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| **Radiocommunication Study Groups** |  |
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| Annex 9 to Working Party 5A Chair’s Report | |
| WORKING DOCUMENT TOWARDS A PRELIMINARY DRAFT NEW  REPORT ITU-R M.[LMS.SPEC.NEED.ABOVE.275 GHz] | |
| Spectrum needs for land-mobile service applications  in the frequency above 275 GHz | |

(Question ITU-R 256-1/5)

# 1 Introduction

Report ITU-R Report M.2417 presents initial spectrum needs for some LMS (land-mobile service) applications above 275 GHz where the spectrum need is 50 GHz. This bandwidth is sufficient to support high-data rate transmission for LMS applications. 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 this spectrum bandwidth and the technical and operational characteristics provided in Report ITU-R M.2417.

This Report further studied the spectrum need for LMS applications operating in the frequency above 275 GHz, taking into account high-volume UHDTV (Ultra-high-definition TV) transmission for CPMS (close proximity mobile systems) and AR/VR (augmented reality/ virtual reality) applications and high-data-speed transmission by wireless links in data centres using the current attainable technical parameters such as the spectrum efficiency at the 300 GHz band. This Report also provides RF technologies to support high-speed data transmission wirelessly and the attainable important parameter such as the spectrum efficiency to evaluate the spectrum need for LMS applications above 275 GHz.

# 2 Scope

This Report addresses the estimation of the spectrum needs for LMS applications operating in the frequency above 275 GHz.

# 3 Related Reports ITU-R

|  |  |
| --- | --- |
| [F.2416](https://www.itu.int/pub/R-REP-F.2416) | Technical and operational characteristics of land-mobile service applications in the frequency range 275-450 GHz |
| [M.2417](https://www.itu.int/pub/R-REP-M.2417) | Technical and operational characteristics of land-mobile service applications in the frequency range 275-450 GHz |
| [M.2516](https://www.itu.int/pub/R-REP-M.2516) | Future technology trends of terrestrial International Mobile Telecommunications systems towards 2030 and beyond |

**4 List of acronyms and abbreviations**

|  |  |
| --- | --- |
| AR | Augmented reality |
| UHDTV | Ultra-high-definition TV |
| VR | Virtual reality |

# 5 LMS applications operating in the frequency 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 required 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. THz (1 THz = 1012 Hz) spectrum may provide sufficient bandwidths for transmitting uncompressed 8K video.

TABLE 1

Example of streaming data rate of uncompressed and compressed UHDTV

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Resolution | Frame frequency (Hz) | Multilevel gradation (bit) | Color depth (bit) | Streaming data rate (Gbit/s) | |
| Uncompressed | H.265 (1/300) |
| 7680 × 4320 | 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 LMS applications provided in Report ITU-R M.2417

[Note: This section will be further studied at the next meeting.]

Seven LMS applications are provided in Report ITU-R M.2417-1. Key elements which specify the spectrum need are summarized in Table 2.

TABLE 2

LMS applications and their key elements

|  |  |  |
| --- | --- | --- |
| LMS applications | Range of data rates | Remarks |
| Kiosk downloading mobile system |  |  |
| Automatic turnstile downloading mobile system |  |  |
| Inter-chip communication system |  |  |
| Intra-device communications |  |  |
| Wireless links for data centres |  |  |
| Virtual reality |  |  |
| Industrial applications |  |  |

## 5.3 Performance of spectrum using current technologies

This section provides the measured spectrum using transceivers fabricated by COMS (Complementary metal-oxide-semiconductor) technology and the comparison results between the measured spectrum and spectrum mask defined in Report ITU-R M.2417. The performance of the CMOS transceiver is summarized in Figure 3. Three channels whose channel numbers are referred from Report ITU-R M.2417 are selected to evaluate transmission performance of single-chip transceiver using 16-QAM modulation scheme. The transmission data rates of 28.16 Gbit/s and 80 Gbit/s are achieved by the channel 49 and 66 whose bandwidths are 8.64 GHz and 25.92 GHz, respectively. Although the spectrum efficiency larger than 3 is feasible by the current SISO technologies, higher spectrum efficiency could be achieved by an introduction of MIMO transmission[[1]](#footnote-1). 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 footprint. This MIMO system also improves spectrum efficiency by exploiting higher spatial resolution and frequency reuse. Figure 3 shows the results of 16 QAM transmission only, but if higher-order modulation scheme such as 64 QAM could be used for signal transmission, the spectrum efficiency would be further improved.

FIGURE 3

Characteristics of single-chip transceiver [1]



The measured spectrum of Ch. 66 in Figure 3 is compared with the generic spectrum mask defined in Report ITU-R M.2417. Figure 4 shows the measured results (blue line) and the generic spectrum mask (red line). It could be noted that the out-of-band emission level of the measured spectrum is well suited within the generic spectrum mask.

FIGURE 4

Comparison between measured spectrum and generic spectrum mask

## 5.3 Survey of achievable data rates and spectrum efficiency

This section overviews achievable data rates and spectrum efficiency based on technical papers published at international academia symposia and journals in the frequency range 230-300 GHz [1]‑[10]. Figure 5 and 6 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 QPSK modulation and polarization-diversity MIMO transmission [8]. It is noted that MIMO may increase not only data rates of LMS applications, but also spectrum efficiency of LMS transceivers in the frequency above 275 GHz. The higher QAM induces higher transmitted power, to get the same S/N in the Rx as lower QAM. Table 3 summarizes the technical parameters published in Ref. [1]-[10] which are used for Figures 5 and 6.

FIGURE 5

Achievable data rates in the frequency range 230-300 GHz



FIGURE 6

Achievable spectrum efficiency in the frequency range 230-300 GHz



TABLE 3

Survey of technical parameters published in academia symposia and journals

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Ref. no. | Center 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 | 40nm CMOS | TX-RX |
| [1] | 257 | 8.64(1) | 16 QAM | 28.16 | 3.3 | 40nm 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 | 40nm CMOS | TX |
| [9] | 300 | 25.92(1) | 32 QAM | 105 | 4.1 | 40nm 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.2417-1.  (2) 3-dB RF bandwidth.  (3) 6-dB RF bandwidth. | | | | | | | |

# 6 Estimation of spectrum needs

## 6.1 CPMS and AR/VR applications

Ultra-high definition television (UHDTV) or 8K videos whose uncompressed streaming data rates are 24 Gb/s, 48 Gb/s, 96 Gb/s and 144 Gb/s depending on frame rates from 30 to 120 fps, as shown in Table 1, will be serviced by digital platformers for CPMS application. In order to transmit and receive the maximum uncompressed streaming data of 144 Gbit/s, the required bandwidth of those transceivers is estimated using the spectrum efficiency depending on modulation scheme and *n* × *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/px and HEVC (High Efficiency Video Coding) codec[[2]](#footnote-2). Table 4 summarizes the relationship between high-volume video size and file downloading time as a function of data rates. Since the duration of contact between CPMS devices at the automatic turnstile is around 250 msec and the link setup time between CPMS devices is 2 msec [11]. In order to download high-volume video content such as 22 GB within 248 msec, the data rate of 710 Gbit/s is required which corresponds to the estimated spectrum of 47 GHz, if the spectrum efficiency is assumed to be 15. The range of spectrum needs for CPMS applications changes depending on system parameters, but the frequency 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 msec in the range of spectrum efficiency 2-32 for CPMS applications. The high spectrum efficiency is achieved by a combination of multi-level modulation scheme and MIMO technologies. IEEE 802 developed IEEE Std 802.15.3eTM-2017[[3]](#footnote-3) and this standard specified the maximum data rate of 157.7 Gbit/s using 64 QAM and *16*×*16* MIMO transmission which corresponds to the spectrum efficiency of 73. Although the operational frequencies of this standard are the 60-GHz band, it should be noted that the high-order modulation and MIMO transmission are applied to improve the spectrum efficiency at the 300-GHz band. The range of the spectrum efficiency used in Table 2 is estimated using the current attainable spectrum efficiency in Figure 4, the modulation multilevel number 4-256 and multiple-input/multiple-output numbers 2-4.The maximum data rate for AR/VR applications are 144 Gbit/s, as shown in Table 1. The required spectrum need for this application is estimated using 144 Gbit/s and the spectrum efficiency. If the spectrum efficiency of the transceivers equipped with AR/VR devices is 3 based on the condition of SISO transmission in Figure 4, the required bandwidth of AR/VR devices is estimated to be 48 GHz. The required bandwidth could be further decreased depending on use of high-order modulation scheme and MIMO transmission.

TABLE 4

Estimated downloading time of high-volume video content

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Video size (GB/hour) | Downloading time (sec) | | | | |
| 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 |

TABLE 5

Estimated spectrum required to support high-volume video transmission within 248 msec in the range of spectrum efficiency 2-24

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 8K video size (GB) | Length (minutes) | Required data rates (Gbit/s) | Spectrum (GHz) | | | | |
| Spectrum efficiency  2 | Spectrum efficiency  4 | Spectrum efficiency  8 | Spectrum efficiency  16 | Spectrum efficiency  24 |
| 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) switch that consists of 24-48 ports with access layer connections in the range of data rates 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 spectrum required to support data rates of 100-1 200 Gbit/s in the range of the spectrum efficiency 2-32. The estimated spectrum varies from 2.5 to 200 GHz depending on the spectrum efficiency as a function of modulation schemes such as 64-QAM 256-QAM and 1024-QAM, as well as a stream number between transmitters and receivers. If wireless links in data centres are specified to cover the data rates 400/800 Gbit/s between aggregation/distribution and core switches, the range of the spectrum bandwidth becomes 17-100 GHz if the spectrum efficiency is in the range of 8-24, as shown in Table 4.

TABLE 6

Estimated spectrum required to support switching speed of 100-1200 Gbit/s

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Data rate (Gbit/s) | Spectrum (GHz); spectrum efficiency | | | | |
| 2 | 4 | 8 | 16 | 24 |
| 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 |

## 6.3 Other applications

*[TBD]*

# 7 Summary

*[TBD]*

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3. See IEEE Xplore <https://ieeexplore.ieee.org/document/7942281>. [↑](#footnote-ref-3)