Radiocommunication Study Groups

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Working Party 5D

ATTACHMENT 1 ON SPECTRUM NEEDS TO
A LIAISON STATEMENT TO TASK GROUP 5/1

SPECTRUM NEEDS FOR THE TERRESTRIAL COMPONENT OF IMT IN THE FREQUENCY RANGE BETWEEN 24.25 GHz AND 86 GHz

1 General considerations

Recommendation ITU-R M.2083, *"IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond,"* identifies three main usage scenarios currently envisaged for IMT-2020, while acknowledging the possible emergence of additional use cases. The three usage scenarios are enhanced mobile broadband, ultra-reliable and low latency communications, and massive machine-type communications.

Among these scenarios, spectrum in the frequency range between 24.25-86 GHz would be needed to satisfy the expected data rates of the enhanced mobile broadband usage scenario. IMT-2020 systems will incorporate the use of new technologies that benefit from the physical characteristics of the frequency bands in the range from 24.25 to 86 GHz and the large bandwidths potentially available.

Considering the above, WP 5D considered various approaches to determining the spectrum needs of IMT in this frequency range as detailed below.

It should be noted that the estimated results presented in the document are based on envisaged characteristics of a set of applications for IMT-2020 in the frequency bands above 24.25 GHz. If the applications usage of IMT-2020 are different from the assumption (e.g., some of the applications are accommodated by other non-IMT technologies, such as RLAN), some of the input parameter values for the approaches to determining the spectrum needs have to be adjusted accordingly.

2 Approaches to determining spectrum needs and obtained results

It is to be understood that each approach to determining the spectrum needs outlined below has advantages and disadvantages, and some approaches may be more sensitive to the input parameter values selected to determine the spectrum needs.

2.1 Traffic forecast-based approach

This approach has been used previously in Report ITU-R M.2290, which utilized user demand forecasts to predict future usage of IMT.

No estimate based on the traffic forecast-based approach has been provided for the studies on spectrum needs under Resolution **238 (WRC-15)**.

2.2 Application-based approach

An example of this approach can be found in Recommendation ITU-R M.1651 *"A method for assessing the required spectrum for broadband nomadic wireless access systems including radio local area networks using the 5 GHz band"* which provides the methodology for assessing spectrum requirements for RLANs. Recommendation ITU-R M.1651 was developed and utilized in the WRC-03 study cycle, then again as part of RLAN spectrum requirements under WRC-15 agenda item 1.1.

This application-based approach focuses on the advanced applications for IMT-2020 using frequency range between 24.25 GHz and 86 GHz, which are mainly expected to require higher data rate than IMT-Advanced. The input parameters on the applications could reflect different situations for various countries with less complexity than the previous approach based on traffic forecasts.

This approach could be considered together with information from other approaches.

In order to calculate the total amount of spectrum needs **R** (Hz) in this approach, the following equations are used:

$$\mathbf{R}_{\mathbf{ts}} = M\,(\textit{Connection density, Application data rate, Usage patterns}) \,/\, R\,(\textit{Cell area, Spectral efficiency})$$

$$\mathbf{R}_{\mathbf{t}} = \sum \mathbf{R}_{\mathbf{ts}}$$

$$\mathbf{R} = \max(\mathbf{R}_{\mathbf{t}})$$

In the above equations, $\mathbf{R}_{\mathbf{ts}}$ represents a set of spectrum needs in given teledensities and service types (Hz), *M* is a function of the market-related parameters, such as *Connection density*, *Application data rate* and *Usage patterns, and R* is a function of the radio-related parameters, such as *Cell area and Spectral efficiency*. **R** is therefore the spectrum needs for IMT-2020 as the maximum from the set of needs based on the set of teledensities $\mathbf{R}_{t}$.

Table 1 shows two examples of the estimated spectrum needs for the different frequency ranges between 24.25 GHz and 86 GHz using the application-based approach. Further details of this approach can be found in section A.1 in the Annex A.

TABLE 1

Estimated spectrum needs based on the application-based approach

Example	**Teledensities**	**24.25-33.4 GHz**	**37-52.6 GHz**	**66-86 GHz**	**Total**
Example 1	Overcrowded, Dense urban and Urban areas	3.3 GHz	6.1 GHz	9.3 GHz	18.7 GHz
	Dense urban and Urban areas	2.0 GHz	3.7 GHz	5.7 GHz	11.4 GHz
Example 2	Highly crowded area	666 MHz	1.2 GHz	1.9 GHz	3.7 GHz
	Crowded area	333 MHz	608 MHz	933 MHz	1.8 GHz

2.3 Technical performance-based approach

The concept of this approach is as follows:

Factors such as peak data rate to be supported by a radio system, spectral efficiency, user experienced data rate, expected device density, etc. all impact spectrum needs. In addition, usage scenarios, including their associated expected coverage area, deployment environments, and target applications introduce technical requirements and conditions on a radio system that directly or indirectly impact spectrum needs. For instance, all other aspects held constant, a system targeting an application requiring 100 Mbits/s user rate would require ten times more spectrum than a system targeting another application requiring only 10 Mbits/s user rate.

One can perform simple, rough estimates of spectrum needs based on key Technical Performance Requirements (TPRs) (e.g., peak data rate, user experienced data rate and area traffic capacity), or one can perform detailed calculations involving aspects such as link budget and system-level simulations. Either way, for the system to support these TPRs, certain capabilities need to exist in the radio interface, irrespective of geography or user demand/device projections.

This approach could be considered together with information from other approaches.

Two types of the technical performance-based approaches are currently being considered.

2.3.1 Type 1

A very simple equation is used to calculate the bandwidth B (Hz), expressed as a product of the required user/device data rate D (bits/s) and the number of simultaneously served users/devices (N) in the cell, divided by the spectral efficiency S (bits/s/Hz). In short, $B = (D \times N) / S$.

Table 2 shows examples of the estimated spectrum needs using the Type 1 technical performance-based approach. Further details of this approach can be found in section A.2.1 in the Annex A.

TABLE 2

Estimated spectrum needs based on the Type 1 technical performance-based approach

Examples	**Spectrum needs**
#1 – Based on cell-edge user throughput and spectral efficiency targets in Recommendation ITU-R M.2083 with *N* simultaneously served users/devices at the cell-edge	User experienced data rate of 1 Gbit/s: 3.33 GHz (*N*=1), 6.67 GHz (*N*=2), 13.33 GHz (*N*=4), e.g., Indoor User experienced data rate of 100 Mbits/s: 0.67 GHz (*N*=1), 1.32 GHz (*N*=2), 2.64 GHz (*N*=4), for wide area coverage
#2 – Based on cell-edge user spectral efficiency (obtained from 3GPP technical specifications) and data rate targets (from Recommendation ITU-R M.2083) in two given test environments	0.83-4.17 GHz (for eMBB Dense Urban) 3-15 GHz (for eMBB Indoor Hotspot)
#3 – Impact of latency and spectral efficiency targets and a typical user throughput value on spectrum needs	With a file transfer of 10 Mbits by a single user at cell-edge in 1 msec: 33.33 GHz (one direction) With a file transfer of 1 Mbit by a single user at cell-edge in 1 msec: 3.33 GHz (one direction) With a file transfer of 0.1 Mbits by a single user at cell-edge in 1 msec: 333 MHz (one direction)

2.3.2 Type 2

The spectrum needs are estimated based on different TPRs of IMT-2020 including user experienced data rate, peak data rate and area traffic capacity. The spectrum needs estimate based on each TPR traverses and combines all the IMT-2020 deployment scenarios. These scenarios could be divided into indoor hotspot, micro & macro layers in dense urban and urban macro. Considering that the spectrum needs should satisfy all the key capabilities of the network, the maximum spectrum needs result obtained from different TPRs is regarded as the final spectrum needs of IMT-2020.

In the Type 2 analysis below, the following assumptions are made:

– The macro cells in dense urban and urban scenarios for seamless wide-area coverage are provided by the frequency range below 6 GHz.

– The micro in dense urban and indoor hotspot scenarios to fulfil the requirement of extremely high transmission rate are provided by the frequency range between 24.25-86 GHz. Among the frequencies of 24.25-86 GHz, the frequencies of 24.25-43.5 GHz are suitable for the micro scenario due to better propagation characteristics.

Based on the above, Table 3 provides relationship between deployment scenarios and frequency ranges for IMT-2020 assumed in the Type 2 analysis.

TABLE 3

Deployment scenarios and frequency ranges for IMT-2020 assumed in the Type 2 analysis

Deployment scenarios	**Indoor hotspot**	**Dense urban**		**Urban macro**
		Micro	**Macro**	
Frequency range	24.25-86 GHz	24.25-43.5 GHz	<6 GHz	<6 GHz

Section A.2.2 in the Annex A provides details of one example of the Type 2 based on the key capabilities, deployment scenarios and the mapping of deployment scenarios and suggested frequency ranges, as mentioned above. The estimated spectrum needs are summarized in Table 4.

TABLE 4

Spectrum needs estimate result of IMT-2020 for different frequency ranges between 24.25 GHz and 86 GHz

Deployment scenario	**Micro**	**Indoor hotspot**
Total spectrum needs for 24.25-86 GHz	14.8-19.7 GHz*	
Spectrum needs for 24.25-43.5 GHz	5.8-7.7 GHz	9-12 GHz
Spectrum needs for 45.5-86 GHz	–**	

* Considering the coexistence between multiple network operators (e.g. the guard band(s) may be required in the case of multiple network operators scenarios), the total spectrum needs are expected to be increased.

** The division in this table regarding frequency ranges and deployment scenarios is just an indicative example on how spectrum needs could be distributed for different spectrum sub-ranges within 24.25-86 GHz and different deployment scenarios. This table should not be understood nor used to exclude any possible IMT-2020 deployment options in the range 45.5-86 GHz.

3 Information on spectrum needs in some countries

Annex B to this document and Attachment 4.18 to Document 5D/530 *"Summary of responses to questions on spectrum needs for IMT under WRC-19 agenda item 1.13"* is a compilation of information as received from some administrations in response to the questions in Attachment 4.17 to Document 5D/374. Each response contained in the Annex B and the summary of responses has not been considered by WP 5D, as it is the national considerations on their spectrum needs for IMT in the frequency range 24.25-86 GHz by those administrations.

It should be noted that this information addresses spectrum needs within the entire frequency range between 24.25 GHz and 86 GHz; some of which are not for the specific frequency bands listed in *resolves to invite ITU-R* 2 in Resolution **238 (WRC-15)**.

Using this information, Table 5 summarizes the spectrum needs for the different frequency ranges between 24.25 GHz and 86 GHz.

TABLE 5

Spectrum needs based on the information from some countries

Frequency ranges	**24.25-43.5 GHz**	**43.5-86 GHz**
Spectrum needs	2-6 GHz	5-10 GHz

4 Summary

Studies for WRC-19 agenda item 1.13 estimated the spectrum needs for the terrestrial component of IMT in the frequency range between 24.25 GHz and 86 GHz, in accordance with Resolution **238 (WRC-15)** and CA/226.

Terrestrial IMT-2020 systems will incorporate the use of new technologies that benefit from the physical characteristics of the frequencies in the frequency range from 24.25 to 86 GHz and the large bandwidths potentially available which will provide higher data rates and lower latencies. A number of approaches were considered and the results obtained using the application-based and the technical performance-based approaches are summarized in Table 6. The estimated spectrum needs would be different based on the approaches used together with the assumptions thereof.

Furthermore, some administrations provided information on spectrum needs in their countries based on their national considerations, which is also summarized in Table 6.

TABLE 6

Spectrum needs for frequency ranges between 24.25 and 86 GHz

	Examples	**Associated conditions for different examples (For details, please see the corresponding sections in the Annex A)**	**Spectrum needs in total (GHz)**	**Spectrum needs (GHz) per range**
Application-based approach	1	Overcrowded, Dense urban and Urban areas	18.7	3.3 (24.25-33.4 GHz range) 6.1 (37-52.6 GHz range) 9.3 (66-86 GHz range)
		Dense urban and Urban areas	11.4	2.0 (24.25-33.4 GHz range) 3.7 (37-52.6 GHz range) 5.7 (66-86 GHz range)
	2	Highly crowded area	3.7	0.67 (24.25-33.4 GHz range) 1.2 (37-52.6 GHz range) 1.9 (66-86 GHz range)
		Crowded area	1.8	0.33 (24.25-33.4 GHz range) 0.61 (37-52.6 GHz range) 0.93 (66-86 GHz range)
Technical performance-based approach (Type 1)	1	User experienced data rate of 1 Gbit/s with *N* simultaneously served users/devices at the cell-edge, e.g., Indoor	3.33 (*N*=1), 6.67 (*N*=2), 13.33 (*N*=4)	Not available
		User experienced data rate of 100 Mbits/s with *N* simultaneously served users/devices at the cell-edge, for wide area coverage	0.67 (*N*=1), 1.32 (*N*=2), 2.64 (*N*=4)	Not available
	2	eMBB Dense Urban	0.83-4.17	Not available
		eMBB Indoor Hotspot	3-15	Not available
	3	With a file transfer of 10 Mbits by a single user at cell-edge in 1 msec	33.33 GHz (one direction)	Not available
		With a file transfer of 1 Mbit by a single user at cell-edge in 1 msec	3.33 GHz (one direction)	
		With a file transfer of 0.1 Mbits by a single user at cell-edge in 1 msec	333 MHz (one direction)	
Technical performance-based approach (Type 2)	–	Dense urban micro	14.8-19.7	5.8-7.7 (24.25-43.5 GHz range)
		Indoor hotspot		9-12 (24.25-43.5GHz and 45.5-86 GHz range)
Information from some countries based on their national considerations	–	–	7-16	2-6 (24.25-43.5 GHz range) 5-10 (43.5-86 GHz range)

As indicated in these approaches, for the spectrum needs of IMT-2020 in the range of 24.25 and 86 GHz, different channel propagation characteristics and available channel bandwidth should be taken into account. With a view to accommodating the wide range of usage and deployment scenarios for IMT-2020, it is important to consider different frequencies within the range 24.25 and 86 GHz.

5 Abbreviations

3GPP	3rd Generation Partnership Project
DU	dense urban
eMBB	enhanced mobile broadband
InH	indoor hotspot
ISD	inter-site distance
MBB	mobile broadband
MCS	modulation and coding scheme
mMTC	massive machine-type communications
RLAN	radio local area network
SC	service categorisation
TPR	technical performance requirement
urLLC	ultra-reliable and low latency communications

ANNEX A

Detailed process of approaches and obtained results

A.1 Application-based approach

This approach can:

– Take account of the capabilities and usage scenarios of IMT-2020.

– Be adapted to take account of the large range of frequency bands under study.

– Readily be implemented in common software tools such as a spreadsheet.

– Be easily used for “what-if” analysis of the results.

The results of this calculation procedure need to be considered carefully given that the output might be sensitive to the input parameter values on the usage of advanced applications in the age of IMT-2020 which can be drawn from a large range of possible values. This input parameter, on the other hand, could reflect the different situation by regions or countries.

A.1.1 Input parameters

Input parameters to the assessment process can be grouped as:

Market related:

– Connection density

– Application data rate

– Application usage pattern assumptions

Radio related:

– Cell area (Inter-Site Distance - ISD)

– Spectral efficiency

A.1.2 Step by step approach

The following steps 1 to 3 and the final calculation are the essence of the ‘Application based determination’.

Step 1

Service Categorisation (SC)

A matrix of 9 service categorisations (SC1 to SC9) can be identified across three teledensity (connection density) types considered most appropriate for enhanced MBB (e.g. Overcrowded area, Dense urban area and Urban area) and three service types broadly characterising a range of application data rates (e.g., ‘Super high’ data rate application, ‘High’ data rate application and ‘Medium’ data rate application) in the following way.

TABLE A.1-1

Service Categorisation (SC)

Teledensity / Service type	Overcrowded area	Dense urban area	Urban area
Super-high data rate application	SC1	SC4	SC7
High data rate application	SC2	SC5	SC8
Medium data rate application	SC3	SC6	SC9

These examples are considered to have the most impact on the spectrum needs for enhanced MBB however other teledensity scenarios can be considered.

Teledensity definition

Each teledensity parameter can be characterized by connection density by assessing the number of users or devices in a given area and communication activity factor.

Connection density (/km^2) defined in Recommendation ITU-R M.2083 can be calculated by evaluating the active number of users or devices in a given area in the teledensity considered. Simply:

Connection density = (Number of users or devices in a given area) × (Activity factor)

The number of users or devices in a given area can be defined differently by regions or countries, thereby reflecting different situations for user densities.

Activity factor can reflect the proportion of users/devices that are simultaneously actively communicating. It will be dependent upon when any services or applications are consumed and could vary with time. It is important to take this into account.

Service type data rates

Application data rates need to be assigned to each service type.

User experienced data rates discussed in Recommendation ITU-R M.2083 suggests data rates that might range from 1 Gbit/s for the 'Super high' data rate application service type to 100 Mbits/s for the 'Medium' data rate application service type.

Recommendation ITU-R M.2083 indicates that "the values recommended are targets for research and investigation for IMT-2020."

Step 2

Usage Pattern

An application usage pattern is defined as a common user(s) behaviour denoting the percentage of active user/device using a given service type in a given teledensity. The values for the input can be defined differently by regions or countries in percentage (%).

Activity factor and usage pattern could be influenced according to different frequency ranges to reflect the different operational environments anticipated.

Step 3

Deployment considerations

Assuming a regular cellular pattern, inter-site distances (ISD) and spectral efficiency figures can be derived or extrapolated from Recommendation ITU-R M.2083 and the relevant IMT-Advanced performance objectives and should be assigned to each Teledensity. Calculated spectrum needs are based on IMT deployment scenarios corresponding to macro cell scenarios with three-sector antenna base stations.

A.1.3 Calculation Process

The total amount of spectrum needs **R** (Hz) can be calculated in the following way:

$$\mathbf{R_{ts}} = (C \times A \times U) / I / S$$

$$\mathbf{R_t} = \sum \mathbf{R_{ts}}$$

$$\mathbf{R} = \max(\mathbf{R_t})$$

where:

C = Connection density (users/km^2);

A = Application data rate (bits/s);

U = Usage patterns (%);

I = Number of cells/km^2 based on the ISD (km);

S = Spectral efficiency (bits/s/Hz);

$\mathbf{R_{ts}}$ = A set of spectrum needs in given teledensities and service types (Hz);

$\mathbf{R_t}$ = A set of spectrum needs in given teledensities (Hz).

R is therefore the spectrum needs for IMT-2020 as the maximum from the set of needs based on the set of teledensities $\mathbf{R_t}$. It is not confined to a cell, application and teledensity.

A.1.4 Examples of input parameters values and obtained results

Examples of this application-based approach adjusted for WRC-19 agenda item 1.13 and Resolution **238 (WRC-15)** can be described as follows.

(1) Input parameters

Connection density

In Example 1, considered user or device densities might range from 1 per 4 m^2 in an overcrowded area to 50 per 10 000 m^2 in an urban area example. Consequential *Connection density* might range from 225 000 per km^2 down to 2 500 per km^2 depending on the activity factor assumed.[1]

In Example 2, in order to account for different situations that can be encountered, the user densities are assumed to be lower than in Example 1 and all other assumptions are identical to Example 1.

TABLE A.1-2A

Teledensity in Example 1

Teledensity	Number of devices per area	Activity factor	Connection density
Overcrowded area	1 / 4 m^2	90%	225 000 /km^2
Dense urban area	5 / 100 m^2	70%	35 000 /km^2
Urban area	50 / 10 000 m^2	50%	2 500 /km^2

[1] Based on 'NGMN 5G White Paper' and 'Recommendation ITU-R M.2083' published in 2015.

TABLE A.1-2B

Teledensity in Example 2

Teledensity	Connection density
Highly-crowded area	45 000 /km^2
Crowded area	22 500 /km^2

Application data rate

Considered data rates might range from 1 Gbit/s for the Super-high data rate application service type to 100 Mbits/s for the Medium data rate application service type depending on the information source, e.g., user experienced data rate in Recommendation ITU-R M.2083.

TABLE A.1-3

Service type data rates

Service type	Application data rate
Medium data rate application[2]	100 Mbits/s
High data rate application[3]	500 Mbits/s
Super-high data rate application[4]	1 Gbit/s

Application usage pattern

Usage pattern could be influenced according to different frequency ranges to reflect the different operational environments anticipated and different situations in various countries. One example below is taking into account multiple sources[5] on the proportion of active users using advanced applications such as video streaming services at present.

TABLE A.1-4

Application usage pattern

Range / Service type	24.25-33.4 GHz	37-52.6 GHz	66-86 GHz
Medium data rate application	5%	3%	2%
High data rate application	3%	6%	6%
Super-high data rate application	2%	4%	8%

[2] E.g., 360 view with 4K resolution: 65 Mbits/s (H.265) and 130 Mbits/s (VAR for peak).

[3] E.g., 360 view with 8K resolution: 258 Mbits/s (H.265) and 516 Mbits/s (VAR for peak).

[4] E.g., Spherical view for holography: 4 to 8 times more than 360 views.

[5] Flurry Analytics et al.: YouTube (3%) and Entertainment (17%) in the US,
Flurry Analytics: Music, Media & Entertainment (10%) in some EU countries,
Ericsson Mobility Report 2015: Video streaming (6.5 to 13%) in the US, Sweden and Russia,
Ericsson Consumer Insight Summary Report 2015: Entertainment (6 to 21%) in some countries,
Forrester's US Consumer Technographics Behavioural Study: Video streaming (9%) in the US,
Nielsen: Entertainment including video, audio, and gaming (32%) in the US,
comScore Mobile Metrix: Multimedia (5%) in the US.

Cell area and Spectral efficiency of IMT-2020

Inter-site distances for *Cell area* and *Spectral Efficiency* figures from the related ITU-R documents should be assigned to each teledensity.

TABLE A.1-5

Deployment considerations

	Overcrowded area, Highly crowded area, Crowded area	Dense urban area	Urban area
ISD	100 m	200 m	500 m
Spectral efficiency	7.8 bits/s/Hz/cell		

(2) Spectrum needs

Table A.1-6 show two examples of the estimated spectrum needs for the different frequency ranges between 24.25 GHz and 86 GHz.

TABLE A.1-6

Spectrum needs for the bands between 24.25 GHz and 86 GHz

Example	Teledensities	24.25-33.4 GHz	37-52.6 GHz	66-86 GHz
Example 1	Overcrowded, Dense urban and Urban areas	3.3 GHz	6.1 GHz	9.3 GHz
	Dense urban and Urban areas	2.0 GHz	3.7 GHz	5.7 GHz
Example 2	Highly crowded area	666 MHz	1.2 GHz	1.9 GHz
	Crowded area	333 MHz	608 MHz	933 MHz

A.2 Technical performance-based approach

A.2.1 Type 1

Three examples are presented below. All these examples use one or more of the TPRs as expressed in Recommendation ITU-R M.2083.

Example 1 – Based on cell-edge user throughput and spectral efficiency targets in M.2083

As a rudimentary example, starting with user experienced data rate, if:

– D: Maximum data rate supported by a user/device

– N: Number of simultaneously served users/devices in a cell

– S: Spectral efficiency (bits/s/Hz).

the amount of spectrum required to support such rate could be calculated as $B = (D \times N) / S$.

Based on the above formula, and considering a user experienced data rate of 1 Gbit/s and a 3× spectral efficiency increase over IMT-Advanced for cell-edge users/devices for the case of Indoor Hotspot (as per Recommendation ITU-R M.2083), i.e. spectral efficiency = 0.3 bits/s/Hz, B (in GHz) could be calculated as follows:

TABLE A.2-1A

Amount of spectrum required to support a user/device experienced data rate of 1 Gbit/s (indoor hotspot)

Number of simultaneously served users/devices in a cell	$N = 1$	$N = 2$	$N = 4$
Amount of spectrum required B (GHz)	3.33	6.67	13.33

These results do not consider factors such as multiple carriers for frequency reuse and multiple network operators, which would also need to be taken into account.

The above example uses the highest cell-edge spectral efficiency and highest cell-edge data rate requirement among various environments. Other environments would result in other spectrum needs for cell-edge users/devices. The Example 1 does not take into account distribution of the users within a cell and activity of users/devices, which requires further considerations for spectrum needs.

Considering a user experienced data rate of 100 Mbits/s for the case of outdoor urban and spectral efficiency = 0.15 bits/s/Hz, B (in GHz) could be calculated as follows:

TABLE A.2-1B

Amount of spectrum required to support a user/device experienced data rate of 100 Mbits/s (Outdoor - urban)

Number of simultaneously served users/devices in a cell	$N = 1$	$N = 2$	$N = 4$
Amount of spectrum required B (GHz)	0.67	1.32	2.64

Example 2 – Based on cell-edge user spectral efficiency (obtained from 3GPP technical specifications) and data rate targets (from Recommendation ITU-R M.2083) in two given test environments

This example uses the same equation as in Example 1, i.e. $B = D \times N / S$, for two test environments[6] – eMBB Dense Urban (eMBB-DU) and eMBB Indoor Hotspot (eMBB-InH). Spectral efficiencies (S) are drawn from the 3GPP technical specifications; data rate requirements (D) are as per Recommendation ITU-R M.2083 and the number of simultaneously served users/devices (N) in each test environment is derived according to the considerations detailed below:

1 The users or devices considered are the ones at cell-edge. Though there may be users/devices spread throughout the cell, the ones at cell-edge place the most demands on the base-station from a spectrum point-of-view, and if their demands can be met, the average spectrum demands in the cell will be met:

   a) Cell-edge data rate requirements are assumed as the user-experienced data-rates for urban areas and hotspots from Recommendation ITU-R M.2083.

   b) Cell-edge user spectral efficiency in eMBB-DU scenario is assumed as the spectral efficiency for the lowest Modulation and Coding Scheme (MCS) in IMT-Advanced[7]. Since the achievable spectral efficiency depends on the

[6] A test environment is defined as the combination of a usage scenario (eMBB, mMTC or urLLC) and a geographic environment (e.g. Indoor-hotspot, Dense-urban, Rural, etc.)

[7] 3GPP TS 36.213: Table 7.1.7.2.1-1.

number of resource blocks to be used, the average value, 0.15 bit/s/Hz, is adopted. It should be noted that the spectrum efficiency of the lowest MCS would be almost the same between IMT-Advanced and IMT-2020

c) Cell-edge user spectral efficiency for the indoor scenario (eMBB-InH) is assumed to have 100% improvement, i.e. 0.3 bit/s/Hz.

TABLE A.2-2

Two test environments, associated data rates and spectral efficiencies

	Cell-edge condition
eMBB-DU	
Data rate requirement	100 Mbits/s
Spectral efficiency	0.15 bits/s/Hz
eMBB-InH	
Data rate requirement	1 Gbit/s
Spectral efficiency	0.3 bits/s/Hz

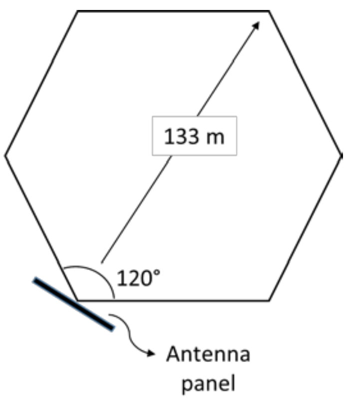
2 The number of served cell-edge users/devices, *N*, to be used for the spectrum needs estimate, is derived as follows for both eMBB-DU and eMBB-InH test environments:

eMBB-DU

3 Assume a single-sector base station with a planar antenna panel which provides a 120 degree azimuth coverage; assume that the single-sector cell coverage area is equivalent to the area of one sector in a tri-sectorized cell grid ($A_{sector} = 1/(2 \cdot \sqrt{3}) \cdot ISD^2$) with inter-site-distance (ISD) of 200 m, i.e. 0.0115 km^2.

FIGURE A.2-1

Single-sector base station coverage for eMBB-DU test environment



4 Assume the population density as the averaged value over the world's top 100 cities[8], i.e. population density = 19 102/km^2, year 2016:

a) Assume a growth-rate[9] of 1.5%.

b) By year 2024, population density = 21 681/ km^2.

5 So, no. of users or subscriptions/cell in the year 2024 = 250 (rounded-off).

eMBB-InH

6 Consider the CICG Room-1 (http://www.cicg.ch/en/room-1/):

a) Total area = 1426 m^2.

b) No. of seats = 892 in auditorium style (standard), 940 maximum (on quotation).

c) Assume 900 people within the room.

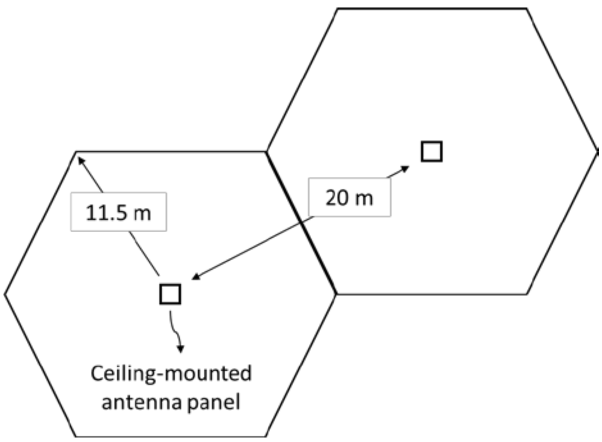
7 Assume ceiling-mounted single-sector access points with ISD = 20 m:

a) Coverage area per omni-cell access point is A = $(\sqrt{3}/2)\cdot ISD^2 = 346.4$ m^2.

b) No. of access points required to cover the CICG Room 1 = 5.

FIGURE A.2-2

Single-sector base station coverage for eMBB-InH test environment



8 So, no. of users or subscriptions/access point = 180.

9 In this example, only the active users/devices in cell-edge conditions are considered for the spectrum needs estimate in both eMBB-DU and eMBB-InH scenarios. Two factors are introduced:

a) Consider that only a small percentage of active users/devices are under cell-edge conditions; assume $\alpha_{\text{users cell-edge}} = 5\%$.

b) Let β_{activity} be an indicator of the generated traffic i.e. percentage of subscriptions that have data to be transferred; the assumed values vary from 10% to 50% in this example.

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8 *Demographia*: p. 50, Table 3.

9 UN1: Figure 3, p. 4 – growth of urban population in India, UN2: Figure 11, p. 16 – growth of medium-sized cities in India.

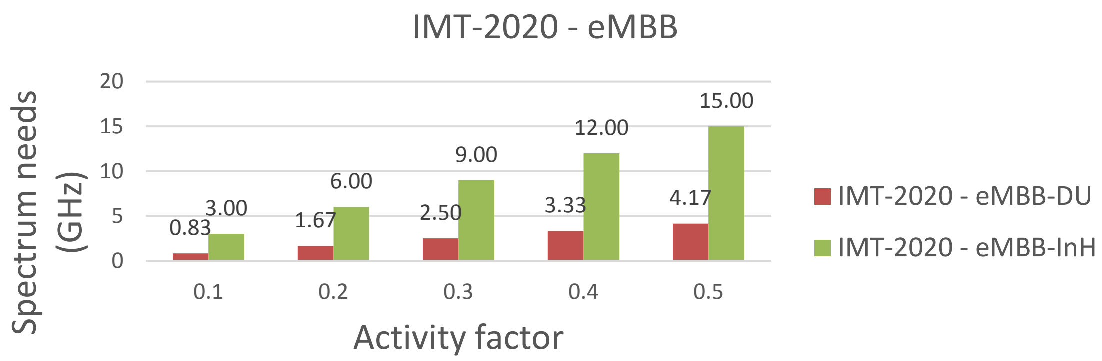
c) Then the number of active cell-edge users could be derived as:

$N = \alpha_{\text{users cell-edge}} \times \beta_{\text{activity}}$.

10 The spectrum needs is calculated for activity factors ranging from 10% to 50% using the formula $B = (D \times N) / S$. The resulting spectrum needs are as shown in Figure A.2-3:

FIGURE A.2-3

Spectrum needs estimates for eMBB-DU and eMBB-InH environments in Example 2



As can be seen in Figure A.2-3, the spectrum needs vary from 0.83-4.17 GHz, for eMBB-DU, and 3-15 GHz, for eMBB-InH.

Example 3 – Impact of latency and spectral efficiency targets and a typical user throughput value on spectrum needs

Consider a single user in a "test environment" consisting of an urLLC usage scenario in an InH deployment:

1 Assume the user is downloading high-quality photographs with overall size of 10 Mbits.

2 Assume a latency requirement of 10 ms, which corresponds to the instant speed of 10 Mbits/10 ms or 1 Gbit/s.

a) Low-latencies are required in automation, virtual and augmented reality, PS & "mission-critical" communications.

3 Spectral efficiency → 3 × 0.1 = 0.3 bits/s/Hz.

a) As per Recommendation ITU-R M.2083, 3 times the corresponding spectrum efficiency in Report ITU-R M.2134.

4 Spectrum needs = (1 Gbit/s) / (0.3 bits/s/Hz) = 3.33 GHz (one direction) for 10 Mbits/ 10 ms or 1 Gbit/s.

a) For 1 ms delay, 33.33 GHz would be required.

5 Using the same calculation procedure:

b) For 1 ms delay, 3.33 GHz (one direction) would be required for a single user which is downloading high-quality photographs with overall size of 1 Mbit.

c) For 1 ms delay, 333 MHz (one direction) would be required for a single user which is downloading high-quality photographs with overall size of 0.1 Mbits.

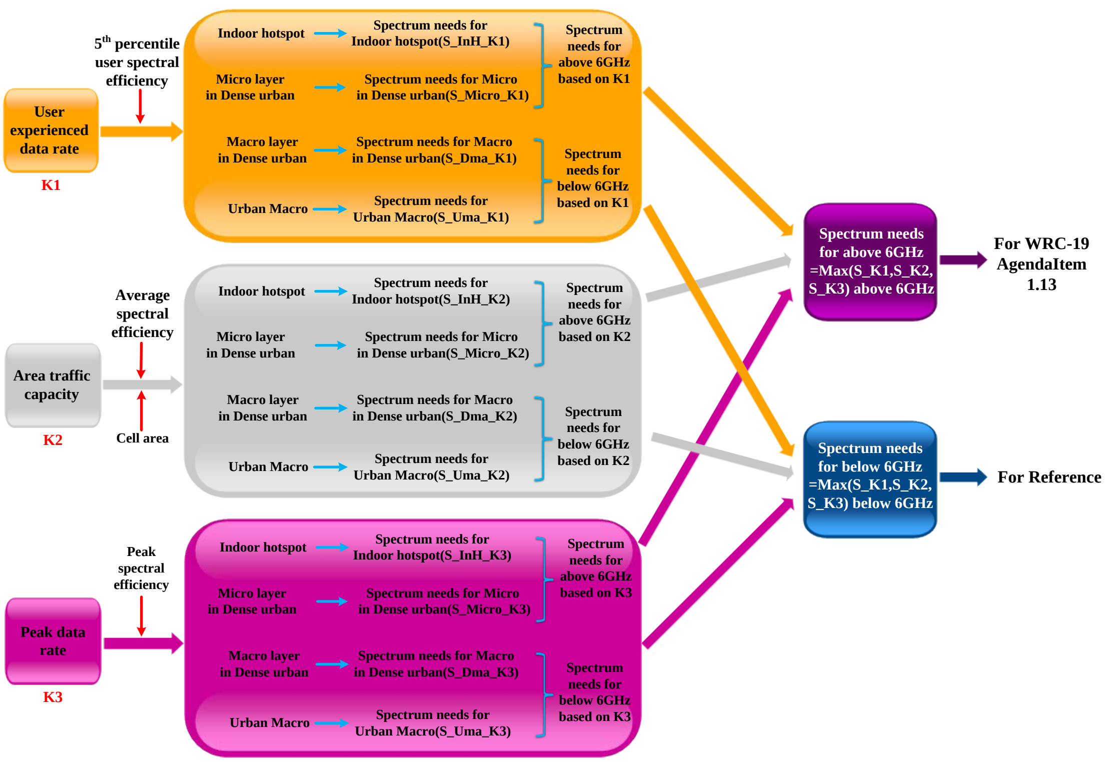
A.2.2 Type 2

(1) General description

The spectrum needs can be estimated based on different key capabilities of eMBB scenario of IMT-2020. User experienced data rate, peak data rate and area traffic capacity are three main key capabilities to be considered in this Type 2 as shown in the following figure. Each key capability could be mapped to different deployment scenarios including indoor hotspot, micro & macro layers in dense urban and urban macro. As in each deployment scenario the key deployment solutions and parameters are defined, it is feasible to estimate the spectrum efficiency of the network via numerical analyses or system level simulations. Combining the performance requirements in each key capability and its mapping relation to the specific deployment scenario, with the estimated spectrum efficiency of the network in each deployment scenario, the spectrum needs of each deployment scenario could be calculated. Then, the spectrum needs for each key capability which considers all deployment scenarios could be further derived according to the user distribution and spectrum strategy. Considering that the spectrum needs should satisfy all the key capabilities of the network, the maximum one of spectrum needs obtained from different key capabilities is regarded as the final spectrum needs which includes the lower frequency range (below 6 GHz) and higher frequency range (above 6 GHz) for eMBB of IMT-2020. The spectrum needs for above 6 GHz is used to satisfy the future development requirement of IMT-2020 in the frequency range between 24.25-86 GHz under WRC-19 agenda item 1.13, while the spectrum needs for below 6 GHz can be used as a reference.

FIGURE A.2-4

Spectrum needs estimate approach for eMBB



(2) Calculation method

K1: User experienced data rate

Following equation can be used for the IMT spectrum needs estimate with user experienced data rate of IMT-2020.

Spectrum needs = User experienced data rate / 5^{th} percentile user spectral efficiency

Input parameter:

– User experienced data rate (bits/s)

– 5^{th} percentile user spectral efficiency (bits/s/Hz)

K2: Area traffic capacity

Following equation can be used for the IMT spectrum needs estimate with area traffic capacity of IMT-2020.

Spectrum needs = Area traffic capacity × Cell area / Average spectral efficiency

Input parameter:

– Area traffic capacity (bits/s/m^2)

– Cell area (m^2/cell)

– Average spectral efficiency (bits/s/Hz)

K3: Peak data rate

Following equation can be used for the IMT spectrum needs estimate with peak data rate of IMT-2020.

Spectrum needs = Peak data rate / Peak spectral efficiency

Input parameter:

– Peak data rate (bits/s)

– Peak spectral efficiency (bits/s/Hz)

(3) Spectrum needs estimate steps

Step 1: Key capabilities and relative technical parameters

Confirm the target value of 3 key capabilities and relative technical parameters in different deployment scenarios.

User experienced data rate (K1): User experienced data rate (bits/s), active user numbers per cell (user/cell) and 5^{th} percentile user spectral efficiency (bits/s/Hz)

Area traffic capacity (K2): Area traffic capacity (Mbits/s/m^2) and cell area and average spectral efficiency (bits/s/Hz)

Peak data rate (K3): Peak data rate (Gbits/s) and peak spectral efficiency (bits/s/Hz)

Step 2: Spectrum needs for deployment scenarios

Calculate the spectrum needs for all the deployment scenarios based on 3 key capabilities according to the calculation methodology described in “(2) Calculation method” above. The uplink spectrum needs and downlink spectrum needs could be calculated respectively and derived to the total spectrum needs for every deployment scenarios based on each key capability.

Step 3: Spectrum needs for key capabilities

The spectrum needs for each key capability which considers all deployment scenarios could be further derived according to the user distribution and spectrum strategy, which includes the lower frequency range (below 6 GHz) and higher frequency range (above 6 GHz) for eMBB of IMT-2020.

Step 4: Final spectrum needs

The maximum one of spectrum needs obtained from different key capabilities should be regarded as the final spectrum needs which includes the lower frequency range (below 6 GHz) and higher frequency range (above 6 GHz) for eMBB of IMT-2020.

(4) Spectrum needs estimate result

Based on the technical performance-based approach with three key capabilities of IMT-2020 described above, the spectrum needs estimate results for IMT-2020 for both below 6 GHz and above 6 GHz are summarized in the Table A.2-3 below.

TABLE A.2-3

Spectrum needs estimate result of IMT-2020 for both below 6 GHz and above 6 GHz

<table>
<tr><th>Deployment scenario</th><th>Macro</th><th>Micro</th><th>Indoor hotspot</th></tr>
<tr><td>Total spectrum needs for below 6 GHz</td><td>808-1078 MHz*</td><td>–</td><td>–</td></tr>
<tr><td>Total spectrum needs for 24.25-86 GHz</td><td>–</td><td colspan="2">14.8-19.7 GHz*</td></tr>
<tr><td>Spectrum needs for 24.25-43.5 GHz**</td><td>–</td><td>5.8-7.7 GHz</td><td rowspan="2">9-12 GHz</td></tr>
<tr><td>Spectrum needs for 45.5-86 GHz**</td><td>–</td><td>–</td></tr>
</table>

* Considering the coexistence between multiple network operators (e.g. the guard band(s) may be required in the case of multiple network operators scenarios), the total spectrum needs are expected to be increased.

** The division in this table regarding frequency ranges and deployment scenarios is just an indicative example how spectrum needs could be distributed for different spectrum sub-ranges within 24.25-86 GHz and different deployment scenarios. This table should not be understood nor used to exclude any possible IMT-2020 deployment options in these sub-ranges.

ANNEX B

Information on spectrum needs in some countries

The following information was provided by some administrations with regard to their national considerations on spectrum needs for IMT in the frequency range 24.25-86 GHz or for the fifth generation (5G) mobile communications, which would relate to the spectrum needs for the terrestrial component of IMT in the frequency range between 24.25 GHz and 86 GHz indicated in *resolves to invite ITU-R* 1 in Resolution **238 (WRC-15)**.

– The United States has made available 3.85 GHz of spectrum for licensed operation in the 27.5-28.35 GHz, 38.6-40 GHz, 37-38.6 GHz frequency bands on a shared basis with existing services including the fixed satellite service and an additional 7 GHz for licensed-exempt operation in the 64-71 GHz spectrum.

– The Republic of Korea plans to provide 4 GHz of bandwidth for 5G service in the band above 24.25 GHz: 3 GHz in the band 26.5-29.5 GHz by 2018 when 5G systems are available, at latest by 2021 and additional 1 GHz by 2026 taking into account WRC-19 results.

– Sweden provides information on the spectrum needs in Sweden for IMT in the respective frequency ranges as shown below:

Frequency range (GHz)	Spectrum needs (GHz) in Sweden
24.25-33.4	3
37-43.5	2.5
45.5-52.6	2.5
66-86	4.5

– Brazil proposes the spectrum needs based on the application approach. The spectrum needs can be distributed in the following ranges:

Frequency range (GHz)	Spectrum needs (GHz) in Brazil
24.25-33.4	4.0
37.0-52.6	To be developed
66.0-86.0	At least 6.0
Total	10 to 18

– Egypt (Arab Republic of) provides information on the spectrum needs in Egypt for IMT in the respective frequency ranges as shown below:

Frequency range (GHz)	Spectrum needs (GHz)* in Egypt
24.25-27.5 and 31.8-33.4	2
37-43.5	2
45.5-50.2 and 50.4-52.6	2
66-76	4
81-86 GHz	3

Note *: These numbers are based on a preliminary assessment.

– Bahrain (Kingdom of) provides information on the spectrum needs in Bahrain for IMT in the respective frequency ranges as shown below:

Frequency range (GHz)	**Spectrum needs (GHz) in Bahrain**
24.25-27.5 and 37-43.5	6
24.25-86	10

– Russian Federation provides information on the spectrum needs in Russian Federation for IMT in the respective frequency ranges as shown below:

Frequency range (GHz)	**Spectrum needs (GHz) in Russian Federation**
24.25-43.5	2
43.5-86	5