9. Spectrum Implications

To realize the "Extreme Flexibility" of 5G, it is necessary to utilize all frequency bands, including both the lower ranges (below 6GHz) and the higher ones (above 6GHz), while considering the different characteristics of each frequency band.

The first section of this chapter will describe the roles of both lower bands and higher bands, and the following section will focus on the evaluation of preferable frequency bands in the range between 6 and 100GHz. The results came from a study that includes three stages of evaluation, i.e. 5G intra-system, inter-system, harmonization point of view, respectively. The resulting preferred bands from the results of Stage 2 are then discussed.

9.1 Concept for 5G spectrum

As shown in Chapter 4, mobile communication traffic has been increasing at a high rate in recent years. This growth is predicted to continue into the next decade, especially in consideration of the addition of new traffic types generated by the variety of new use cases of 5G. This high traffic growth leads to the conclusion that the spectrum below 6 GHz, both currently used and future plans, targeted for exclusive licensing to mobile broadband operators could be exhausted before the end of the decade. Thus, there is a high demand to be able to utilize new spectra above 6GHz on top of the current spectra already in use for the mobile communication. The allocation of new spectra is not only essential for the mobile industry to expand its business opportunities, but also key factor in enabling other industries to be able to offer their customers new services and improve their productivities utilizing 5G. Without allocating new spectra, serious economic losses will occur in countries.

Industry, academia and regulatory agencies are already aware of these facts and challenges and they are working tirelessly to tackle the spectrum scarcity problem in a variety of ways. Some examples include:

- Improving spectral efficiency by employing such techniques as higher modulation and coding schemes, and spatial multiplexing in the physical (PHY) layer as well as reducing control overhead in the medium access control (MAC) layer;
- Reducing cell sizes by using less transmit power and reusing the spectrum intelligently, and more recently overlapping deployments of small cells over macro cell with interference coordination amongst cells, in other words, Heterogeneous Network, which could notably mitigate outages at the cell edge of smaller cells;

- Optimizing media content (i.e. compression) for transporting it more efficiently over the network;
- Pursuing the use of higher frequency bands above 6 GHz, which has garnered significant attention recently, even with technical challenges in terms of path loss and cost of RF components,;
- Offloading traffic to wireless LAN (WLAN), which practically improves as much capacity of the mobile network as WLAN offloading offers.

Among those efforts above, the radio communication industry is investing heavily in development of higher frequency bands above 6 GHz, including mmWave. This is primarily due to the availability and use of wider bandwidth, which will be become necessary for the enhanced mobile broadband usage scenario and increasing traffic.

In addition to the enhanced mobile broadband usage scenario, the increasing momentum of the Internet of Things (IoT) means the infrastructure for 5G will have additional requirements, including supporting massive connectivity and ultra-reliability with ultra-low latency, on top of the long-pursued challenge to enhance peak data rate. Some IoT use cases may also require larger coverage area with lower power consumption than today.

These new use cases will require the utilization of all frequency bands, including both the lower ranges of the spectrum below 6GHz and higher ranges above 6GHz, depending on the different characteristics of each frequency band. It is especially important to have Heterogeneous Network deployment across lower and higher frequency bands be common in the 5G era. This new concept of spectrum deployment will give 5G systems extreme flexibility in networks and services.

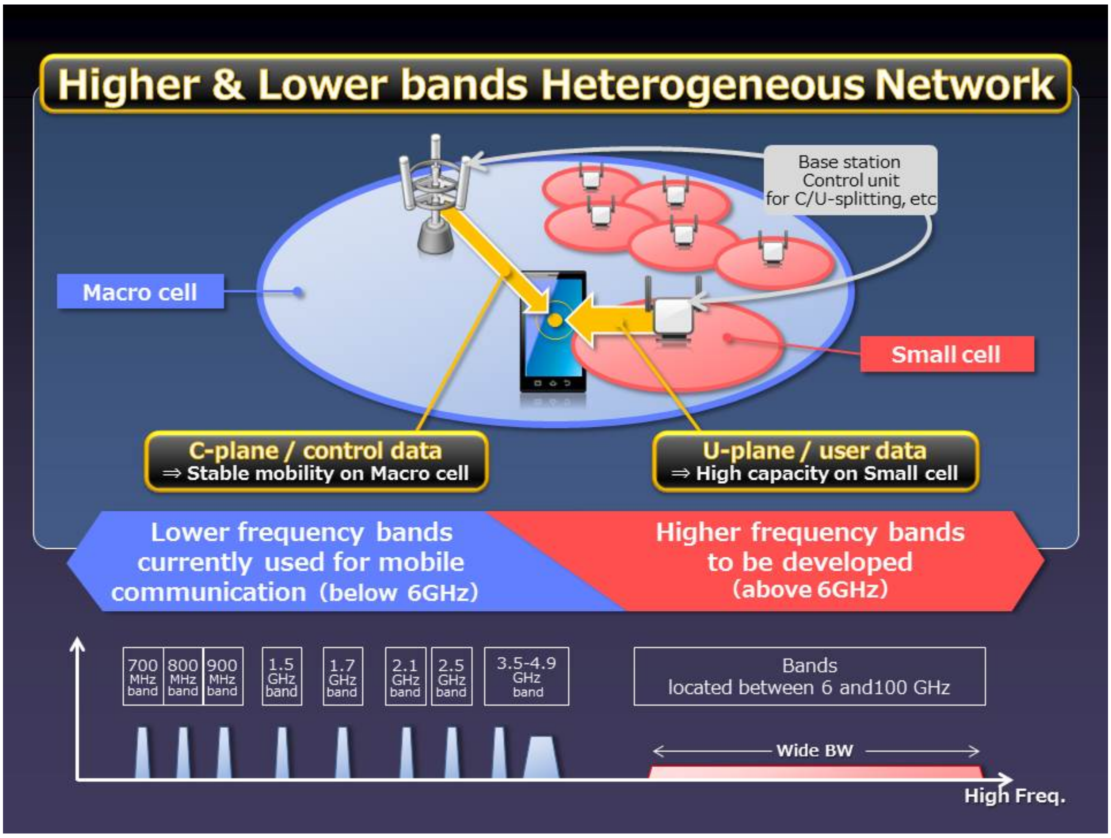


Fig. 9.1-1 Heterogeneous Network in 5G across lower and higher frequency bands

9.2 Below 6GHz

9.2.1 Roles of bands below 6GHz

Diverse demands and larger scale of performance ranges will be required in future radio networks in order to provide mobile users with a variety of services at any occasion, anytime and anywhere as needed.

In the lower frequency bands below 6GHz, radio wave propagation has the following inherent characteristics:

- Lower propagation loss due to the distance
- Larger diffraction and reflection effects, which can cover shadowed areas such as behind buildings or hilly terrain
- Better penetration from outdoor to indoor through building walls or window glass

Thus, the lower frequency bands below 6GHz are more suitable for wider and contiguous coverage. These benefits also assist the implementation of seamless mobility for tracking mobile devices.

On the other hand, the available bandwidth is relatively narrow in these bands. In addition, a larger cell radius results in the possibility of the multi-path propagation with a longer delay. A larger cell radius also results in the possibilities of larger interferences.

Taking the above characteristics into account, the bands below 6GHz will still play a very important role in the 5G era by providing:

- Conventional types of services and deployments;
- New IoT/M2M services, especially for low bit rate and low power consumption in the wide field area;
- Carriers for C-plane in C/U-split Heterogeneous Network deployment;
- Fundamental cells of 5G network for universal service continuity, where higher frequency small cells are not deployed

It should also be noted that bands below 6GHz are important for the backward compatibility and roaming support.

Services in 5G specific higher bands may be limited in some areas on location by location basis, while 4G/3G service areas are spread widely and contiguously. In order to ensure seamless service for mobile devices even in such a composite cell structure, user devices should be able to work accessing either 3G/4G or 5G radio network. This means backward compatible operation will be required for future mobile networks. In order to be backward compatible, conventional lower frequencies will be required to work as the fundamental band even within the structure of a 5G radio access network.

In addition, considering the frequency arrangement commonly used worldwide according to the already identified spectra for IMT by ITU-R under the international harmonization, the bands below 6GHz are thought to be suitably applicable for international roaming, at least at the beginning of the 5G era.

9.2.2 Technical Implementation and Challenges

Since the bands below 6GHz have been used in 3G/4G systems, technical challenges for utilizing these bands are the same as 3G/4G and therefor do not pose a challenge for 5G.

In principle, it seems there are no fundamental issues left in order to utilize these bands. However, there are some difficulties and challenges in implementation. One difficulty is the complexity of mobile devices needed to support the diverse frequency arrangements. As described in "ARIB 2020 and Beyond Ad Hoc Group White Paper"[9-1], the number of the logical frequency bands specified in 3GPP has been increased to more than 40 bands including both FDD and TDD[9-2]. Furthermore, the different combinations of carrier aggregation have been increasing over time. Small fragmented bands are another difficulty to overcome to use the wider bandwidth required in 5G.

It will also be necessary to develop mitigation techniques and coordination schemes for frequency sharing with incumbent radio systems for the new frequency bands to be introduced towards the year 2020.

9.2.3 Current spectrum allocation and its plan in Japan, below 6GHz

Fig.9.2.3-1 shows current allocation for IMT, Broadband Wireless Access (BWA) and Personal Handy-phone System (PHS) in Japan, which includes:

- 700M, 800M, 900M, 1.5G, 1.7G, and 2GHz bands for LTE/LTE-Advanced (FDD)
- 1.9GHz band for PHS
- 2.5GHz band for BWA
- 3.5GHz band for LTE-Advanced (TDD)

The total bandwidth allocated for these uses is approximately 640MHz.

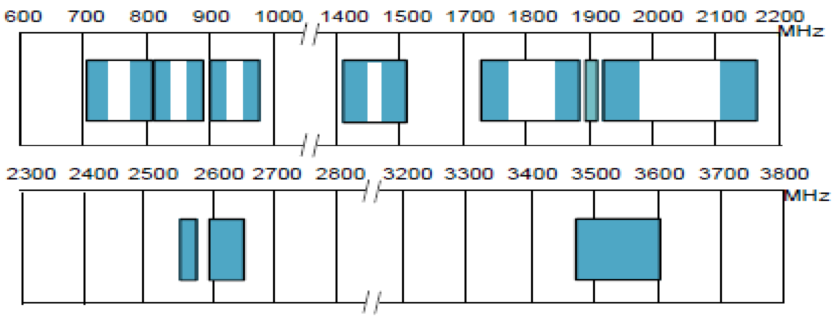


Fig. 9.2.3-1 Allocation for IMT, BWA and PHS in Japan (as of Dec. 2015) [9-3]

According to the report of the Commission on Radio Policy Vision in 2014[9-4], the total amount of spectrum bandwidth targeted for IMT, BWA, PHS and WLAN is 2700MHz for the frequency below 6GHz by the year 2020 in Japan. The candidate bands to be newly allocated below 6GHz include the 4GHz band (3.6-4.2GHz) and the 4.5GHz band (4.4-4.9GHz).

9.2.4 Spectrum identified for IMT below 6GHz in WRC-15

IMT bands have been identified in ITU Radio Regulation as a result of WRC (World Radiocommunication Conference).

In WRC-15 (Nov. 2015), among the bands proposed by Japan, 1.5GHz band (1427-1518MHz) which has already been allocated for mobile phone systems in Japan since 2G era, has been identified for IMT globally.

9.3 Above 6GHz

9.3.1 Roles of bands above 6GHz

Future 5G systems will need to support very high data throughput to cope with the growth of the data traffic and new and emerging usage scenarios, especially for enhanced mobile broadband scenarios. These scenarios may require contiguous and broader bandwidth than that of current mobile systems. Furthermore the development of technologies such as small cells, 3D beamforming and massive MIMO techniques may realize their full potential when applied to smaller wavelength, which is characteristic of higher frequency bands.

In order to address the challenges above, there has been ongoing research and development concerning the suitability of mobile broadband systems in frequency bands above 6GHz[9-5]. It is expected that the use of higher frequencies above 6GHz will become one of the key enabling components of 5G.

9.3.2 Preferred frequency ranges/bands

It is required to identify the frequency ranges or bands above 6GHz on which to deploy 5G systems. To facilitate this identification, an analytical investigation is being conducted to identify these preferred frequency ranges or bands for 5G.

9.3.2.1 Procedure of investigation

The process for the analytical investigation on the frequency bands between 6 and 100GHz consists of the three stages described in the figure below.

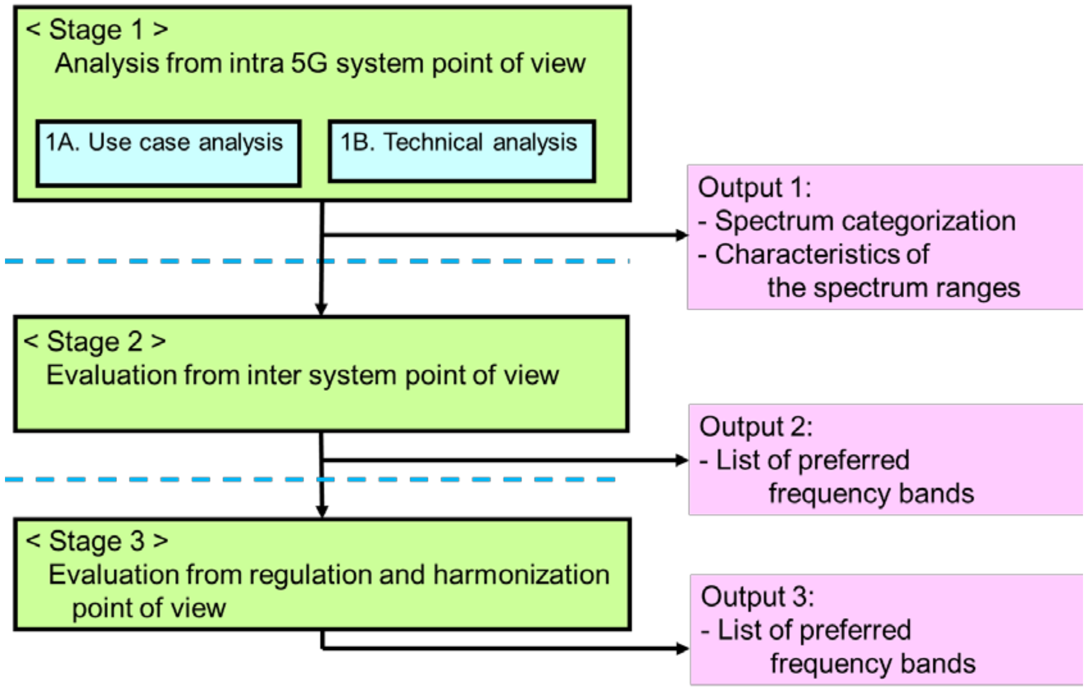


Fig.9.3.2.1-1 Process of spectrum analysis on above 6GHz for 5G

In Stage 1, the use case analysis and technical analysis were done in order to have technical characteristics of the frequency ranges 6 to 30GHz, 30 to 60GHz and 60 to 100GHz respectively.

In Stage 2, each frequency band was evaluated for 5G deployment while considering the incumbent radio systems already deployed in Japan on the frequency bands. This stage resulted in a list of preferred frequency bands

In Stage 3, the bands listed after the evaluation process in Stage 2 are being further evaluated in consideration of views from other countries and/or regions and spectrum harmonization. Stage 3 will result in another list of preferred frequency bands, which are potentially a subset of the Stage 2 output.

9.3.2.2 Stage1: Analysis from intra 5G system point of view

In this sub-section, results of the analysis for 6-100 GHz are shown, from the intra 5G system point of view, targeting to determine preferred frequency ranges from both a) bandwidth requirements coming from use case analysis for 5G era, and b) feasibility analysis on the technical aspects. Those analyses include general classification of the frequency band into several groups, and further investigation into coverage examples and typical deployment scenarios.

Firstly, in order to simplify discussion for frequency dependent characteristics, we classified the targeted frequency bands i.e. 6-100 GHz into 3 groups as follows:

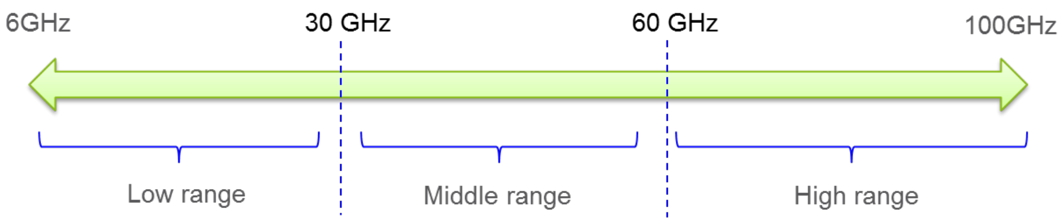
Low range 6-30 GHz / Middle range 30-60 GHz / High range 60-100 GHz

Secondly, we attempted to determine the bandwidth requirements per each spectrum range, based on use case analysis in the 5G era, which is summarized in Chapter 7.

Thirdly, we conducted a study of the following items for technical analysis.

- Frequency vs. distance attenuation
- Impact of rain attenuation
- Atmospheric influence
- Fractional bandwidth
- Antenna size / number of elements / antenna gain
- Devices (semiconductors, filters, connectors, etc.)

Finally, we concluded the study of stage 1 as described below (Fig.9.3.2.2-1).



Spectrum range	Low (6 – 30GHz)	Middle (30 – 60GHz)	High (60 – 100GHz)
Practical range of a contiguous spectrum bandwidth (Note 1)	Approx. 300MHz - 1.5GHz	Approx. 1.5GHz - 3GHz	Approx. 3 – 5GHz
Coverage example (Note 2)	Several 100m – Approx. 1km	⟷	Several 10m – Approx. 100m
Deployment scenario	Different scenarios for mobile communication are possible (Outdoor, Indoor, Outdoor to indoor, Hotspot and so on)	⟷	Scenarios for wider bandwidth and dense deployment (Indoor, Hotspot and so on)

(Note 1) These values are contiguous spectrum bandwidth considering fractional bandwidth of 5% with respect to the carrier frequency. The fractional bandwidth of 5% is derived by reviewing the existing 3GPP frequency bands. The values do neither represent required spectrum bandwidth (spectrum demand), nor imply any actual spectrum assignment which is subject to administrative authorities. This bandwidth is desired to be contiguous, in terms of the efficient use of spectrum and implementation (on the other hand, considering 5G applications (Mobile Broadband, M2M and so on), bandwidth of several 100MHz to several GHz is desired, however it is necessary to consider actually available bandwidth for 5G in each range).
(Note 2) The coverage values can vary depending on radio propagation condition, deployment scenario, applicable radio technologies and so on .

Fig. 9.3.2.2-1 Result of Stage 1

9.3.2.3 Stage2: Evaluation from inter system point of view

This sub-section shows the results of the Stage 2 evaluation on the preferred frequency bands from an inter system point of view. Inter system indicates considerations on the incumbent radio systems that are already deployed in Japan on the frequency bands. We evaluated the possibility of frequency sharing between IMT system and the incumbent radio systems in Japan on the frequency bands above 6GHz (6GHz to 100GHz). The evaluation was based on the following evaluation criteria decided within the 5GMF.

<Evaluation criteria of the frequency bands>

4 levels were set in order to express the results of the evaluation on possibility of frequency sharing as follows:

Level 1 : No possibility for sharing

a) Bands listed in Footnote 5.340 of ITU-R Radio Regulation or in Footnote J107 of national allocation in Japan, where all emissions are prohibited.

b) Systems which are related to safety of human life and are always in use (e.g. Aeronautical radionavigation)

Level 2 : Difficult for sharing

Level 3 : Possible for sharing under certain conditions and worth considering for sharing

a) The incumbent radio system has already been shared with land mobile communication systems in other bands.

b) Sharing may be possible under certain operation conditions.

(The incumbent radio system is also operated by the mobile communication operator, e.g. wireless entrance for IMT, etc.)

c) Sharing is possible technically by introducing a certain sharing technology, mitigation technique, and/or geographical/allochronic isolation.

(e.g. The incumbent radio system is in use only when a disaster occurs, etc.)

Level 4 : Possible for sharing

(e.g. No radio license is found in the public data base, or only radio stations for experimental or temporary operations are assigned.)

(Note) Unlicensed ISM (Industry - Science - Medical) bands were not evaluated such as 24-24.25GHz, and 57-66GHz.

Frequency bands in Levels 3 and 4 have a high possibility of frequency sharing and are therefore the preferred bands for 5G.

The results of the Stage 2 evaluation determining which frequency bands can be called level 3 or 4 are listed in the following tables. (Table 9.3.2.3-1, 9.3.2.3-2, 9.3.2.3-3)

Table 9.3.2.3-1 Results of Stage2 (6-30GHz)

Frequency Band (GHz)	Bandwidth (GHz)	Level of sharing possibility
5.925 – 7.25	1.325	3, 4
7.375 – 8.75	1.375	3, 4
10 – 10.5	0.5	3
10.55 – 10.68	0.13	3
10.7 – 11.7	1.0	3
14.5 – 15.35	0.85	3
15.4 – 21.4	6.0	3, 4
22 – 23.6	1.6	3
24.75 – 31	6.25	3, 4

Table 9.3.2.3-2 Results of Stage2 (30-60GHz)

Frequency Band (GHz)	Bandwidth (GHz)	Level of sharing possibility
31 – 31.3	0.3	4
31.5 – 42.5	11	3, 4
45.3 – 47	1.7	4
47 – 50.2	3.2	3, 4
50.4 – 52.6	2.2	3, 4
54.25 – 57	2.75	3

Table 9.3.2.3-3 Results of Stage2 (60-100GHz)

Frequency Band (GHz)	Bandwidth (GHz)	Level of sharing possibility
66 – 76	10	3, 4
81 – 86	5	3
92 – 100	8	4

All results of evaluation are shown in the following Figures (Fig. 9.3.2.3-1 to Fig. 9.3.2.3-4).

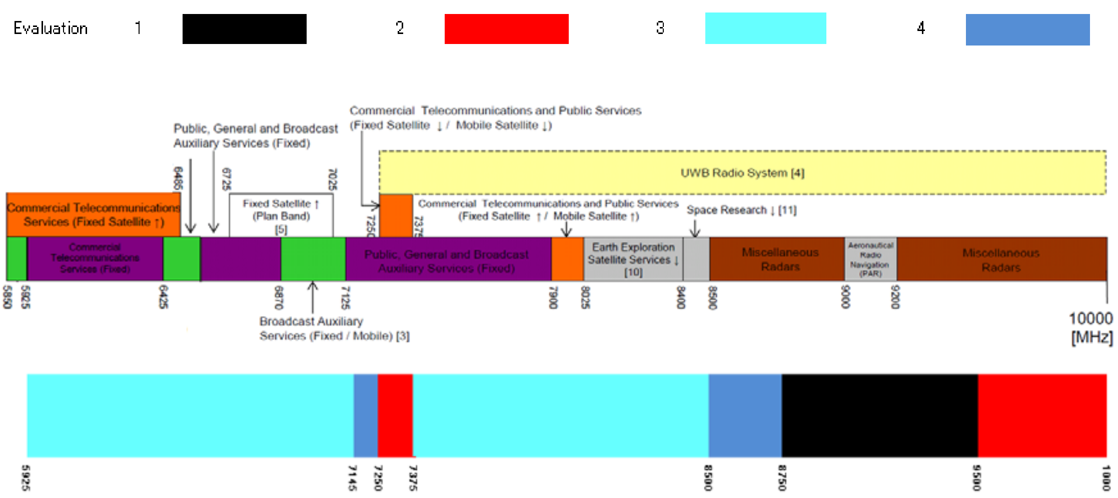


Fig. 9.3.2.3-1 Result of Stage 2 (6-10GHz)

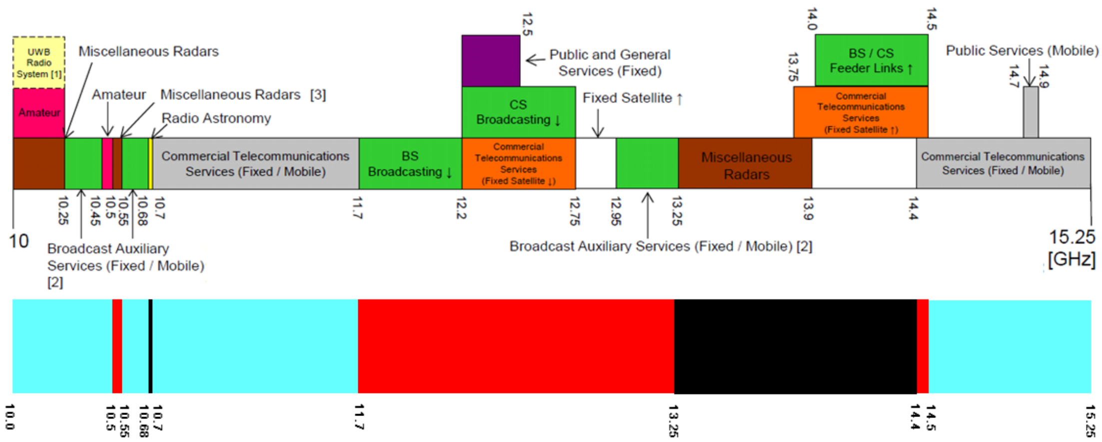


Fig. 9.3.2.3-2 Result of Stage 2 (10-15.25GHz)

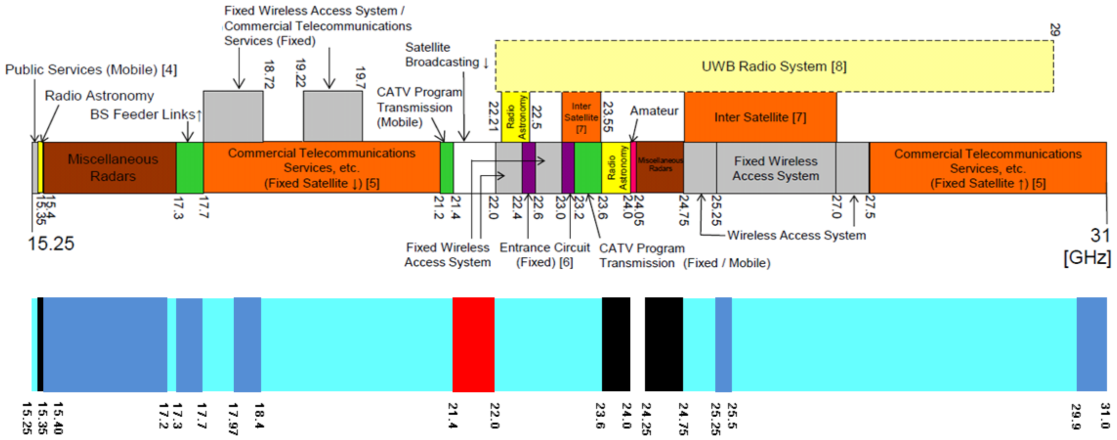


Fig. 9.3.2.3-3 Result of Stage 2 (15.25-31GHz)

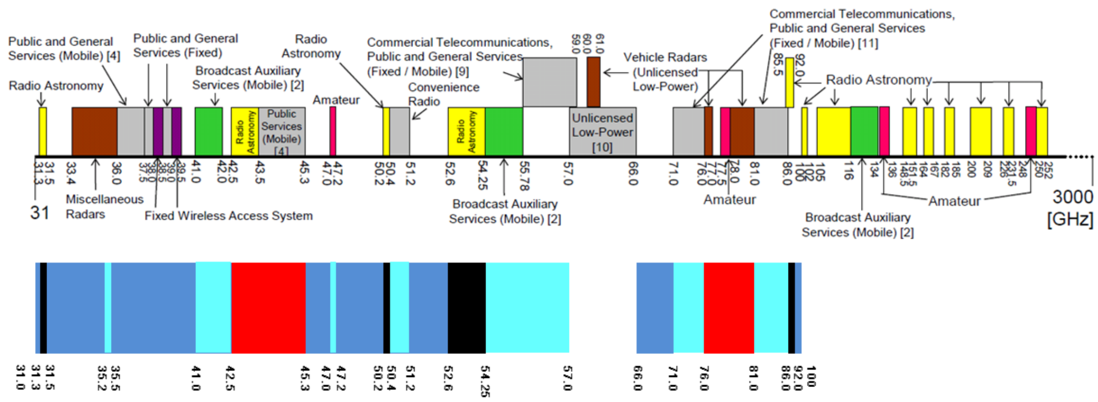


Fig. 9.3.2.3-4 Result of Stage 2 (31-100GHz)

9.3.2.4 Stage3: Evaluation from regulation and harmonization point of view

5GMF will continue further evaluation from the point of view of international harmonization. The spectrum ranges in WRC-19 Agenda Item 1.13 (see section 9.3.4) will be also taken into account.

9.3.3 Technical implementation issue and Challenges

Frequency bands above 6GHz have already been used for many years for satellite communications, radar applications, fixed services, short range & broadband WLAN (WiGig®), etc. Since many technologies have already been developed utilizing these higher bands and there seems no fatal issue to introduce 5G in these bands.

This will, however, be the first time a cellular system is deployed in these bands and there are still some technical issues and challenges to be solved from a deployment and/or implementation point of view.

9.3.3.1 Propagation losses

One major characteristic of higher frequency bands is propagation loss.

(a) Loss due to distance / Antenna gain

Propagation loss becomes larger as frequency becomes higher. Across the same distance, the loss increases in 6dB when the frequency is doubled.

On the other hand, the size of the antenna element becomes smaller as the frequency increases. This means that, in higher frequency bands, high antenna gain can be obtained by directional antennas, for example an array antenna, with a realistic physical size. Since antenna gain of same aperture size increases in 6dB when frequency is doubled, the increase of propagation loss can be compensated using array antennas or other similar antennas.

However, antenna beam width becomes narrower as antenna gain increases. Also, hardware complexity increases as the number of elements in an array antenna increases. Thus, there is a trade-off between antenna gain and coverage area.

(b) Loss due to gasses, vapor, rain and mist

In the case of several 10 meters to a couple of 100 meter coverage distance, most of these characteristics seem to be of little concern compared to the free space loss due to distance. The loss around 60GHz due to gasses and the loss due to heavy rain (>30mm/h) should be taken into account in certain deployments.

However, these attenuations vary as temperatures and air pressure changes. Although the variation is not very large, it should be noted that there may occur unwanted “cell breathing” due to air temperature and pressure which is not seen in lower frequency band.

Detailed figures of these characteristics are shown in ANNEX [9].

9.3.3.2 RF Devices and Components

(a) Power amplifier devices for transmitter

One of key devices used in higher frequencies are power amplifiers for transmitters, both in the base station and in the terminal.

Such devices for 6 to 100 GHz are already available, although cost reduction and performance improvements are still necessary.

(b) Filters and passive devices

Passive devices including filters give us another challenge in higher frequency bands.

Some of the existing filter types used in the frequency below 6GHz may not work for the frequency bands above 6GHz. The introduction of new types of filters like the miniaturized Surface Mount Device (SMD) type waveguide filter is also necessary

(c) RF connectors and cables

The wavelength at very high frequencies is comparable or even shorter compared to the physical size of RF connectors, which makes it difficult to have good impedance matching. In addition, the increase of AC resistance due to skin effects becomes more remarkable.

Besides improvements to RF connectors and cables, these effects can be avoided by careful design of equipment, e.g. using frequency down conversion so that RF connectors and/or RF cables are only inserted at IF (Intermediate Frequency), etc.

9.3.4 WRC-19 Agenda Item 1.13

The WRC-15 decided to consider the identification of frequencies for IMT in the frequency range of 24.25GHz-86GHz at WRC-19 under Agenda Item 1.13.

Table 9.3.4-1 shows comparison between frequency bands listed under WRC-19 AI1.13 and the result of Stage 2 evaluation (levels 3 and 4) in 5GMF.

5GMF will continue to evaluate all the frequency bands listed in this table.

Table 9.3.4-1 Frequency bands listed under WRC-19 AI1.13
and the result of 5GMF Stage 2 evaluation
(green: which have allocations to the mobile service on a primary basis
yellow: which may be considered for additional allocations to the mobile service on a primary basis)
(a) 6-30GHz

WRC-19 Agenda Item 1.13			5GMF Stage2 (levels 3 & 4)		
BW(GHz)	frequency band(GHz)		frequency band(GHz)		BW(GHz)
			5.925	7.250	1.325
			7.375	8.750	1.375
			10.000	10.500	0.500
			10.550	10.680	0.130
			10.700	11.700	1.000
			14.500	15.350	0.850
			15.400	21.400	6.000
			22.000	23.600	1.600
3.250	24.250	27.500			
			24.750	31.000	6.250

(b) 30-60GHz

WRC-19 Agenda Item 1.13			5GMF Stage2 (levels 3 & 4)		
BW(GHz)	frequency band(GHz)		frequency band(GHz)		BW(GHz)
			24.75	31.00	(repeated)
			31.00	31.30	0.30
			31.50	42.50	11.00
1.60	31.80	33.40			
3.50	37.00	40.50			
2.00	40.50	42.50			
1.00	42.50	43.50			
			45.30	47.00	1.70
1.50	45.50	47.00			
0.20	47.00	47.20	47.00	50.20	3.20
3.00	47.20	50.20			
2.20	50.40	52.60	50.40	52.60	2.20
			54.25	57.00	2.75

(c) 60-100GHz

WRC-19 Agenda Item 1.13			5GMF Stage2 (levels 3 & 4)		
BW(GHz)	frequency band(GHz)		frequency band(GHz)		BW(GHz)
10.00	66.00	76.00	66.00	76.00	10.00
5.00	81.00	86.00	81.00	86.00	5.00
			92.00	100.00	8.00

References

[9-1] ARIB 2020 and Beyond Ad Hoc Group White Paper, "Mobile Communications Systems for 2020 and beyond" Version 1.0.0, Oct. 2014

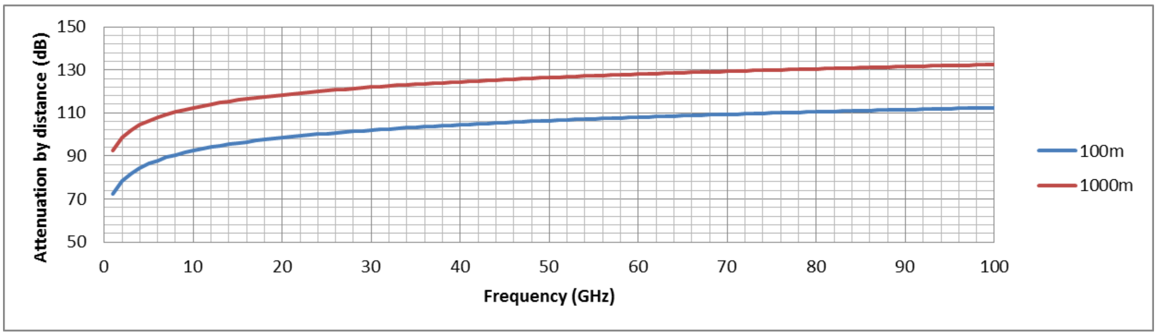
[9-2] 3GPP TS 36.101 V13.2.1, "Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) radio transmission and reception (Release 13)", Jan. 2016

[9-3] Ministry of Interal Affairs and Communications, Information and Communications Council #114 materials, Dec.11, 2015 (in Japanese)

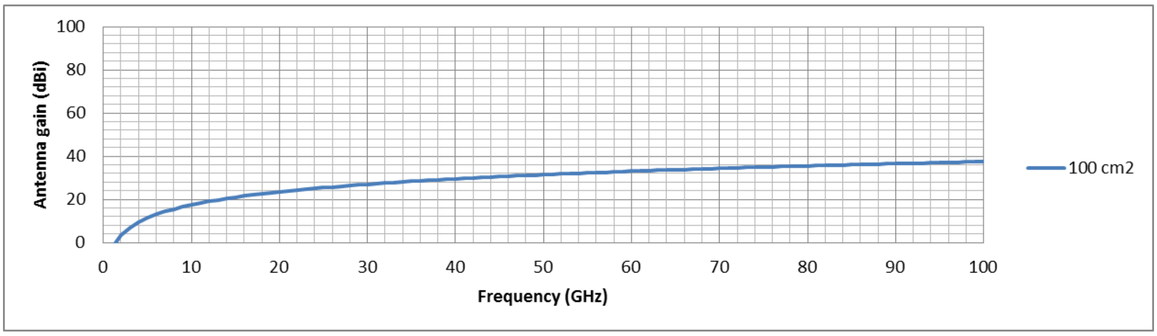
[9-4] Ministry of Interal Affairs and Communications, Report of the Commission on Radio Policy Vision, Dec. 26, 2014 (in Japanese)

[9-5] Report ITU-R M.2376-0, "Technical feasibility of IMT in bands above 6 GHz", July 2015

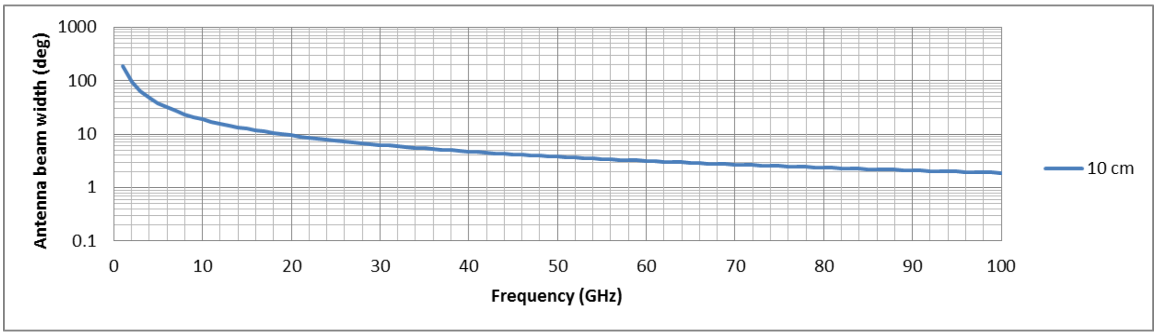
Annex [9] Characteristics of propagation loss above 6GHz



(a) Propagation loss in free space vs. frequency

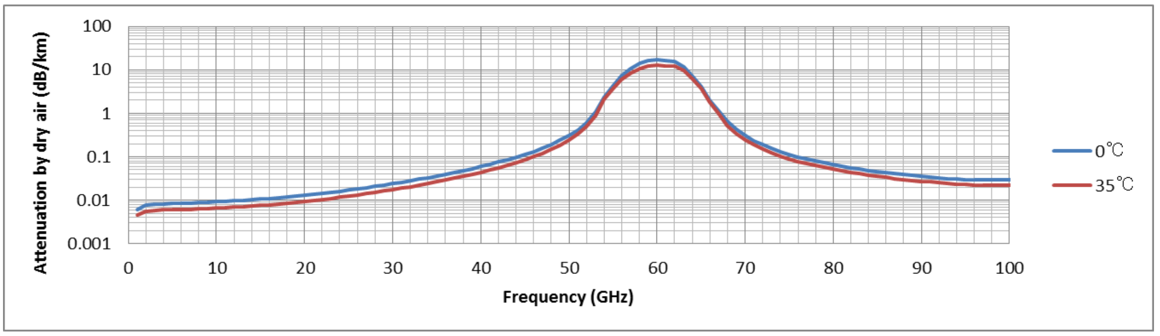


(b) Antenna gain of directional antenna with fixed aperture area

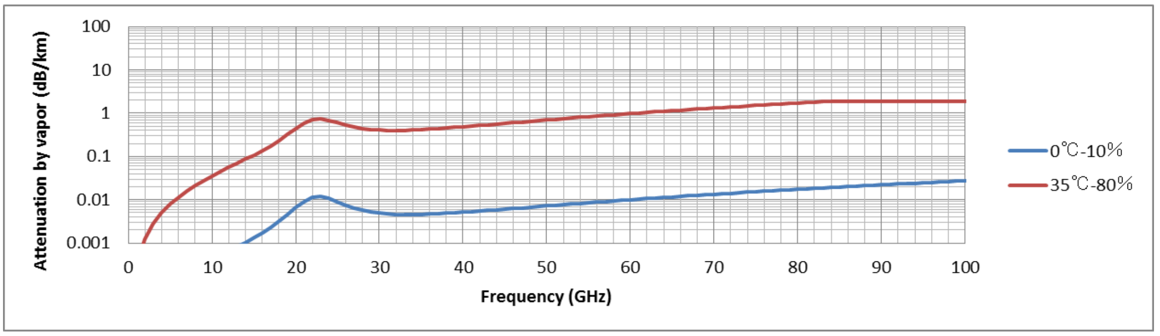


(c) Antenna beam width of directional antenna with fixed antenna width

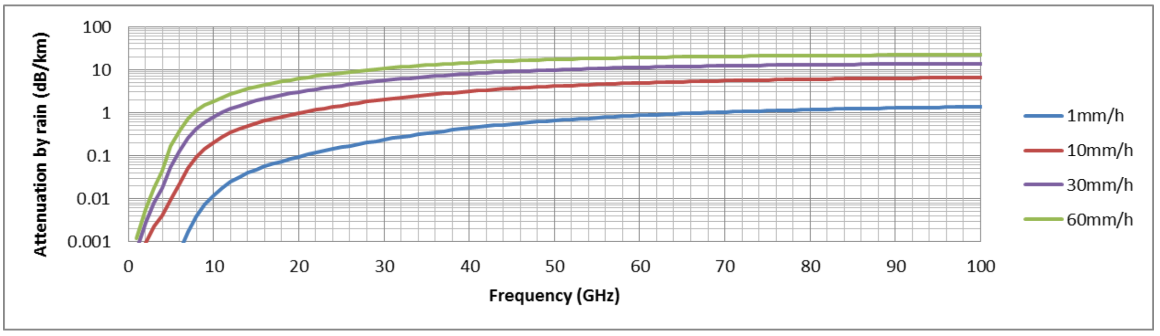
Fig.A[9]-1 Frequency dependency of propagation loss in free space and antenna characteristics



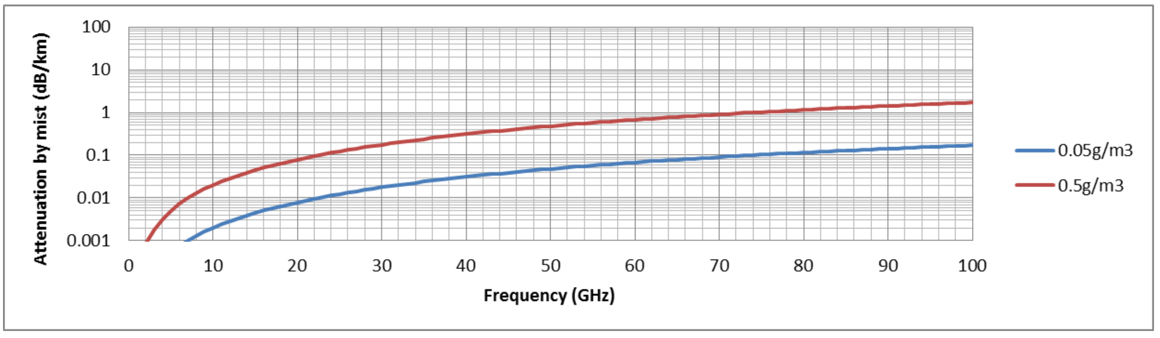
(a) loss due to gas (dry air)



(b) loss due to vapor



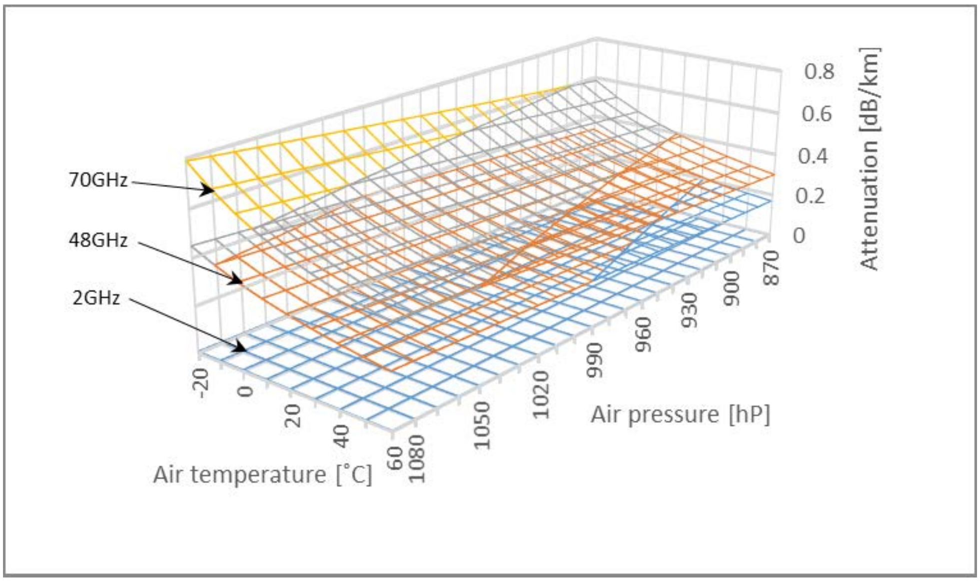
(c) loss due to rain



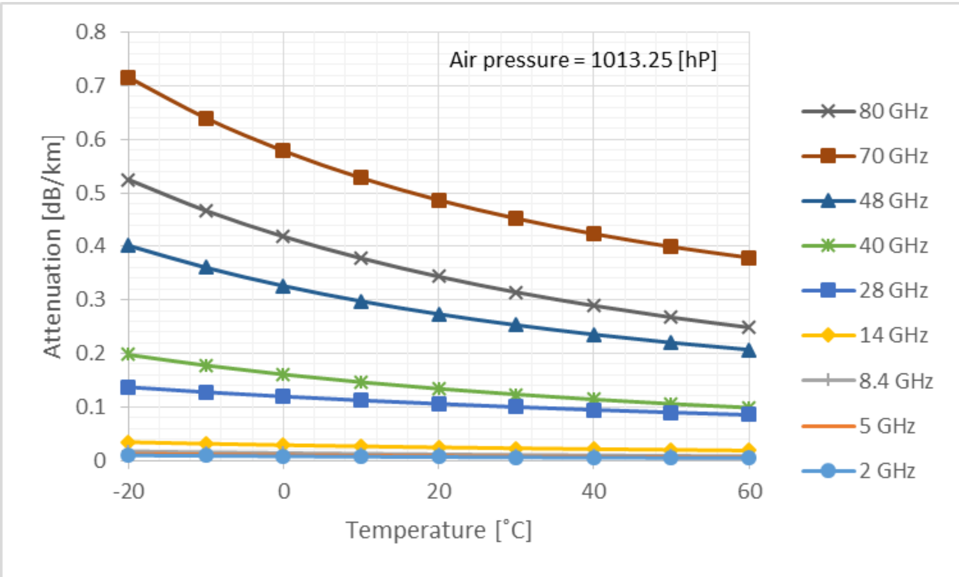
(d) loss due to mist

Fig.A[9]-2 Frequency dependency of propagation loss due to gas, etc.

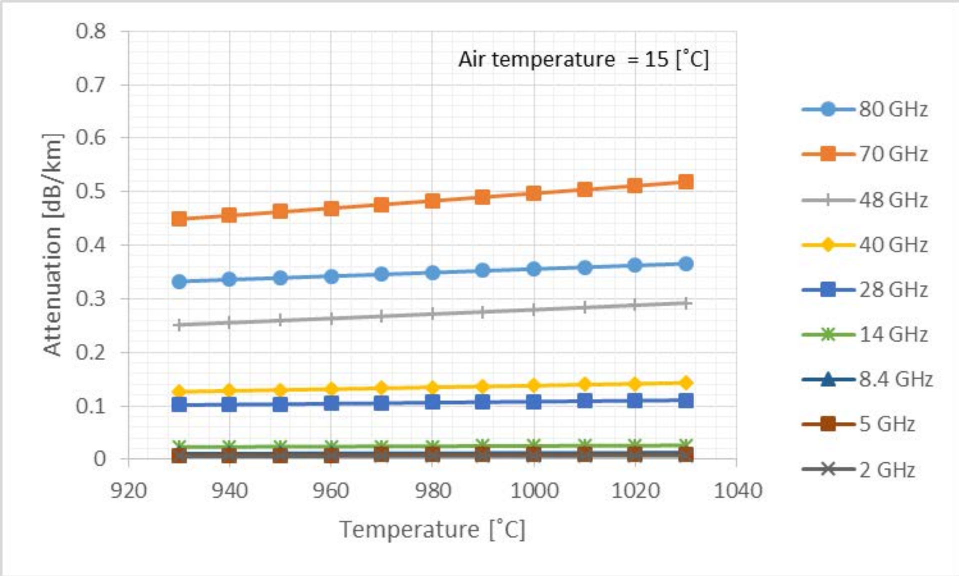
[A9-1][A9-2][A9-3]



(a) Attenuation due to atmospheric gasses (vs. air pressure and temperature)



(b) Attenuation due to atmospheric gasses vs. air temperature



(c) Attenuation due to atmospheric gasses vs. air pressure

Fig.A[9]-3 Detailed analysis of attenuation due to atmospheric gasses [A9-1]

References

[A9-1] ITU-R, "Attenuation by atmospheric gases", Recommendation ITU-R P.676-10, Sep. 2013

[A9-2] ITU-R, "Specific attenuation model for rain for use in prediction methods", Recommendation ITU-R P.838-3, Mar. 2005

[A9-3] ITU-R, "Attenuation due to clouds and fog", Recommendation ITU-R P.840-6, Sep. 2013

Terminology, abbreviations

Abbreviation	Unabbreviated term
3D	Three Dimensional
AC	Alternating Current
BW	BandWidth
C-plane	Control plane
FDD	Frequency Division Duplex
IMT	International Mobile Telecommunications
IoT	Internet of Things
ITU	International Telecommunication Union
ITU-R	ITU Radiocommunication sector
M2M	Machine To Machine
MIMO	Multiple Input Multiple Output
RF	Radio Frequency
TDD	Time Division Duplex
U-plane	User plane
WLAN	Wireless Local Area Network
WRC	World Radiocommunication Conference