arrangements for fixed wireless systems operating in the 71-76 and 81-86 GHz bands

Recommendation ITU-R F.2086: Deployment scenarios for point-to-point systems in the fixed service

Recommendation ITU-R M.1224: Vocabulary of terms for International Mobile Telecommunications (IMT)

Recommendation ITU-R M.1390: Methodology for the calculation of IMT-2000 terrestrial spectrum requirements

Recommendation ITU-R M.1457: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications-2000 (IMT-2000)

Recommendation ITU-R M.1645: Framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000

Recommendation ITU-R M.1768: Methodology for calculation of spectrum requirements for the terrestrial component of International Mobile Telecommunications

Recommendation ITU-R M.2012: Detailed specifications of the terrestrial radio interfaces of International Mobile Telecommunications Advanced (IMT-Advanced)

Recommendation ITU-R P.530: Propagation data and prediction methods required for the design of terrestrial line-of-sight systems

Recommendation ITU-R P.676: Attenuation by atmospheric gases

Recommendation ITU-R P.837: Characteristics of precipitation for propagation modelling

Recommendation ITU-R P.838: Specific attenuation model for rain for use in prediction methods

Report ITU-R F.2107: Characteristics and applications of fixed wireless systems operating in frequency ranges between 57 GHz and 134 GHz

Report ITU-R F.2323: Fixed service use and future trends

Report ITU-R M.2243: Assessment of the global mobile broadband deployments and forecasts for International Mobile Telecommunications

Report ITU-R M.2292: Characteristics of terrestrial IMT-Advanced systems for frequency sharing/interference analyses

Report ITU-R M.2375: Architecture and Topology of IMT Networks

Report ITU-R M.2370: IMT Traffic estimates for the years 2020-2030

Handbook on Land Mobile (including Wireless Access) – Volume 5: Deployment of Broadband Wireless Access Systems: http://www.itu.int/pub/R-HDB-57

Handbook on Deployment of IMT-2000 systems: http://www.itu.int/pub/T-HDB-MOB.01-2003/en

Handbook on Global Trends IMT:	http://www.itu.int/pub/R-HDB-62
ECC Report 173:	Fixed Service in Europe, Current use and future trends post 2011 (http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCRep173.PDF)

4 List of acronyms and definitions

4.1 List of acronyms

eNB	evolved Node B
FS	Fixed service
IMT	International Mobile Telecommunications
IMT-2000	International Mobile Telecommunication-2000
IMT-Advanced	International Mobile Telecommunications-Advanced
IPsec	Security architecture for Internet Protocol
MME	Mobile management entity
NLoS	Non-line-of-sight
P-P	Point-to-point
QAM	Quadrature amplitude modulation
QoE	Quality of experience
QoS	Quality of service
RAN	Radio access network
RRH	Remote radio head
SGW	Serving gateway

4.2 Definitions

Transport: The functional process of transferring information between different locations.

The connection or network of connections between network elements allowing for the transfer of information.

NOTE – In some descriptions of IMT networks, transport can be categorized as backhaul, midhaul[2] or fronthaul.

Backhaul: Link connection between the base station and higher level network elements.

NOTE – In an IMT-Advanced network, the connection between an eNB and higher level network elements (such as mobile management entity (MME) and serving gateway (SGW)) carrying S1 interface.

Fronthaul: Link connection between the base station baseband and remote radio head (RRH).

NOTE – In an IMT-Advanced network, the connection between a data processing/control unit and a remote radio head within one eNB carrying CPRI/ORI interface.

2 Some standards organizations use the term 'midhaul' to refer to the link connection between different base stations, typically between macro and small base stations and with tighter performance requirements than backhaul.

5 Impact of mobile broadband networks on fixed transport network requirements

In the development of IMT and other terrestrial mobile broadband applications, it is envisioned that different radio access systems will be connected via flexible core networks. IMT-Advanced will influence the evolution of fixed wireless transport networks. Besides the requirement to transport larger quantities of traffic, which will be discussed in § 6, it is expected that IMT-Advanced deployments will use different cell radii than IMT-2000. As mobile broadband moves to IMT-Advanced and beyond with the increased implementation of small cells, there is a need to have access to wireless short-haul very high capacity links in urban areas close to users where in many cases fiber is not available.

5.1 IMT-Advanced network evolution and associated transport requirements

To be able to assess the transport requirements in IMT networks it is important to understand the evolving radio access network growth strategies and deployments, which will have an impact on the fixed wireless solutions. The latest information on the architecture, topology and transport requirements of IMT networks can be found in Report ITU-R M.2375. More specifically, the cell structure for IMT-Advanced networks is available in Report ITU-R M.2292. Parts of the essence of these IMT-related ITU-R texts are provided in Annex 1 to this Report for information.

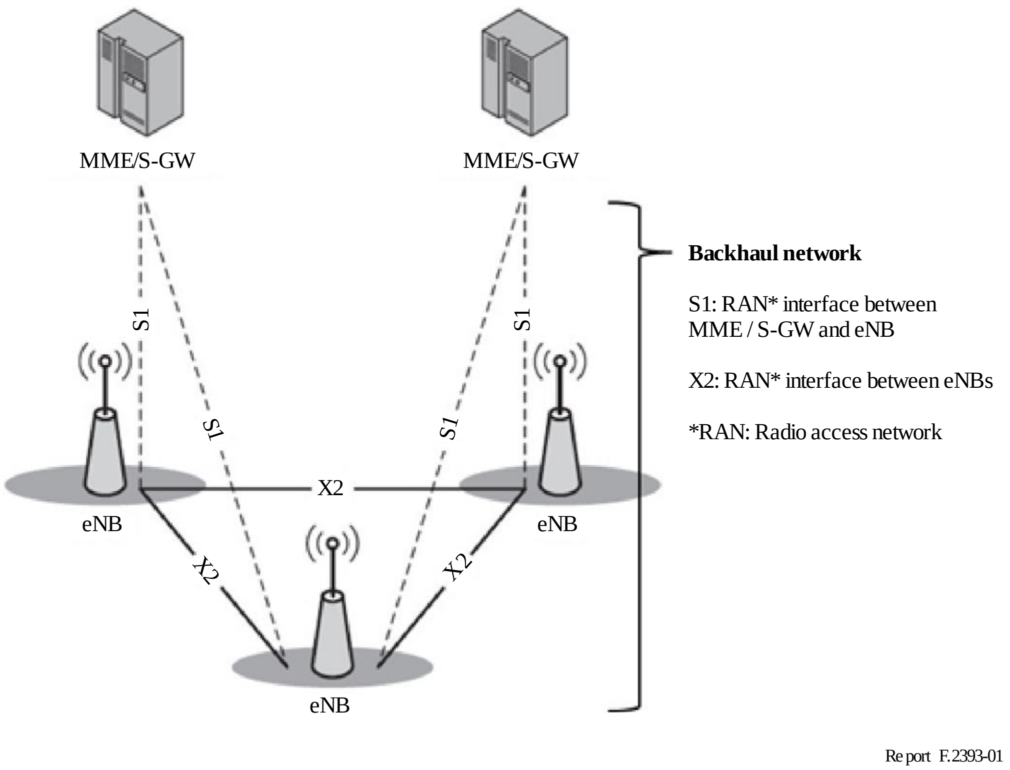
5.1.1 Cell structures for IMT-Advanced network[3]

In the Evolved Universal Terrestrial Radio Access Network (E-UTRAN), the evolved Node Bs (eNBs) are interconnected with each other by means of the X2 interface. The eNBs are also connected by means of the S1 interface to the EPC (Evolved Packet Core, i.e. MME or SGW). The E-UTRAN architecture is illustrated in Fig. 1 below.

[3] Based on 3GPP technical specification as reflected in Report ITU-R M.2375.

FIGURE 1

E-UTRAN architecture
(Reproduced from Figure 4.2.1-1 in Report ITU-R M.2375)



The use of remote radio heads, as shown in Fig. 2, illustrates the actual usage of fronthaul, especially for the following purposes:

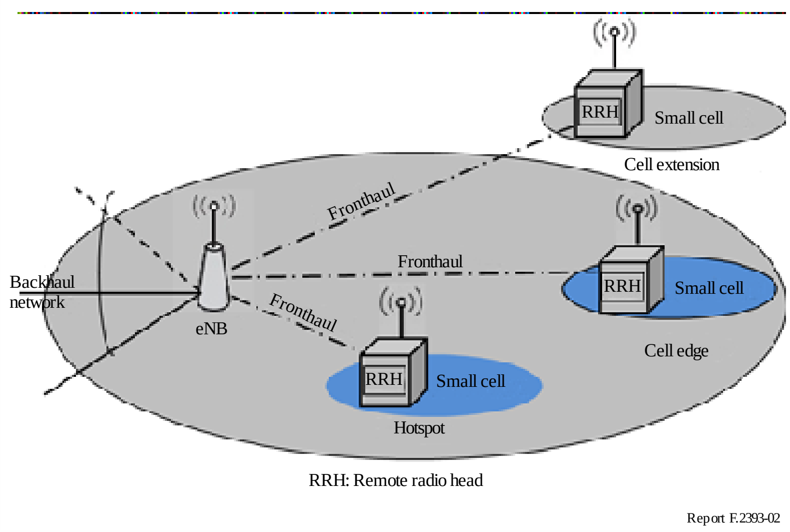
– boosting capacity by adding small cells within an existing macro eNB footprint, in this case remote radio heads may be deployed in hotspots or cell edges and heterogeneous networks are constructed (see Annex 1); or

– extending a macro footprint by deploying small cells out of its footprint;

– solving lack of sufficient RF coverage (RF deadspot) within macro footprint.

FIGURE 2

Actual usage of fronthauls in IMT-Advanced network



In many cases of the above mentioned scenarios, it will not be technically and/or financially viable to deploy wireline based transport (fiber optic, cable, etc.) to connect small cells together and with upper level nodes. Therefore, wireless transport may become the only effective alternative to provide this important link. It will be subject to the same constraints as the small cells in terms of location, space and power.

Another important aspect, also covered in more detail in Annex 1, is latency. The endless race to maximize the use of spectrum, by including deployment of small cells, requires tight coordination with macro cells and upper level nodes. This creates the need to account for delay variations and synchronization. Wireless transport must not become the bottleneck and should avoid impacting the quality delivery of services to users.

In considering the capacity aspects of future transport links, information on the expected increase in IMT traffic is needed. In this regard, Report ITU-R M.2243 – Assessment of the global mobile broadband deployments and forecasts for International Mobile Telecommunications, concluded that global mobile traffic in the world would represent more than 30 times increase during this decade (2010-2020). Furthermore, this global mobile traffic is estimated to continue to increase more than 70 times by the year 2030 according to Report ITU-R M.2370, particularly due to the expansion of video and M2M applications. Such traffic growth will certainly impact the transport capacity requirements of mobile networks.

5.1.2 New transport requirements

As shown in the previous section, changes foreseen in IMT networks and traffic are driving required modifications in transport networks. However, a number of challenges must be overcome in order to support mobile broadband networks.

1) Transporting more traffic to accommodate the increases in data throughput required by users.

2) Transporting this traffic with low latency, in order to prevent negative impact on the users' quality of experience (QoE).

Specifically for small cell and small cell extensions:

3) Cost effectiveness, ease of installation, and size of footprints, as large number of new small cells are expected to address the demand for mobile broadband growth beyond the traditional densification by cell splitting.

4) Deployment challenges may necessitate the use of a new form factor antenna.

Section 6 will explore the various existing FS frequency bands that can support these requirements.

5.2 Other mobile broadband network evolution and associated transport requirements

For terrestrial mobile broadband networks, including IMT, the topology/configurations of their transport networks are described in the "Handbook on Land Mobile (including Wireless Access) – Volume 5: Deployment of Broadband Wireless Access Systems".

6 FS transport network applications

In this section, the fixed service frequency bands and their appropriateness/usability for handling traffic from IMT and other terrestrial mobile broadband systems are reviewed. Included in this section are: technical and physical characteristics of the bands, requirements for current and future fixed wireless systems in the bands, as well as other factors that influence the appropriateness and usability of the bands. In addition, a comparison of the topology and band specifics is provided.

6.1 Characteristics of FS RF bands

In general, all frequency bands available for the fixed service could be for transport networks. In the following sections, technical characteristics of certain fixed service bands such as appropriate transmission capacities, RF channel spacing, RF channel size availability and typical link lengths are examined.

First and foremost, the increase in the traffic requirements for IMT and other terrestrial mobile broadband systems requires a minimal transmission capacity. Links with insufficient capacity would become bottlenecks, impacting the operations of the mobile broadband system. Therefore, links with narrow RF channels are not suitable, as they will not support the basic capacity demands of IMT networks.

Transmission capacity of the fixed service link must be appropriate to fulfil the requirements of the mobile system, e.g. the capacity of mobile base stations that the fixed link needs to backhaul.

According to Report ITU-R M.2375, an LTE capacity requirement is proposed using a model for predicting traffic levels in transport networks used to backhaul mature, fully loaded long term evolution (LTE) eNBs. This information is illustrated in Figs 3-1 and 3-2 which show traffic for any number of eNBs, for downlink and uplink configurations, respectively. Each curve indicates the traffic bound in different cases as elaborated in Tables 1-1 and 1-2 for downlink and uplink traffic, respectively. The horizontal axis is labelled for the number of tricell eNBs commonly used to provide macro layer coverage across a wide area. This scale can easily be converted to represent single cell eNBs such as micro and pico cells.

TABLE 1-1

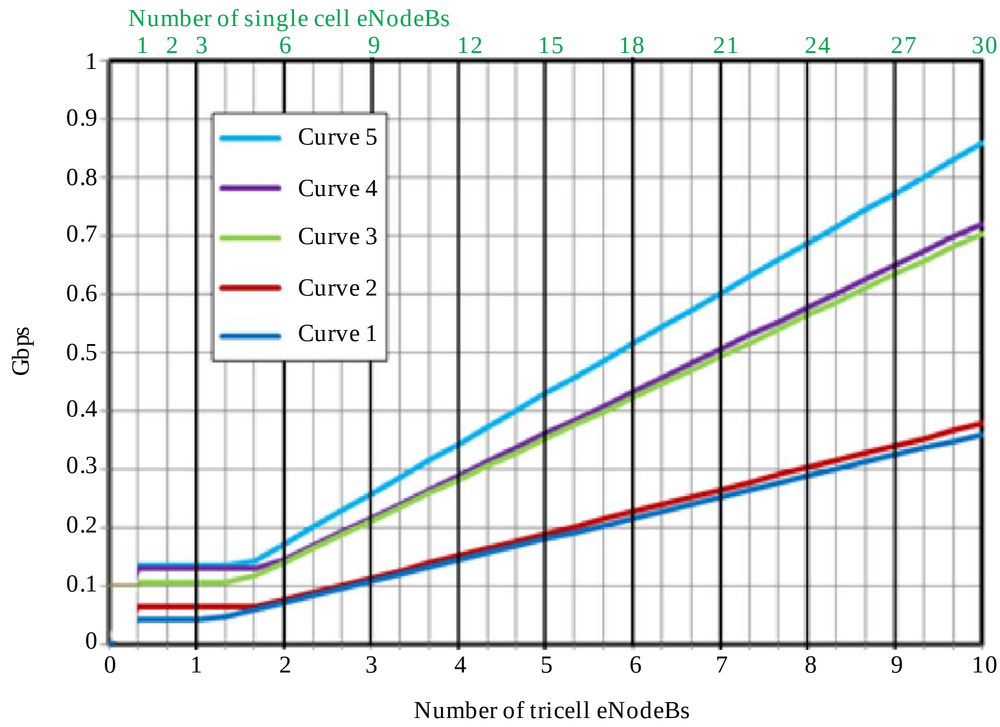
Downlink traffic for various configurations of tricell LTE eNB

Cases	**MIMO**	**Bandwidth (MHz)**	**Bit rate (Mbps)**	**Traffic (Mbps) (*)**		**IP security**
				Busy time mean	**Peak (95 percentile)**	
Curve 1	2x2	10	50	36.0	41.6	No
Curve 2	2x2	10	100	37.8	64.4	No
Curve 3	2x2	20	100	70.4	105.3	No
Curve 4	2x2	20	150	72.1	129.5	No
Curve 5	4x2	20	150	85.8	135.4	No

(*) – Total U-plane + Transport overhead.

FIGURE 3-1

Downlink traffic for multi-eNBs



Report F.2393-03-01

TABLE 1-2

Uplink traffic for various Configurations of tricell LTE eNB

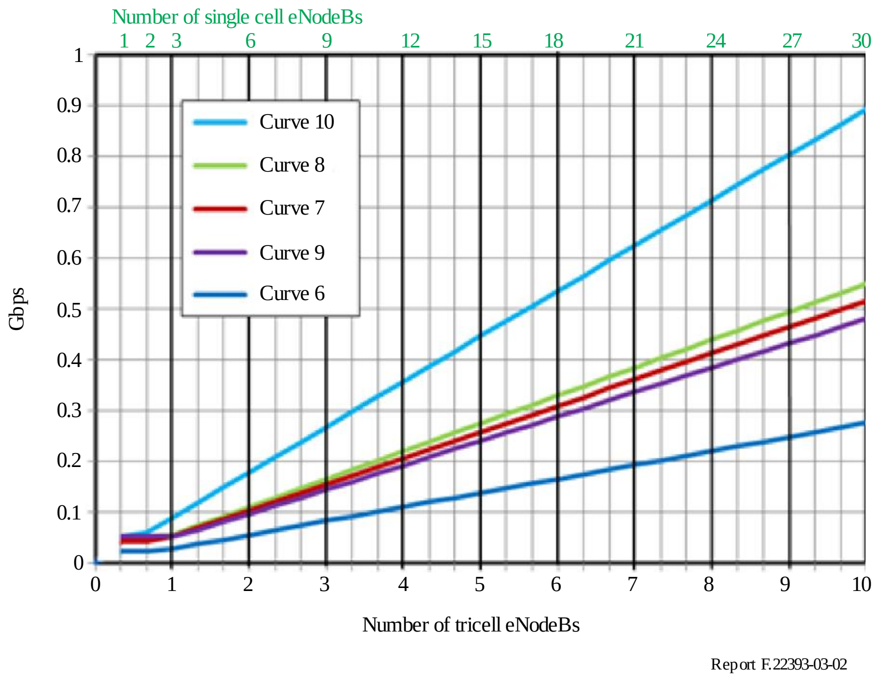
Cases	MIMO	Bandwidth (MHz)	Bit rate (Mbps)	Traffic (Mbps) (*)		IP security
				Busy time mean	Peak (95 percentile)	
Curve 6	1x2	10	50	27.5	22.8	No
Curve 7(**)	1x2	20	50	51.5	42.0	No
Curve 8	1x2	20	75	54.9	52.5	No
Curve 9	1x2	20	50	48.0	51.6	No
Curve 10	1x4	20	50	89.2	50.8	No

(*) – Total U-plane + Transport overhead.

(**) – Assuming Multi User MIMO.

FIGURE 3-2

Uplink traffic for multi-eNBs



The traffic curves comprise a plateau to the left, representing single cell peak, and a linear slope to the right, with a gradient representing the busy time mean. The plateaus illustrate the benefit of aggregating small numbers of cells together (up to about 5). For two or more tricell eNBs, the traffic is proportional to the number of eNBs, and no further aggregation gains are available.

With these capacity requirements in mind, it is then possible to identify the various fixed service bands which are capable of supporting deployment of IMT and other terrestrial mobile broadband systems. They can be divided in three broad categories, each fulfilling specific traffic requirements: Low frequency bands, mid-range frequency bands and high frequency bands.

6.1.1 Frequency bands below 11 GHz

Due to their good propagation characteristics, the main application of these bands is to support long-haul hops (typically 20 kilometres or more[4]). These bands are very important for the deployment of mobile broadband services in communities outside urban areas, as well as along corridors between population centers, where wired transport media (such as fiber) are not technically and/or economically feasible. It should also be recognized that the long-hop lengths achievable in these fixed service 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 with their better propagation characteristics can compensate for losses due to obstacles between two fixed stations. The following bands could be considered for fulfilling the above-mentioned applications:

---

4 This value should be considered as an average and is not necessarily applicable in all environments where a microwave hop is being implemented (see the statistical data for FS deployment parameters in Annex 2 to Recommendation ITU-R F.2086, noting the limited sample size and level of variability in the data in Annex 2 of Recommendation ITU-R F.2086). The reader is encouraged to refer to Recommendation ITU-R P.530 and other ITU-R P-Series documents for planning wireless backhaul hops.

TABLE 2

Band[(a)] (GHz)	**Frequency range (GHz)**	**Recommendations ITU-R F Series**	**Channel separation (MHz)**
2[(b)]	1.7-2.1; 1.9-2.3; 2.3-2.5	382 746, Annex 1	29 Up to 28
4	3.8-4.2 3.6-4.2	382 635	Up to 29 Up to 80
Upper 4	4.4-5.0	1099	Up to 80
Lower 6	5.925-6.425	383	Up to 40
Upper 6	6.425-7.11	384	Up to 80
7	7.11 to 7.90	385	Up to 28
8	7.725 to 8.5	386	Up to 40
10	10.0 to 10.68	747 1568	Up to 28 Up to 30

NOTES –

(a) Although these are parts of the bands included in Recommendation ITU-R F.746, all frequency bands may not be designated for fixed service use in some countries.

(b) Frequency bands below 2 GHz are not recommended, as it is anticipated these would not support the transmission capacity required for IMT and similar mobile broadband systems.

6.1.2 Frequency bands between 11 and 23 GHz

Fixed service frequency bands in this range support medium-haul links (typically between about 8 and 15 km).[5] In this range, larger RF channel bandwidths are possible, enabling better handling of the traffic requirements for IMT and other terrestrial mobile broadband systems in populated areas outside dense city centers, such as suburbs and industrial parks.

TABLE 3

Band[(a)] (GHz)	**Frequency range (GHz)**	**Recommendations ITU-R F Series**	**Channel separation (MHz)**
11	10.7-11.7	387	Up to 80
13	12.7-13.25	497	Up to 28
14	14.25-14.5	746	Up to 28
15	14.4-15.35	636	Up to 56
18	17.7-19.7	595	Up to 220
23	21.2-23.6	637	Up to 112

NOTE –

(a) Although these are parts of the bands included in Recommendation ITU-R F.746, all frequency bands may not be designated for fixed service use in some countries.

5 These values are the average 25th and 75th percentile values as indicated in Annex 2 to Recommendation ITU-R F.2086, noting the limited sample size and level of variability in the data in Annex 2 of Recommendation ITU-R F.2086.

6.1.3 Frequency bands above 23 GHz

The main application for these fixed service frequency bands is for short-haul links (typically less than about 7 kilometres)[6]. However, these links offer very large transmission capacity, which is well suited to fulfill the high traffic requirements and small distances between cells in IMT and similar mobile broadband systems deployed in dense urban areas. Another increasingly important application is delivering traffic from small cells, as the location of small cells often makes fiber use impractical. This could imply use of fixed service systems using new form factor antennas to adapt to challenging environments for traditional parabolic antennas (lamp post, traffic light, etc.). The use of a low profile waveguide slot array antenna for fixed wireless systems for high capacity links and active antennas are being developed in millimetric-wave bands in frequencies above 30 GHz (for these technologies, see Report ITU-R F.2323). It is noted that some of these bands are also suitable for point-to-multipoint systems.

TABLE 4

Band(a) (GHz)	**Frequency range (GHz)**	**Recommendations ITU-R F-Series**	**Channel separation (MHz)**
27	24.25-29.5	748	Up to 112
31	31.0-31.3	746	Up to 50
32	31.8-33.4	1520	Up to 112
38	36.0-40.5	749	Up to 112
42	40.5-43.5	2005	Up to 112
52	51.4-52.6	1496	Up to 56
57	55.78-66	1497	Up to 56
70/80	71-76/81-86	2006	Up to 5000
94	92.0-94 / 94.1-95	2004	Up to100, $N \times 100$

NOTE –

(a) Although these are parts of the bands included in Recommendation ITU-R F.746, all frequency bands may not be designated for fixed service use in some countries.

6.2 Enhancements of link capacity

In order to increase link capacity, two main approaches have been taken by industry:

1) the use of increasingly higher modulation schemes (up to 4096QAM) in conjunction with adaptive modulation; and

2) the use of wider channel spacing, by use of two or more channels with narrower spacing (bonding[7] or aggregation).

---

6 This value is the maximum of median values as indicated in Annex 2 to Recommendation ITU-R F.2086, noting the limited sample size and level of variability in the data in Annex 2 of Recommendation ITU-R F.2086.

7 In the context of this Report, bonding means using wider channel bandwidth, with two or more adjacent channels used as a single channel. Aggregation means using higher bandwidth with two or more non-adjacent channels.

The former point is important as low modulation may not support the required large capacity for IMT-2000 and IMT-Advanced. This second point is supported by the current trend in allowing the use of two adjacent RF channels into one (e.g. Recommendations ITU-R F.384, ITU-R F.387 and ITU-R F.497) resulting in a channel spacing up to about 60 MHz or 80 MHz, in frequency bands up to 13 GHz and by the extension of traditional channel spacing from 56 MHz up to 112 MHz in frequency bands above 15 GHz (e.g. Recommendations ITU-R F.1520 and ITU-R F.749), and up to 224 MHz in frequency bands above 40.5 GHz by CEPT[8]. Wider channel spacing, up to 5 GHz is available in the 71-76/81-86 GHz bands[9], (the E band), allowing transport capacity in the order of several Gigabits per second. Also, RF channel capacity up to 10 Gbps with multilevel modulation schemes is under study[10]. For this reason it is expected that the frequency bands 71-76/81-86 GHz will be used primarily for applications requiring gigabit interconnections rather than for applications that require lower capacity which can be effectively deployed in lower frequency bands (24 to 66 GHz) or in the forthcoming 90 GHz. The RF channel availability in various bands is presented in Table 5.

TABLE 5

Channel size availability according ITU-R radio-frequency channel arrangement Recommendations

Reference Recommendations				**High capacity Channel spacing (MHz) (Note)**
Below 11 GHz	**11 to 23 GHz**	**23 to 43 GHz**	**Above 43 GHz**	
F.382, F.635, F.383, F.384, F.385, F.386, F.747, F.1099	F.387, F.497, F.595, F.636, F.637	F.748, F.749, F.1520, F.2205	F.1496, F.1497	28/30 (2 x 28 possible)
F.635, F.383, F.384, F.386, F.635, F.1099,	F.387, F.595, F.636, F.637	F.748		40 (2 x 40 possible)
F.635, F.1099	F.387			80
	F.636, F.595, F.637	F.748, F.1520, F.749, F.2005	F.1496, F.1497	55/56
	F.595, F.637	F.748, F.1520, F.749, F.2005		110/112
	F.595			220
			F.2006	250 and N x 250 (up to 4750)

NOTE – Some RF channel size, referred in different recommendation annexes, may not be available in some countries.

---

8 ECC Recommendation (01)04 – Recommended guidelines for the accommodation and assignment of multimedia wireless systems (MWS) and point-to-point (P-P) fixed wireless systems in the frequency band 40.5-43.5 GHz. http://www.erodocdb.dk/Docs/doc98/official/pdf/REC0104.PDF and ERC Recommendation 12-11 – Radio frequency channel arrangements for Fixed Service systems operating in the bands 48.5 to 50.2 GHz / 50.9 to 52.6 GHz http://www.erodocdb.dk/Docs/doc98/official/pdf/ERCREC1211.PDF.

9 http://www.itu.int/rec/R-REC-F.2006/en.

10 7th Framework Programme for Research European project: E3NETWORK "Energy efficient E-band transceiver for backhaul of the future networks" available at: http://www.ict-e3network.eu/.

Another solution, enabled by the adoption of packet technologies in fixed service spectrum, is a technique called RF channel aggregation. It can increase a link capacity, overcoming the limitation derived by the modulation schemes and the limited channel spacing available today.

Radio link aggregation[11] is a technique allowing the aggregation of two or more data streams from radio transceivers operating with radio-frequency channels that do not necessarily have the same size or operate in the same frequency band. Used in conjunction with adaptive modulation, this technique provides a seamless single link interconnection carrying an increased capacity. It is worth noting that radio link bonding would provide traffic protection in case of severe propagation conditions, acting as a smart hitless 1:1 or N:1 protection system. When applied to a long haul application, the benefit of radio link aggregation over N RF channels working in conjunction with adaptive modulation becomes more evident when affected by well-known selective phenomena. It allows for more link capacity using fewer RF channels since the protection is obtained through the extra capacity provided by adaptive modulation, available periodically in the unaffected RF channels.

6.3 Impact of rain and gaseous attenuation

Rain and gases in the air can affect the hop length of the fixed wireless systems and therefore the choice of frequency bands for links supporting the deployment of IMT and other terrestrial mobile broadband systems.

For the rain attenuation, the choice of frequency band will be highly dependent on the meteorological condition, i.e. a rainfall rate, of the location where the transport links are deployed. For the gaseous attenuation, the choice will be affected by oxygen absorption which is particularly significant near 60 GHz.

Example calculation on these effects using P-Series Recommendations are provided in Annex 2.

6.4 Non-line-of-sight fixed service links for small cells

As described in § 5.1.1 the evolution to densify radio-access networks with small cells in cluttered urban environments has introduced new challenges for fixed service solutions. A direct line of sight does not always exist between nodes, and this creates a need for near- and non-line-of-sight (NLoS) microwave wireless links.

Using NLoS propagation is a proven approach when it comes to building radio access networks. However, deploying high-performance transport links in places where there is no direct line of sight brings new challenges for network architects. Hence, bands below 6 GHz are often implemented to ensure performance for such environments. However, studies and trials have demonstrated that using frequency bands above 20 GHz can, under certain conditions, deliver performance similar to using bands below 6 GHz – even in locations with no direct line of sight[12]. Indeed, in traditional LoS solutions, high system gain is used to support targeted link distance and to mitigate fading factors, 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

---

11 Gianluca Boiocchi, Paolo DI Prisco, Ahmed Lahrech, Pierre Lopez, Maurizio Moretto and Paolo Volpato, "Next-generation microwave packet radio: Characteristics and evolution areas to support new scenarios in wireless backhauling" *Bell Labs Technical Journal* 18(2), September 2013, available at: http://onlinelibrary.wiley.com/doi/10.1002/bltj.21610/pdf.

12 Jonas Hansryd, Jonas Edstam, Bengt-Erik Olsson and Christina Larsson, "Non-line-of-sight microwave backhaul for small cells", *Ericsson Review*, 22 February 2013; available at: http://www.ericsson.com/res/thecompany/docs/publications/ericsson_review/2013/er-nlos-microwave-backhaul.pdf

to plan NLoS deployments that provide high network performance. And so, in the vast amount of dedicated spectrum available above 20 GHz, the links are is not only capable of providing fiber-like multi-gigabit capacity, but also supporting high performance transport for small cells, even in locations where there is no direct LoS.

6.5 Infrastructure sharing between operators

Where allowed or encouraged by the frequency management authorities, sharing of infrastructure by mobile operators could be advantageous. Information on infrastructure sharing can be found in the Handbook on "Deployment of IMT-2000 systems".

7 Summary

This Report provides how the FS can be used in support of IMT and other mobile broadband systems. As traffic demands for these systems are increasing, FS use in transport is becoming an important application. P-P fixed service systems support transport links including backhaul and fronthaul.

As mobile broadband moves to IMT-Advanced and beyond, it is expected that the cell radii for these systems become smaller as well as their traffic quantity increase. As a result, there is a need for transport with short-haul and very high capacity. For this reason, all frequency bands below 11 GHz to frequency bands above 23 GHz are being used for transport in mobile broadband systems.

In order to increase capacity of transport network using P-P FS systems, there are some approaches such as using higher modulation schemes and wider channel spacing. Another technique for increasing capacity in transport is radio link aggregation enabled by the adoption of packet technologies in the FS systems.

Besides increasing traffic, there are a number of challenges in the FS systems in transport to be overcome in order to support mobile broadband systems. One challenge is to transport traffic with low latency. Other challenges, especially for small cells, are cost effectiveness, ease of installation, size of equipment, and use of a new form factor antenna. Moreover, in urban dense areas where direct line of sight does not exist between nodes, there is need for achievement of transport over NLoS and near LoS environments.

Annex 1

Information on IMT network architecture and cell structure

1 Cell structures for different areas for IMT-Advanced network

According to Report ITU-R M.2292, IMT-advanced network topology adopts different cell sizes for the different areas (urban/suburban/rural) depending on the frequency bands as shown in Tables A1-1, A1-2 and A1-3.

Therefore, it is required to deploy wireless links to meet the cell structure requirements in these Tables for connections between "eNBs" (base stations) or for connections between "eNB" and the upper level node. As for the predicting traffic levels in transport networks in Figs 3-1 and 3-2, the simulation was executed based on urban macro cells with 250 m cell radius.

TABLE A1-1

Deployment-related parameters for IMT bands below 1 GHz
(according to Report ITU-R M.2292)

	Cell radius of macro cells	
Frequency	**Macro rural**	**Macro urban/suburban**
> 1 GHz	> 5 km	0.5-5 km

TABLE A1-2

Deployment-related parameters for IMT bands between 1 and 3 GHz
(according to Report ITU-R M.2292)

	Cell radius of macro cells			Deployment density of small cells within a macro cell	
Frequency	**Macro rural**	**Macro suburban**	**Macro urban**	**Small cell outdoor**	**Small cell indoor**
1 to 2 GHz	> 3 km	0.5-3 km	0.25-1 km	1-3 per Macro urban ≤ 1 per Macro suburban	Depending on indoor coverage capacity demand
2 to 3 GHz	> 2 km	0.4-2.5 km	0.2-0.8 km	1-3 per Macro urban ≤ 1 per Macro suburban	depending on indoor coverage capacity demand

TABLE A1-3

Deployment-related parameters for IMT bands between 3 and 6 GHz
(according to Report ITU-R M.2292)

	Cell radius of macro cells		Deployment density of small cells within a macro cell	
Frequency	**Macro suburban**	**Macro urban**	**Small cell outdoor**	**Small cell indoor**
3 to 6 GHz	0.3-2 km	0.15-0.6 km	1-3 per Macro urban ≤ 1 per Macro suburban	Depending on indoor coverage capacity demand

2 General overview on the recent IMT network architecture and the cell structure

Although macro cells have been proven to be a cost effective solution in most scenarios, meeting the demand for mobile broadband is now increasingly challenging in certain situations; such as:

– large outdoor hotspots, such as town squares and commercial streets with high traffic demand and an already dense macro network (i.e. areas where interference is high);

– large, isolated indoor hotspots, such as businesses and hotels that may be difficult to reach from an outdoor macro network;

– large indoor hotspots, such as shopping malls, airports and subway stations, where mobility demands and interference are high; and

– localized, indoor hotspots or minor coverage holes, such as small offices, restaurants and retail outlets that challenge the deployment and cost structure of conventional cellular networks.

In each of these scenarios, heterogeneous networks in which small cells complement macro cells can address the growing demand for mobile broadband. However, to make this happen, a number of challenges need to be overcome, in particular the transport challenge.

As the number of radio nodes increases, transport links become more important. The link performance not only affects the data throughput available to users, but also the overall performance of the radio-access network; high performance transport links with low latency enables tighter coordination between nodes, which in turn uses available spectrum more efficiently. Networks with large numbers of (small) cell sites require transport solutions that use a combination of physical transmission media, including fiber, copper lines and wireless connectivity. For operators, there is a clear trade-off between using existing infrastructure resources, but perhaps not at exactly the needed location, and investing in dedicated transport links that result in higher overall network performance. This decision also balances installation costs and the time needed for site acquisition and deployment.

Overall, transport links should not limit the radio access network and should have sufficient end-to-end performance to meet the desired user quality of experience (QoE). However, ongoing development of radio networks to maximize the use of available spectrum puts greater demands on delay, delay variation and synchronization – particularly between the macrocells and small cells. Such performance requirements as well as technical performance, immediacy of deployment, capacity, cost and accessibility impact the choice of transport solution for any given scenario. The best solution will result from a holistic view of the network.

The main driver for heterogeneous networks is the users' need for high-quality mobile broadband services everywhere – a requirement that can be met by boosting capacity at hotspots and improving performance both at the cell edges and in buildings. Operators balance supporting users' rising quality demands and minimizing the cost of deploying, operating and maintaining the network. As a result, transport solutions should not limit the performance of heterogeneous networks, and must be cost-efficient, easy to install and rapid to deploy. Network performance should be uniform across the entire network, so that users do not experience a drop in performance when covered by small cells – resulting in a negative experience of the whole network and operator brand.

As IMT networks evolve and grow there are three ways to boost performance. Designing a heterogeneous network in the most effective way means improving, densifying and adding to the mobile broadband infrastructure as follows:

– improving existing macrocell sites: Enhancing macrocells with access to more spectrum, advanced antennas, increased order of diversity on the receiver and/or the transmitter, and greater baseband processing capacity within and between nodes;
– densifying the macro network: Targeted addition of strategically located small cells can improve capacity. This approach keeps the total number of sites relatively low, while network performance becomes less sensitive to traffic location. A simple way to densify a network could be a cell-split, which enables a site to transition, for example, from a three-sector site to a six-sector site. These strategic cells could use macro equipment or even micro equipment;
– adding small cells: Complementing macrocells with small cells and dedicated indoor solutions based on the same or complementary standards. This approach can include the use of microcells, picocells or low-power remote radio units, as well as Wi-Fi.

The most effective way to increase overall network performance is to improve existing radio sites in the macro layer through, for example, carrier aggregation. With carrier aggregation, the main requirement for transport links is the capability to deliver more capacity on existing links.

The second way to increase overall capacity and throughput is to deploy additional macro sites. Site densification is an attractive solution as it keeps the total number of sites low, while network performance is less sensitive to traffic location. To simplify site acquisition in this case, the transport solution should provide low-footprint options.

When and where it is not feasible to improve or densify the macro network within the time and cost constraints dictated by the market, the macro layer can be complemented with small low-power cells and dedicated indoor solutions. The performance advantage delivered by these low-power cells (the amount of traffic they are able to handle) will depend on each small cell's performance, how effectively each is integrated with the macro layer, and the selected transport option.

The deployment of small cells as part of a heterogeneous network solution could involve the installation of thousands of new sites. Managing the deployment of such a large number of radio and transport sites will be a key challenge as operators work to deliver additional capacity and coverage quickly and on budget.

Such deployment highlights the need for cost-efficient solutions that support the overall business case. The chosen transport solution must be cost effective to plan for, install, operate and maintain; it must address the anticipated volume of data traffic that the site will handle, as well as support the required network performance. Developing transport options to support mobile networks that can serve any site, regardless of location, will maximize return on investment for existing sites and active equipment. This is particularly important for small cells that have limited reach and may serve a small percentage of an operator's subscriber base.

Different sites will pose different challenges. Having the flexibility to choose between dedicated high-performance transport links and the reuse of existing resources on site will be essential to supporting short time-to-market at the right cost. This may be increasingly difficult to achieve without a holistic approach to radio, transport and installation services.

While fiber links tend to be the primary mode of transport links employed for high traffic cell sites given its large capacity and high reliability, point-to-point fixed wireless links are cost-efficient technology for flexible and rapid transport link deployment in most rural and remote locations, as well as metropolitan markets. The fixed wireless solution is the dominant transport link medium for mobile networks, and is expected to maintain this position as mobile broadband evolves; with fixed wireless technology that is capable of providing transport link capacity in the order of several gigabits-per-second.[13]

To obtain the maximum performance from the radio network, it is important to have an end-to-end transport solution that does not limit the user's QoE. The challenge is how to strike the best balance of performance, cost, market timing and location.

---

13 Jonas Hansryd and Jonas Edstam, "Microwave capacity evolution", *Ericsson Review*, 2011; available at: http://www.ericsson.com/res/docs/review/Microwave-Capacity-Evolution.pdf.

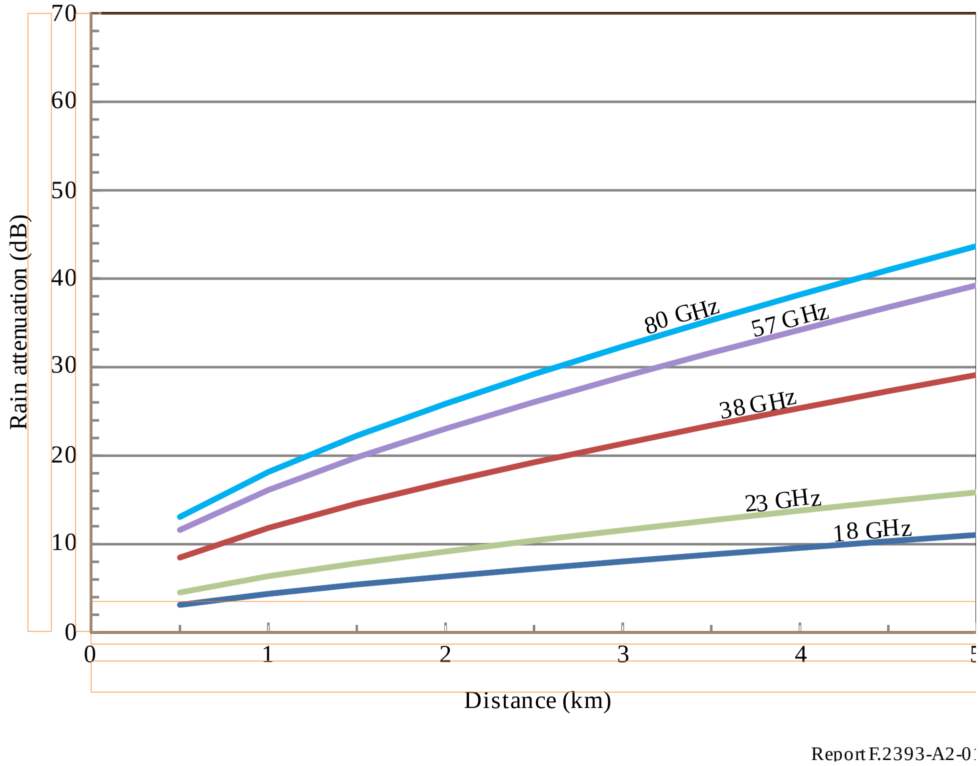
Annex 2

Example calculation on the effects of rain and gaseous attenuation

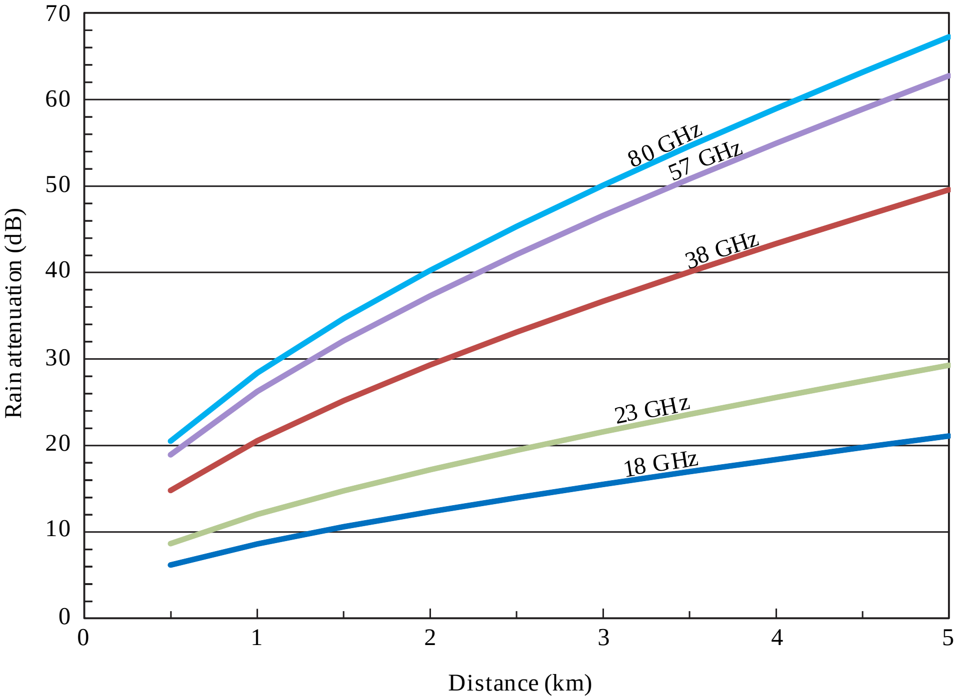
Figure A2-1 shows rain attenuation for the long-term statistics based on Recommendations ITU-R P.530-15 and ITU-R P.838-3. The rain attenuation increases as frequency becomes higher depending on the rain rate $R_{0.01}$ X mm/h, which means that rainfall rate of X mm/hour is exceeded for 0.01% of the time. It is noted that the curve for 23 GHz in Fig. A2-1 (b) of $R_{0.01}$ = 60 mm/h almost shows the same performance (possible distance) as the curve for 38 GHz in Fig. A2-1 (a) of $R_{0.01}$ = 30 mm/h, taking into account the different impact of rain attenuation.

FIGURE A2-1

Rain attenuation versus distance



(a) Rain rate $R_{0.01}$ = 30 mm/h



b) Rain rate $R_{0.01}$ = 60 mm/h

Report F.2393-A2-01b

Figure A2-2 depicts gaseous attenuation consisting of dry air and water vapor based on Annex 2 to Recommendation ITU-R P.676-10. In this calculation, the following parameters are used for ground-level standard according to Recommendation ITU-R P.835-5:

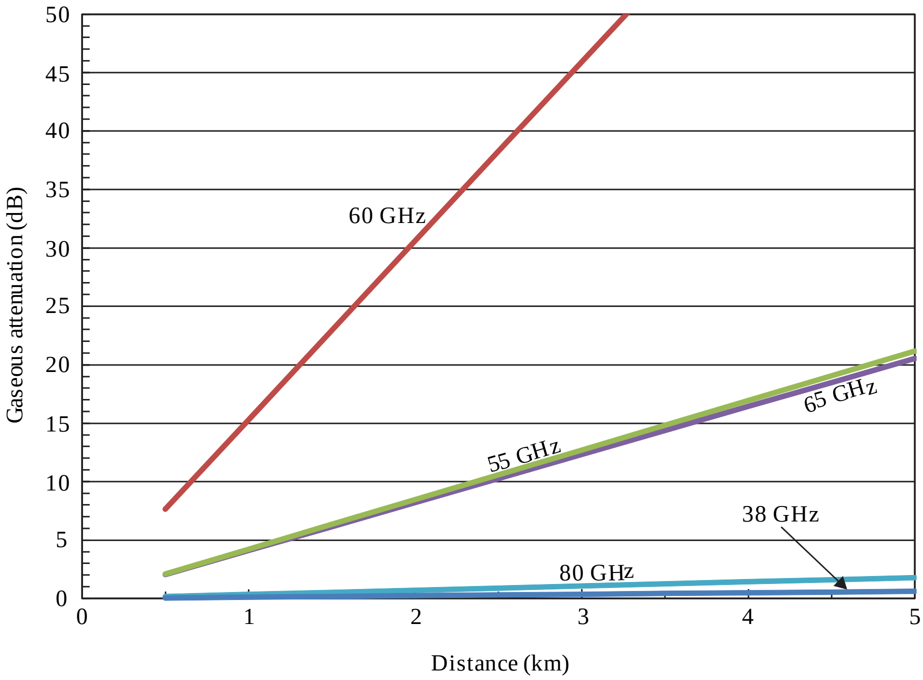
– temperature: 288.15 K;

– pressure: 1013.25 hPa (hectopascal);

– water-vapor density: 7.5 g/cm^3.

FIGURE A2-2

Gaseous attenuation versus distance



Report F.2393-A2-02

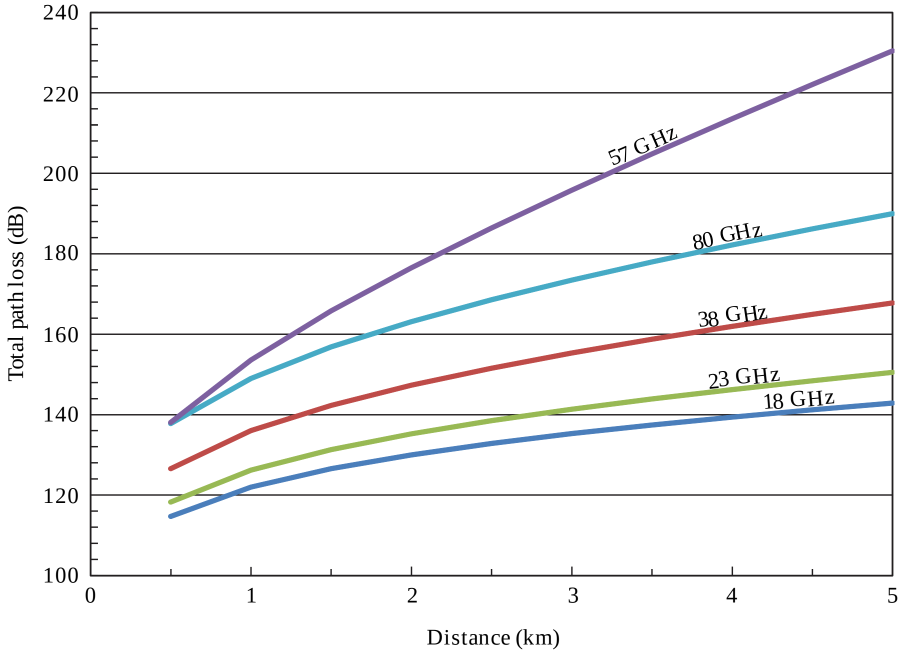
It is observed that there is sharp attenuation near 60 GHz due to oxygen absorption.

Moreover comparisons are made for the 18, 23, 38, 57 and 80 GHz bands with respect to total path losses consisting of the rain attenuation, the gaseous attenuation and the free-space propagation loss. Figure A2-3 reveals the total path losses.

In general, the total path losses increase as frequency becomes higher. However, care should be taken to the fact that, due to the oxygen absorption near 60 GHz, the 57 GHz curve increases with the steepest incline among other curves and shows larger path loss than that of 80 GHz.

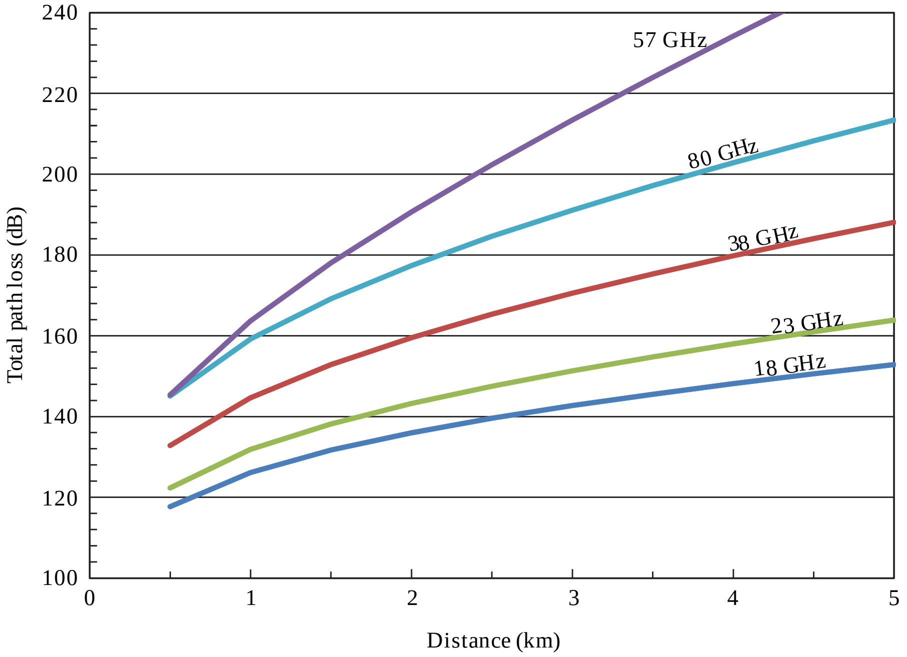
FIGURE A2-3

Total path losses versus distance



a) Rain rate $R_{0.01} = 30$ mm/h

Report F.2393-A2-03a



a) Rain rate $R_{0.01} = 60$ mm/h

Report F.2393-A2-03b