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M Series: Mobile, radiodetermination, amateur and related satellite services

Bandwidth considerations for land mobile service applications in the frequency range 275-450 GHz

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REPORT ITU-R M.2548-0

Bandwidth considerations for land mobile service applications in the frequency range 275-450 GHz

(2024)

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1 Introduction

Report ITU-R M.2417 presents initial bandwidth considerations for some land-mobile service (LMS) applications above 275 GHz where the bandwidth needs are 50 GHz (refer to its Annex 5). This bandwidth should be sufficient to support high-data rate transmission for LMS applications. Radio Regulations (RR) No. **5.564A**, which identifies the frequency bands 275-296 GHz, 306-313 GHz, 318-333 GHz and 356-450 GHz for use by administrations for the implementation of land mobile and fixed service applications where no specific conditions are necessary to protect Earth exploration-satellite service (passive) applications, was added at WRC-19, taking into account the bandwidth and the technical and operational characteristics provided in Report ITU-R M.2417.

The spectrum efficiency[1] is one of important technical parameters for bandwidth considerations of LMS applications operating in the frequencies above 275 GHz. The spectrum efficiency has not been clearly indicated in Reports ITU-R M.2417 and ITU-R SM.2352. However, many technical papers regarding performance of THz transceivers have been published in academic journals (see section 8, Bibliography) and the range of spectrum efficiency could be estimated using information from the above references.

Since high-volume ultra-high-definition TV (UHDTV) transmission for close proximity mobile systems (CPMS) and augmented reality/ virtual reality (AR/VR) applications and high-speed data transmission by wireless links in data centres are expected to use the above identified bands, bandwidth considerations for those applications using the spectrum efficiency could assist to specify the frequency bands. This Report provides information on RF performance and technologies of LMS transceivers which can be utilized to estimate the bandwidth for LMS applications above 275 GHz.

2 Scope

This Report addresses the bandwidth considerations for LMS applications operating in the frequencies above 275 GHz using spectrum efficiency based on the recent studies of RF technologies.

3 Related ITU-R Reports

Report ITU-R F.2416 – Technical and operational characteristics and applications of the point-to-point fixed service applications operating in the frequency band 275-450 GHz

Report ITU-R M.2417 – Technical and operational characteristics of land-mobile service applications in the frequency range 275-450 GHz

Report ITU-R M.2516 – Future technology trends of terrestrial International Mobile Telecommunications systems towards 2030 and beyond

4 List of acronyms and abbreviations

AR	Augmented reality
CMOS	Complementary metal-oxide-semiconductor
CPMS	Close proximity mobile system
HEVC	High efficiency video coding
LMS	Land-mobile service
MIMO	Multiple-input multiple-output

[1] bit/s/Hz.

QAM	Quadrature amplitude modulation
QPSK	Quadrature phase shift keying
SISO	Single-input single-output
THz	Terahertz
TOR	Top-of-rack
UHDTV	Ultra-high-definition television
VR	Virtual reality

5 LMS applications operating in frequencies above 275 GHz

5.1 Streaming data rates of UHDTV

System bandwidths depend on streaming data rates for video signals. Table 1 summarizes streaming data rates for transmitting uncompressed or compressed ultra-high-definition TV signals (8K). It may be preferable to send uncompressed 8K video to avoid large latency, but the uncompressed 8K video requires ultra-high-speed data rates depending on video parameters, as shown in Table 1. Latency is determined from a trade-off between streaming data rates and signal processing capabilities. Unlike lower frequencies, THz (1 THz = 10^{12} Hz) spectrum may provide sufficient bandwidths for transmitting uncompressed 8K video.

TABLE 1

Example of streaming data rates of uncompressed and compressed UHDTV

Resolution	Frame frequency (frame/s)	Multilevel gradation (bit)	Colour depth (bit)	Streaming data rate (Gbit/s)	
				Uncompressed	H.265 (1/300)
7 680 × 4 320	120	12	36	144.0	0.48
	120	8	24	96.0	0.32
	60	8	24	48.0	0.16
	30	8	24	24.0	0.08

5.2 Specific LMS applications and their maximum associated data rates

Specific LMS applications are contained in Report ITU-R M.2417. Table 2 summarizes the maximum preferable data rates for specific LMS applications which can be used to estimate the bandwidths as described below. Information from Report ITU-R SM.2352 is also taken into account for consideration of Table 2.

TABLE 2

Specific LMS applications and their maximum associated data rates

LMS applications	Maximum associated data rates	Remarks
Kiosk downloading mobile system	Several tens of Gbit/s	Mobile terminal to fixed station connections
Automatic turnstile downloading mobile system	A few hundreds of Gbit/s	Mobile terminal to fixed station connections
Inter-chip and intra-device communications	A few tens of Gbit/s	
Wireless links for data centres	Several hundreds of Gbit/s	Intra-rack and inter-rack connections
Virtual reality	Several tens of Gbit/s	Mobile terminal to fixed station connections

5.3 Performance of transceivers for LMS applications in the frequencies above 275 GHz

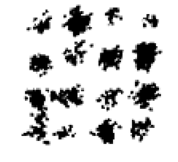
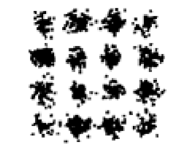
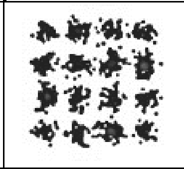
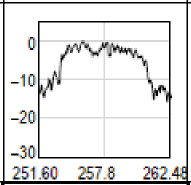
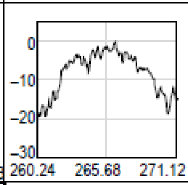
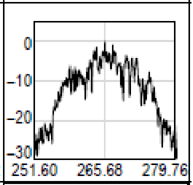
This section provides information on measured signals from transceivers fabricated using complementary metal-oxide-semiconductor (CMOS) technology and compares results between the measured signal and spectrum mask as defined in Report ITU-R M.2417. The performance of the CMOS transceiver is summarized in Fig. 1. Three channels whose channel numbers are referred from Report ITU-R M.2417 are selected to evaluate transmission performance of a single-chip transceiver using 16-QAM modulation scheme. The transmission data rates of 28.16 Gbit/s and 80 Gbit/s are achieved by channel 49 and 66 with bandwidths of 8.64 GHz and 25.92 GHz, respectively.

Although the spectrum efficiency values larger than 3 are feasible by the current single-input single-output (SISO) technologies using 16-QAM modulation, higher spectrum efficiency could be achieved by introduction of multiple-input multiple-output (MIMO) transmission[2]. Report ITU-R M.2516 clearly indicates that due to the extremely short wavelength of terahertz spectrum, antenna elements become much smaller than those designed at millimetre wave bands, and many more antenna elements can be integrated in the same footprint. This MIMO system also improves spectrum efficiency by exploiting higher spatial resolution and frequency reuse. Figure 1 shows the results of 16-QAM transmission only, but if higher-order modulation schemes such as 64-QAM could be used for signal transmission, the spectrum efficiency would be further improved.

[2] See 802.15.3e-2017 – IEEE Standard for High Data Rate Wireless Multi-Media Networks-Amendment 1: High-Rate Close Proximity Point-to-Point Communications.

FIGURE 1

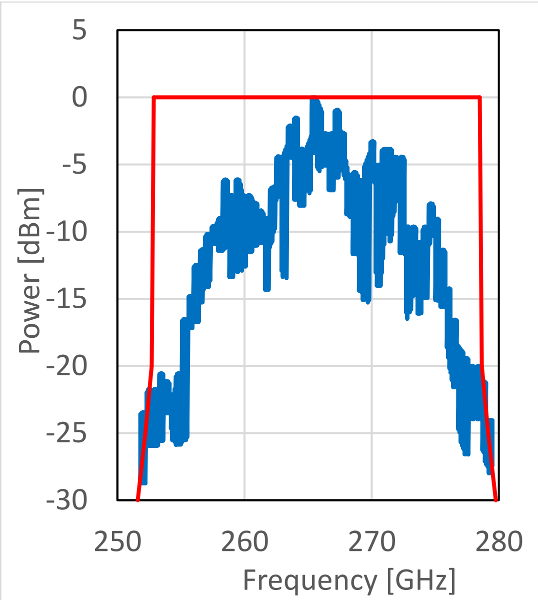
Characteristics of single-chip transceiver [1]

Channel	Ch. 49	Ch. 50	Ch. 66
Center freq.	257.04 GHz	265.68 GHz	265.68 GHz
Modulation	16 QAM	16 QAM	16 QAM
Data rate	28.16 Gbit/s	28.16 Gbit/s	80 Gbit/s
Constellation (Equalized)			
Spectrum			
EVM	10.9 %	11.3 %	12.0 %
Spectrum efficiency	3.26	3.26	3.09

The measured signal of Channel 66 in Fig. 1 is compared with the generic spectrum mask defined in Report ITU-R M.2417. Figure 2 shows the measured results (blue line) and the generic spectrum mask (red line). It should be noted that the out-of-band emission level of the measured signal is well situated within the generic spectrum mask.

FIGURE 2

Comparison between measured spectrum and generic spectrum mask



5.4 Survey of achievable data rates and spectrum efficiency

This section overviews achievable data rates and spectrum efficiency based on technical papers published at international academic symposia and journals in the frequency range 230-300 GHz [1]-[10]. Figures 3 and 4 show achievable data rates in the range of 25-110 Gbit/s and the spectrum efficiency in the range of 1.7-5.7, respectively. The maximum data rate and spectrum efficiency in this survey is 110 Gbit/s and 5.7 using Quadrature phase shift keying (QPSK) modulation and polarization diversity MIMO transmission [8]. It should be noted that MIMO could increase not only data rates of LMS applications, but also spectrum efficiency of LMS transceivers in frequencies above 275 GHz. The higher quadrature amplitude modulation (QAM) requires higher transmit power to get the same signal to noise ratio (S/N) as lower QAM in the receiver. Table 3 summarizes the technical parameters published in [1]-[10] which are used for creating Figs 3 and 4.

FIGURE 3

Achievable data rates in the frequency range 230-300 GHz

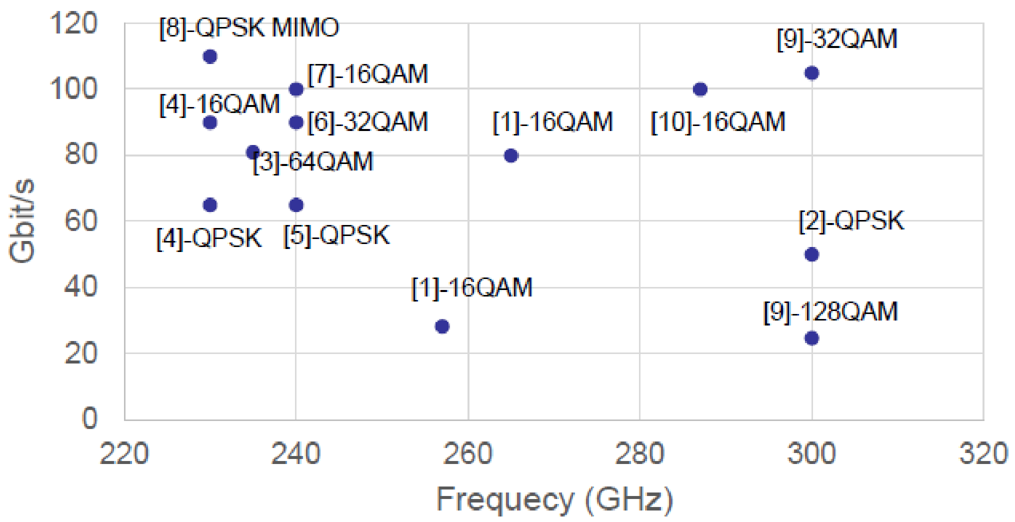


FIGURE 4

Achievable spectrum efficiency in the frequency range 230-300 GHz

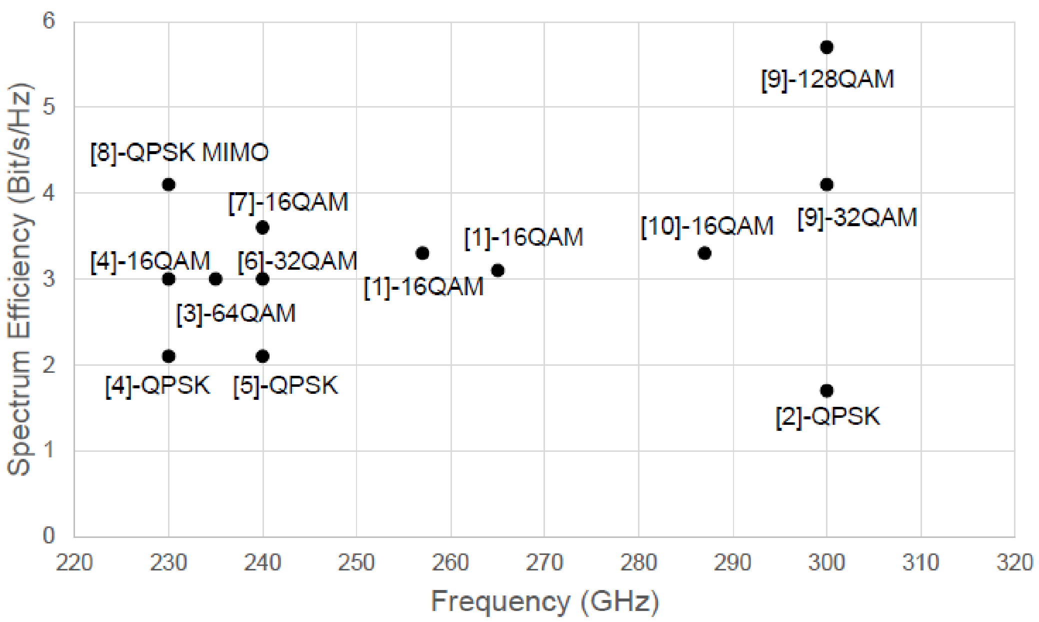


TABLE 3

Survey of technical parameters published in academic symposia and journals

Ref. no.	Centre frequency (GHz)	Channel bandwidth (GHz)	Modulation scheme	Data rate (Gbit/s)	Spectrum efficiency (bit/s/Hz)	Process	Remarks
[1]	265	25.92(1)	16-QAM	80	3.1	40-nm CMOS	TX-RX
[1]	257	8.64(1)	16-QAM	28.16	3.3	40-nm CMOS	TX-RX
[2]	300	30(2)	QPSK	50	1.7	250-nm InP HBT	TX-RX
[3]	235	27(2)	64-QAM	81	3	130-nm SiGe HBT	TX-RX
[4]	230	30(3)	16-QAM	90	3	130-nm SiGe HBT	TX-RX
[4]	230	30(3)	QPSK	65	2.1	130-nm SiGe HBT	TX-RX
[5]	240	30(3)	QPSK	65	2.1	130-nm SiGe HBT	TX-RX
[6]	240	30(3)	32-QAM	90	3	130-nm SiGe HBT	TX-RX
[7]	240	28(2)	16-QAM	100	3.6	130-nm SiGe HBT	TX-RX
[8]	230	27(2)	QPSK	110	4.1	130-nm SiGe HBT	TX-RX Polarization-diversity MIMO
[9]	300	4.32(1)	128-QAM	26.64	5.7	40 nm CMOS	TX
[9]	300	25.92(1)	32-QAM	105	4.1	40 nm CMOS	TX
[10]	287	30(2)	16-QAM	100	3.3	80-nm InP HEMT	TX-RX

(1) Spectrum mask provided in Report ITU-R M.2417.

(2) 3-dB RF bandwidth.

(3) 6-dB RF bandwidth.

6 Bandwidths estimation

6.1 CPMS and AR/VR applications

Ultra-high-definition television (UHDTV) or 8K videos whose uncompressed streaming data rates are 24 Gbit/s, 48 Gbit/s, 96 Gbit/s and 144 Gbit/s, depending on frame rates from 30 to 120 frames per second, as shown in Table 1, are expected to be serviced by digital platformers for CPMS applications. In order to transmit and receive the maximum uncompressed streaming data of 144 Gbit/s, the carrier bandwidth of those transceivers is estimated using spectrum efficiency depending on modulation scheme and $n \times m$ MIMO transmission capabilities. CPMS applications, in particular, automatic turnstile downloading mobile systems are designed to transfer ultra-high-speed data between mobile terminal and automatic turnstile transceivers. One-hour 8K video size is, e.g., 22 GB in the condition of a frame rate of 59.94, a colour depth of 8 bit per pixel and high efficiency video coding (HEVC) codec[3].

Table 4 summarizes the relationship between high-volume video size and file downloading time as a function of data rates. As an example, since the duration of contact between CPMS devices at the automatic turnstile is around 250 ms and the link setup time between CPMS devices is 2 ms [11], in order to download high-volume video content such as 22 GB within 248 ms, the data rate of 710 Gbit/s is required which corresponds to the estimated bandwidth of 47 GHz, if the spectrum efficiency is assumed to be 15 bit/s/Hz. The ranges of bandwidths for CPMS applications vary according to system parameters, but the carrier bandwidth around 50 GHz introduced in Annex 5 to Report ITU-R M.2417 could provide sufficient downloading time for CPMS devices at the automatic turnstile. Table 5 summarizes the estimated spectrum required to support high-volume video transmission within 248 ms with spectrum efficiency in the range of 2 to 32 bit/s/Hz for CPMS applications. The high spectrum efficiency could be achieved by a combination of multi-level modulation scheme and MIMO technologies.

IEEE 802 has developed IEEE Std 802.15.3e™-2017[4] and this standard specifies the maximum data rate of 157.7 Gbit/s using 64-QAM and 16 × 16 MIMO transmission which correspond to a spectrum efficiency of 73 bit/s/Hz. Although the operational frequencies of this standard are around 60 GHz, it should be noted that the high-order modulation and MIMO transmission are also applied to improve the spectrum efficiency around 300 GHz. The range of the spectrum efficiency values used in Table 5 is referred from the current attainable spectrum efficiency values provided in Fig. 2, taking into account the modulation multilevel number 4-QAM to 256-QAM and 2 to 4 MIMO layers.

The maximum data rate for AR/VR applications are 144 Gbit/s, as shown in Table 1. If the spectrum efficiency of the transceivers equipped with AR/VR devices is 3 bit/s/Hz, which utilize SISO transmission, the estimated carrier bandwidth of AR/VR device is estimated to be 48 GHz. The estimated carrier bandwidth of AR/VR could be also further decreased through the use of higher order modulation schemes and MIMO transmission.

TABLE 4

Estimated downloading time of high-volume video content

Video size (GB/hour)	**Downloading time (s)**				
	10 Gbit/s	**50 Gbit/s**	**100 Gbit/s**	**500 Gbit/s**	**1 000 Gbit/s**
1	0.8	0.16	0.08	0.016	0.008
5	4.0	0.8	0.4	0.08	0.04
10	8.0	1.6	0.8	0.16	0.08
50	40.0	8.0	4.0	0.8	0.4

[3] https://www.macxdvd.com/mac-video-converter-pro/compress-reduce-8k-video-size.htm

[4] See 802.15.3e-2017 – IEEE Standard for High Data Rate Wireless Multi-Media Networks--Amendment 1: High-Rate Close Proximity Point-to-Point Communications.

TABLE 5

Estimated bandwidth required to support high-volume video transmission within 248 ms for a range of spectrum efficiency values (bits/s/Hz)

8K video size (GB)	8K video transmission time (minutes)	Data rate (Gbit/s)	Estimated carrier bandwidth (GHz)				
			Spectrum efficiency 2 (bit/s/Hz)	Spectrum efficiency 4 (bit/s/Hz)	Spectrum efficiency 8 (bit/s/Hz)	Spectrum efficiency 16 (bit/s/Hz)	Spectrum efficiency 24 (bit/s/Hz)
0.375	1	12	6	3	1.5	0.75	0.5
22	60	710	355	178	89	44	29
37	100	1 194	597	299	149	75	49

6.2 Wireless links in data centres

High-speed optical links could be replaced with wireless links in two-tier (spine-leaf) or three-tier architectures consisting of two or three layers between servers and core networks, respectively. Each layer has high-speed switches which are known as access, aggregation/distribution and core switches. Access switches are the traditional Top-of-Rack (TOR) switches that consist of 24 to 48 ports with access layer connections with data rates in the range of 1-40 Gbit/s. Aggregation/distribution switches are mid-tier speed switches which support data rates of 10-400 Gbit/s. Core switches have the highest throughput in the range of 100-800 Gbit/s.

The trend of data rates between each tier is increasing from 25-100 Gbit/s to 100-400 Gbit/s, and data rates between aggregation/distribution and core switches is moving to 400-800 Gbit/s in recent years. Table 6 summarizes estimated bandwidths to support data rates of 100-1 200 Gbit/s with spectrum efficiency values in the range of 2 to 32 bit/s/Hz. The estimated bandwidths are varied from 2.5 to 200 GHz depending on spectrum efficiency which is a function of modulation schemes such as 64-QAM, 256-QAM and 1024-QAM, and the number of streams between transmitters and receivers. If wireless links in data centres are specified to cover the data rates in the range of 400-800 Gbit/s between aggregation/distribution and core switches, the range for estimated carrier bandwidth becomes 16.7-100 GHz if the spectrum efficiency is in the range of 8 to 24 bit/s/Hz, as shown in Table 6.

TABLE 6

Estimated bandwidth to support throughput of 100-1 200 Gbit/s

Data rate (Gbit/s)	Bandwidth (GHz)				
	Spectrum efficiency 2 (bit/s/Hz)	Spectrum efficiency 4 (bit/s/Hz)	Spectrum efficiency 8 (bit/s/Hz)	Spectrum efficiency 16 (bit/s/Hz)	Spectrum efficiency 24 (bit/s/Hz)
100	50	25	12.5	6.25	4.17
400	200	100	50	25	16.7
800	400	200	100	50	33.3
1200	600	300	150	75	50

7 Summary

The bandwidths for LMS applications are estimated using spectrum efficiency. It should be noted that a high-volume video content such as uncompressed UHDTV signals could be transferred to mobile terminals within a very short period, e.g. 248 ms, if sufficient carrier bandwidth could be used for the operation. The wireless links in data centres could provide high-throughput links between tiers up to 1 Tbit/s using bandwidths in the range of 60 to 120 GHz with spectrum efficiency in the range of 8 to 16 bit/s/Hz. Therefore, since the widest contiguous bandwidth for LMS application in the frequencies above 275 GHz is 94 GHz, in accordance with RR No. **5.564A**, the transceivers with a spectrum efficiency of 11 can cover the signal transmission of 1 Tbit/s for wireless links in data centres.

This Report may be further updated if the achievable data rate and spectrum efficiency of THz transceivers are advanced in the future.

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