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SERIES L: ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT

ITU-T L.1700 series – Low-cost sustainable telecommunications for rural communications in developing countries using microwave and millimetre radio links

ITU-T L-series Recommendations – Supplement 23

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Supplement 23 to ITU-T L-series Recommendations

ITU-T L.1700 series – Low-cost sustainable telecommunications for rural communications in developing countries using microwave and millimetre radio links

Summary

Supplement 23 to ITU-T L-series of Recommendations provides technical information about the use of microwave radio systems which are available for use in telecommunication networks for rural communications in developing countries. Example applications include: high-capacity backbone networks, synchronous digital hierarchy (SDH) network systems, and use in enterprise networks and mobile backhauls. The attractive features of microwave systems for rural communications in developing countries are: independence from geographical features, such as mountains and archipelagos; rapid system integration at a low cost; robustness against disasters; and security against human interference.

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* To access the Recommendation, type the URL http://handle.itu.int/ in the address field of your web browser, followed by the Recommendation's unique ID. For example, http://handle.itu.int/11.1002/1000/11830-en.

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Introduction

Microwave radio is the most popular method used to connect multiple base stations of mobile communication systems all over the world, and thus has been mass deployed in rural areas.

Microwave systems have many advantages, such as:

1) high economic efficiency during construction period:

   short work period;

   work on points, not lines.

2) high reliability:

   established link designs;

   redundancy (optional).

3) low cost in operation:

   small power consumption;

   highly integrated circuit;

   many advanced technologies for imperfection compensation.

These advantages bring many benefits to the people in developing countries through provision of the economical mobile communication infrastructures.

Microwave radio systems should be included in guides on good practices for setting up low-cost sustainable telecommunication infrastructure for rural communications in developing countries.

Moreover, considering the increase in demand for high capacity, millimeter-wave systems will be useful for concentrated stations.

Supplement 23 to ITU-T L-series Recommendations

ITU-T L.1700 series – Low-cost sustainable telecommunications for rural communications in developing countries using microwave and millimetre radio links

1 Scope

This Supplement provides technical information about the use of microwave radio systems which are available for use in telecommunication networks for rural communications in developing countries. Example applications include: high-capacity backbone networks, synchronous digital hierarchy (SDH) network systems, and use in enterprise networks and mobile backhauls. The attractive features of microwave systems for rural communications in developing countries are independence from geographical features, such as mountains and archipelagos; short-term system integration at a low cost; robustness against disasters; and security against human interference.

2 Abbreviations and acronyms

A/D	Analogue to Digital converter
ACM	Adaptive Coding and Modulation
ANSI	American National Standards Institute
ATPC	Automatic Transmit Power Control
CNR	Carrier-to-Noise Ratio
CS	Channel Separation
D/A	Digital to Analogue Converter
DC	Direct Current
DWRR	Deficit Weighted Round-Robin
ETSI	European Telecommunications Standards Institute
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FS	Fixed Microwave Service
IDU	Indoor Unit
IP	Internet Protocol
LDPC	Low-Density Parity-Check
LSI	Large Scale Integrated circuit
Mbps	Mega bit per second
NF	Noise Figure
ODU	Outdoor Unit
P-MP	Point to Multi-Point
P-P	Point to Point
QAM	Quadrature Amplitude Modulation
QPSK	Quadruple Phase Shift Keying

RF Radio Frequency

RSL Received Signal Level

Rx Receiver

Tx Transmitter

XPIC Cross polarization Interference Canceller

3 System description

3.1 General overview

Microwave radio systems are available in telecommunication and other communication networks at various locations. Figure 1 shows various applications of microwave systems: high-capacity backbone networks, SDH network systems, configure a company's enterprise network, and the last is used in mobile backhauls, which communicate between mobile base stations.

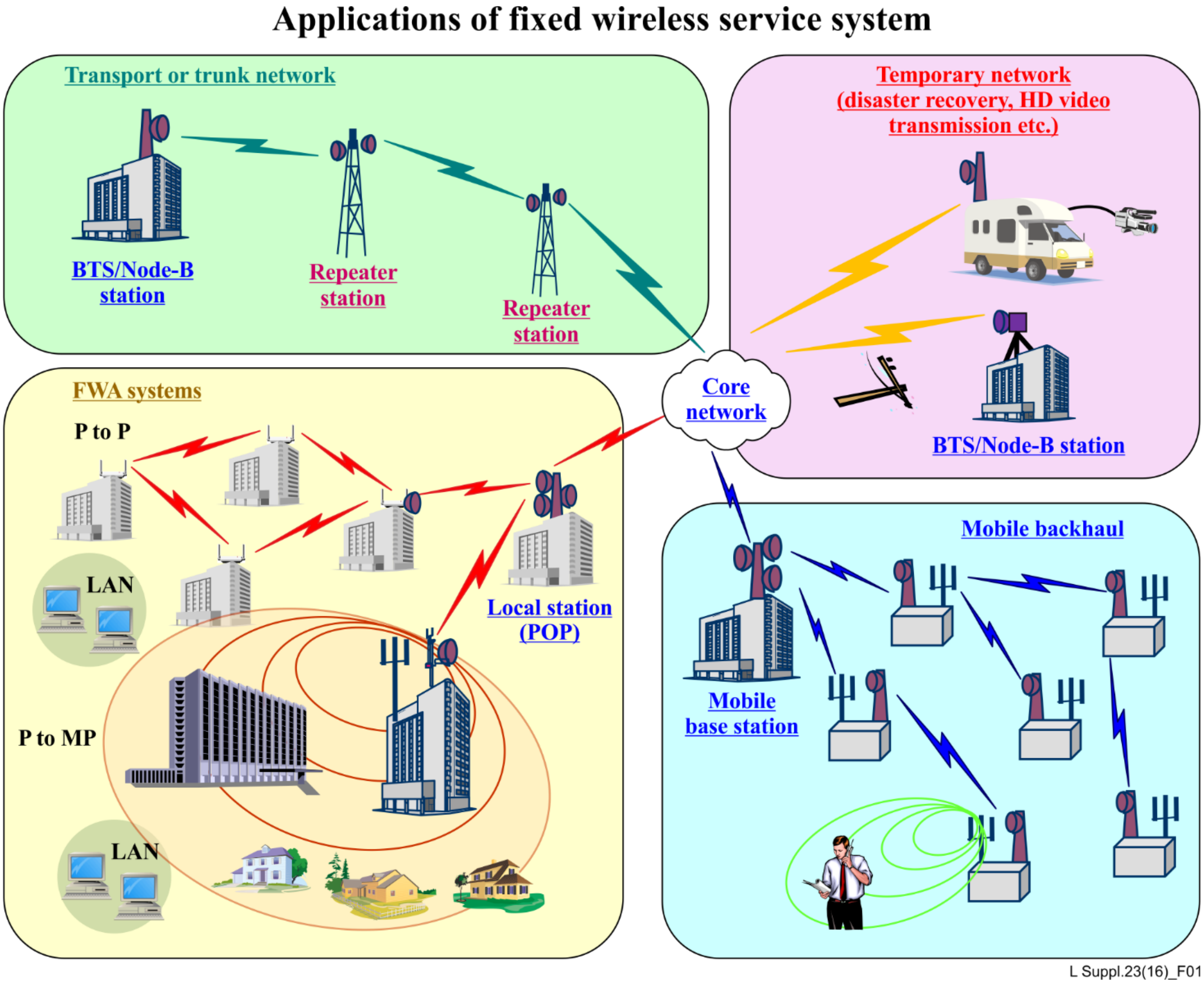

Figure 1 – Applications of fixed wireless service systems

The attractive features of microwave systems are independence from geographical features such as mountains and archipelagos, a short-term, low-cost system integration period, robustness against disasters, and tightness in security such as in terrorism countermeasures that are increasing in importance. These features of microwave systems contribute to rapid and large-scale network deployments in order to quickly acquire cellular phone subscribers. This factor is one that promotes rapid growth in the market.

Generally, millimeter-waves means from 30 GHz to 300 GHz frequency range. However, in this Supplement, over 60 GHz is called millimeter-waves, because up to 42 GHz is covered in the microwave systems.

The 60 GHz band (sometimes called V-band) and 71-76/81-86 GHz band (E-band) are assigned for communication usage.

Millimeter-wave systems also have attractive features like microwave systems as wireless solutions. The additional features of millimeter-waves are high-capacity transmission due to its wide bandwidth.

Millimeter-waves are suitable for high-capacity transmission. However, its available link distance is limited due to absorption by air and rainfall. The link distance of V-band is strongly limited even under fine weather conditions due to oxygen absorption. Therefore, V-band is not suitable for long link distances. On the other hand, this feature is preferable for avoiding interference to or from other systems.

In terms of radio equipment hardware, millimeter-waves have good features, since the "all outdoor type" configuration can be applied. An all outdoor type configuration means that all functionalities of radio transmission equipment are included in one box, which can be installed on a pole with an antenna. This configuration has many preferable features for low-cost and sustainable infrastructures, low-cost, low-power consumption, no need for a shelter for an indoor unit (IDU), etc.

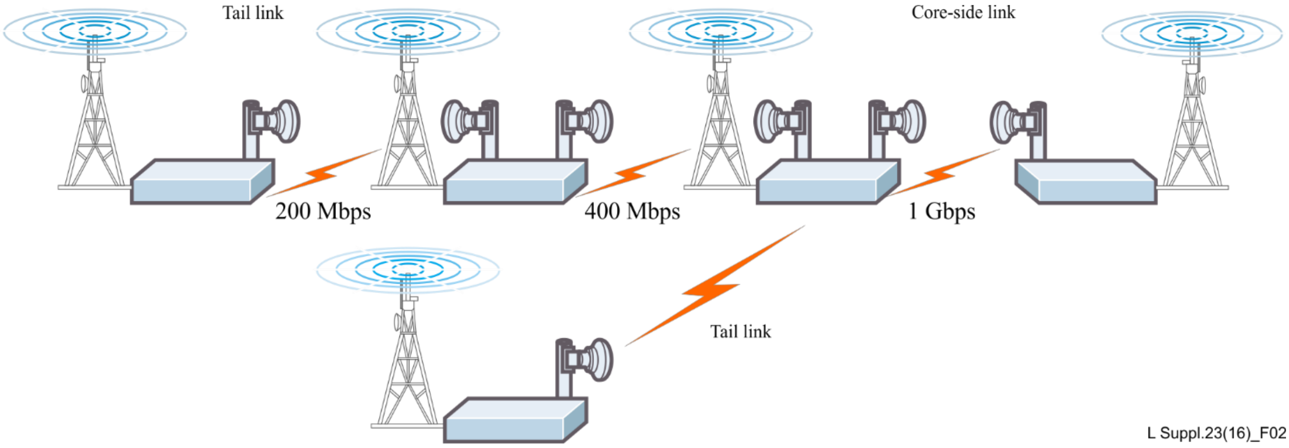

Figure 2 – Features of a mobile backhaul

The required capacity depends on the link characteristics. Microwave radio equipment can change the parameters, modulation and channel separation (CS). Same hardware can be applied to the various links.

3.2 RF frequency and channel separation

Table 1 shows the major radio frequency (RF) bands and CSs applied to mobile backhaul and specified in the European Telecommunications Standards Institute (ETSI).

For higher-frequency bands, more than 100 MHz CS will be available in the near future. Such wideband can support high-capacity transmission of more than 500 Mbps. However, higher frequency bands have relatively large attenuation due to atmospheric gases, rainfall, and free space loss. Appropriate RF bands should be selected depending on the required conditions.

Available minimum CS depends on the modulation scheme.

Table 1 – Major radio frequency bands and channel separations applied to mobile backhaul

Band (GHz)	Recommendation ITU-R	Channel separation (MHz)
10.5	ITU-R F.747	7, 14, 28, 56
11	ITU-R F.387	7, 14, 28, 40, 56
13	ITU-R F.497	7, 14, 28, 56
15	ITU-R F.636	7, 14, 28, 40, 56
18	ITU-R F.595	13.75, 27.5, 55, 110
23	ITU-R F.637	7, 14, 28, 56, 112
26, 28	ITU-R F.748	7, 14, 28, 56, 112
31	ITU-R F.746	7, 14, 28, 56
32	ITU-R F.1520	7, 14, 28, 56, 112
38	ITU-R F.749	7, 14, 28, 56, 112
42	ITU-R F.2005	7, 14, 28, 56, 112

The entire V-band is from 57 to 66 GHz. The usable range in V-band is different for each country. The common usable range is from 59 to 63 GHz. The minimum CS is 50 MHz. The combining of multiple CSs, 100 MHz, 150 MHz, etc., is allowable.

The E-band is 71-76/81-86 GHz. The set of 5 GHz bandwidth is used for dual direction communication. The minimum CS is basically 250 MHz. The one-quarter or one-half is also available as the narrow band. The maximum CS depends on the regulation in each country. ETSI standard provides the specifications for up to 2 GHz CS.

4 Technology

4.1 Multi-level QAM MODEM

Quadruple phase shift keying (QPSK) and multi-level quadrature amplitude modulation (QAM) from 16 QAM to 256 QAM are generally adopted for a modulation scheme for microwave systems. Recently, according to market demands for high capacity, over-256 QAM modulation schemes have been introduced. However, the higher modulation requires a higher carrier-to-noise ratio (CNR).

In the demodulator, coherent detection is executed precisely with many functions, such as equalization and clock synchronization. Recently, these complex functionalities including modulator are implemented in one highly integrated large-scale integrated (LSI) circuit. Therefore, the cost of the MODEM portion has become dramatically cheaper during the past two decades.

The same hardware can be available for a wide range of symbol rates by changing sampling rate at the digital to analogue converter (D/A), analogue to digital converter (A/D) and digital signal processing circuits.

4.2 Equalizer

In the lower RF band below 10 GHz, fixed microwave service (FS) applications are usually for transport networks where FS links are deployed with long-hop distance. In such cases, the system must prepare a counter measure against fading. Adaptive equalization is a mandatory function. Even for the higher RF band, an equalizer is needed to compensate for imperfections in hardware. The equalizers contribute to performance improvement and equipment cost reduction, because introduction of an equalizer enables the use of cheaper RF devices that have insufficient frequency characteristics in the wireless equipment.

4.3 Cross polarization interference canceller

Polarization multiplexing can achieve double capacity without bandwidth expansion. However, the interference between two polarizations causes degradation of bit error ratio (BER) performance, especially for the high multilevel modulation scheme.

This interference can be cancelled by reproducing the "interference condition at the channel" in the demodulator. Cross polarization interference canceller (XPIC) generates a replica of interference, and its output is subtracted from the received signal.

The condition of interference changes momentarily. The equalizer architecture is also used in this case. The difference between the equalizer and the XPIC is only the input signal.

4.4 Automatic transmit power control

Microwave systems have variations in received signal levels (RSLs) due to fading and rainfall. If a microwave system has tolerance against these variations of RSL, the transmission power needs to be high enough to overcome them. This high-power signal might cause interference with other systems, and the power consumption would be high.

In order to avoid these issues, automatic transmit power control (ATPC) is adopted. Under good propagation conditions, the transmitter (Tx) reduces its power. The receiver (Rx) has an RSL detector, and sends the RSL value to the Tx. When the value is too low or too high, the Tx increases or decreases its power until the nominal RSL value is recovered. This power control is executed every few milliseconds. In this way, the required minimum Tx power can be maintained. As a result, power consumption at normal conditions can be kept low.

4.5 Forward error correction

For improving BER performance, error correction is very important. Without forward error correction (FEC), it is difficult for the high-level modulation schemes to guarantee "error free" operation, even under a high CNR condition. FEC can suppress BER performance degradation from various causes, and also contributes to cost reduction.

FEC requires a little bit of redundancy as additional check bits (bytes), and this redundancy decreases the frequency usage efficiency. However, the effect of required noise reduction is larger than the negative effect. As a result, FEC can improve the frequency usage efficiency by allowing higher modulation schemes.

Among the error correcting codes available for microwave systems, the most popular is Reed-Solomon. Today, more powerful codes, such as low-density parity-check (LDPC) code, which is based on iterative decoding, are being adopted.

4.6 Adaptive coding and modulation

Recently, microwave systems are used for IP data transmission, and the capacity does not need to be specified from the legacy circuit switching interface. The capacity can be varied by changing the modulation schemes and coding rates according to the channel condition. In other words, the most important signals can survive even under severe conditions for high-level modulation if capacity reduction due to the down shift of modulation is allowed. This is the concept of adaptive coding and modulation (ACM).

The practical procedure is as follows.

The Rx has a channel quality indicator, and sends the channel quality information to the Tx. The Tx decides the appropriate modulation scheme according to this information. If the quality is degraded, the Tx changes the modulation scheme lower, before a bit error occurs. Otherwise, the Tx changes the modulation scheme higher. The timing of the modulation switching is conveyed to the Rx on ahead. Therefore, the switching is executed without any bit errors.

ACM can achieve the highest capacity and highest reliability.

4.7 Protection

If necessary, microwave radio systems can have redundant configurations. When a regular channel is broken or the quality of a received signal worsens, the signal transmission can automatically be switched to a protection channel.

5 System performance and capacity

5.1 Capacity

Recently, the capacity of microwave system is growing due to bandwidth expansion, adopting of higher modulation schemes and dual polarization transmission. The maximum capacity in one channel (RF frequency) has reached over 1 Gbps. Even a popular system which uses standard modulation scheme, 28 MHz CS and single polarization has a capacity of more than 150 Mbps (corresponding to STM-1). This capacity is sufficient for the mobile backhaul application.

The capacity, *C*, is calculated by the following equation:

$$C = fs \cdot \log_2(M)$$

Where, *M* is modulation level (number of signal points) and *fs* is baud rate.

For example, the capacity of a 256 QAM with 25 Mbaud system is 200 Mbps. However, the net capacity is around 90 percent of C due to the overhead signal insertion. The overhead signal includes FEC redundancy, radio frame overhead and radio control signals.

In millimeter-wave systems, the capacity of a 256 QAM with 220Mbaud system is over 1760 Mbps. However, the net capacity is around 90 percent of C due to the overhead signal insertion. The overhead signal includes FEC redundancy, radio frame overhead and radio control signals.

5.2 Link budget

The link budget can be calculated from some radio parameters.

Modulation schemes and FEC coding determine the required CNR. Baud rate and noise figure (NF) determine the noise power within the signal bandwidth. RF frequency determines the transmission characteristics: free space loss, attenuation due to atmospheric gases, and the effect of rainfall. Antenna size and Tx power determine the total signal power. Each value can be calculated as a function of link distance. The link distance at which RSL margin for the BER=10^{-6} becomes 0 dB shows the limit of link distance under optimal conditions. Also the link availability when considering rainfall conditions can be calculated using equations cited in ITU-R Recommendations. Figure 3 shows an example of link budget calculation, in this case at 18 GHz. The conditions for this calculation are shown in Table 2. The net capacity is 155 Mbps. The fade margin has a positive value even at 50 km. The availability 99.999% point is more than 5 km. The availability 99.999% means that the outage time is only 5 minutes per year. Figure 4 and Table 3 are for an example calculation at 15 GHz, Figure 5 and Table 4 are for an example calculation at 13 GHz, and Figure 6 and Table 5 are for an example calculation at 38 GHz. Table 6 summarizes link distance for availability at the 99.99% and availability 99.999% points for these calculations. Figure 7 and Table 7 provide an additional example calculation at 80 GHz.

Generally speaking, microwave systems have long link distance, and the quality of signal transmissions are stable and good.

Table 2 – Conditions used in Figure 3 link budget calculations

RF frequency	18 GHz
Modulation	256 QAM
Baud rate	24 MHz
Required CNR	27 dB
Tx power	+20 dBm
Antenna gain	38 dBi
NF	5 dB
Rain zone	K

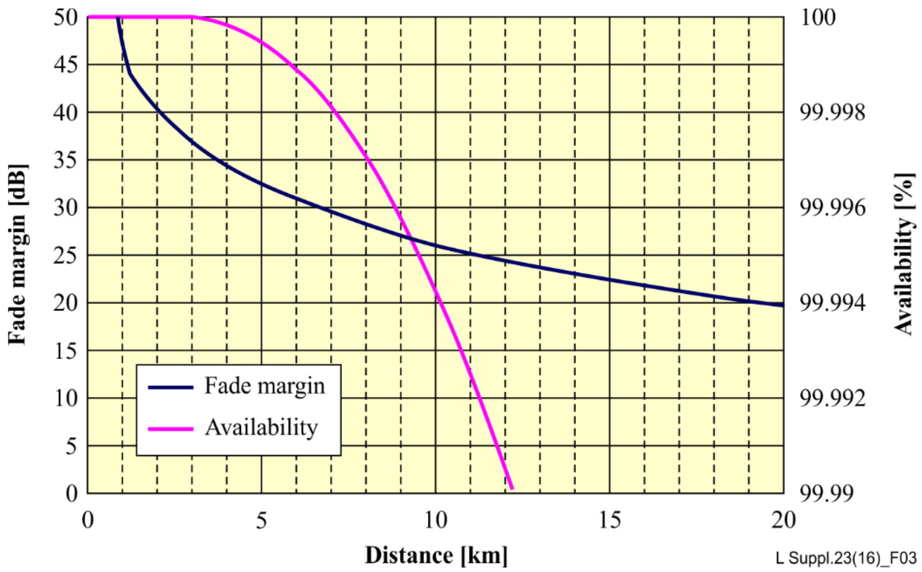

Figure 3 – Example of link budget calculation at 18 GHz: Fade margin and availability versus distance

Table 3 – Conditions used in Figure 4 link budget calculations

RF frequency	15 GHz
Modulation	256 QAM
Baud rate	24 MHz
Required CNR	27 dB
Tx power	+22 dBm
Antenna gain	36 dBi
NF	5 dB
Rain zone	K

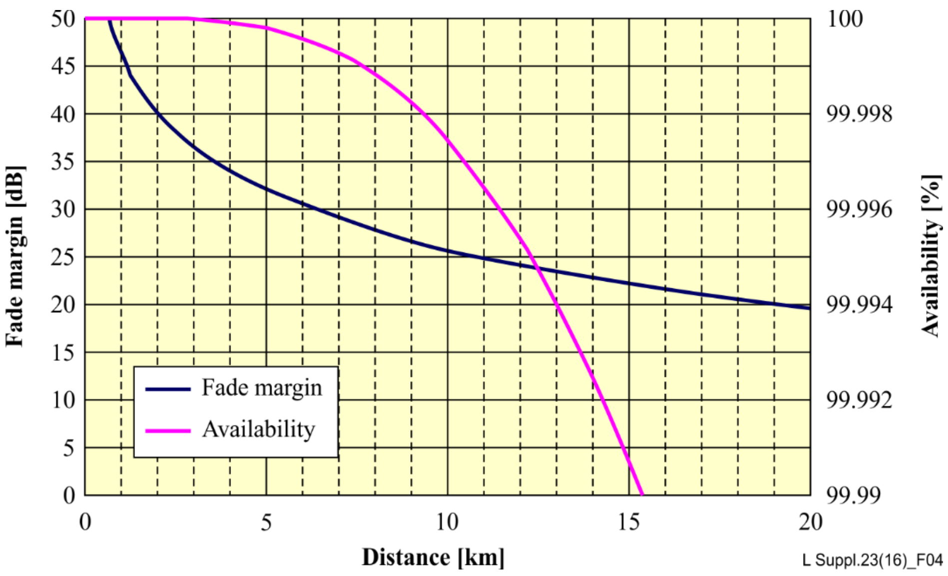

Figure 4 – Example of link budget calculation at 15 GHz: Fade margin and availability versus distance

Table 4 – Conditions used in Figure 5 link budget calculations

RF frequency	13 GHz
Modulation	256 QAM
Baud rate	24 MHz
Required CNR	27 dB
Tx power	+22 dBm
Antenna gain	35 dBi
NF	4 dB
Rain zone	K

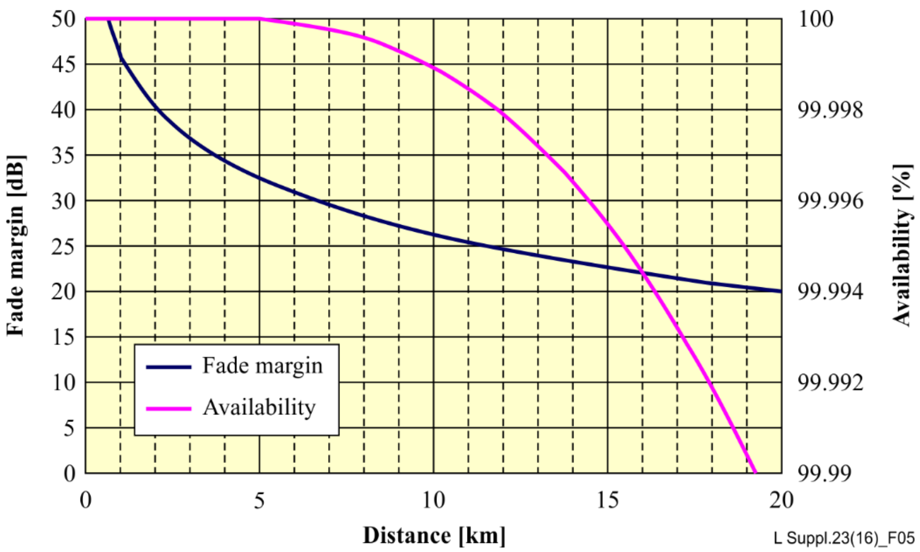

Figure 5 – Example of link budget calculation at 13 GHz: Fade margin and availability versus distance

Table 5 – Conditions used in Figure 6 link budget calculations

RF frequency	38 GHz
Modulation	256 QAM
Baud rate	24 MHz
Required CNR	27 dB
Tx power	+18 dBm
Antenna gain	44 dBi
NF	6 dB
Rain zone	K

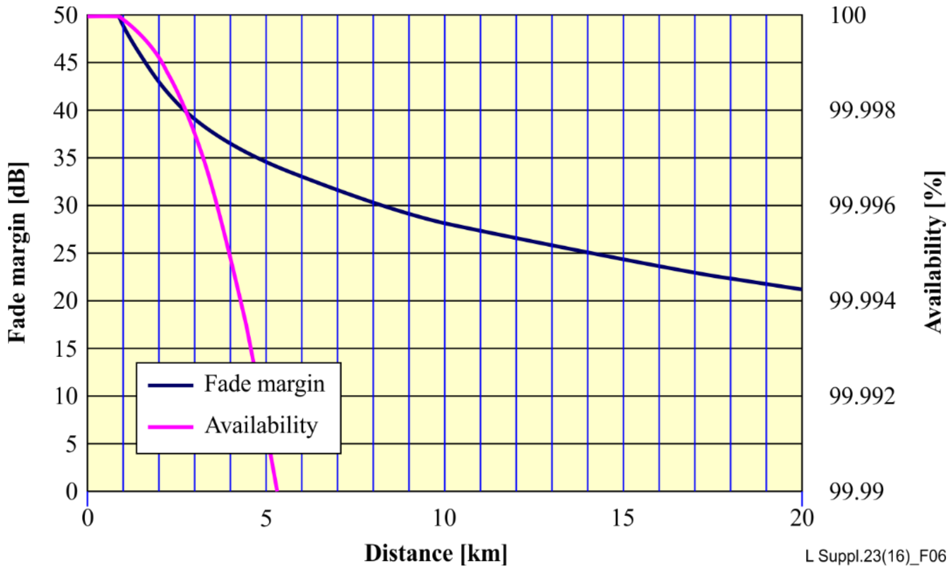

Figure 6 – Example of link budget calculation at 38 GHz: Fade margin and availability versus distance

Table 6 – Link distance for availability 99.99% and 99.999%

Conditions: Rain zone = K, Channel separation = 28 MHz, 256 QAM

RF frequency	Availability =99.99%	Availability =99.999%
13 GHz	19.2 km	9.7 km
15 GHz	15.3 km	7.7 km
18 GHz	12.1 km	5.7 km
38 GHz	5.2 km	2 km

The link budget of millimeter-wave systems can be calculated from some radio parameters same as for microwaves. Some parameters are changed from Table 2 considering the practical conditions of E-band. The link distance is one digit less than microwaves due to the effect of rainfall attenuation. However, when the link distance is up to 500 metres, the wireless systems in E-band can achieve higher-capacity transmission with high availability.

Table 7 – Conditions used in Figure 7 link budget calculations

RF frequency	80 GHz
Modulation	256 QAM
Baud rate	220 MHz
Required CNR	27 dB
Tx power	+10 dBm
Antenna gain	45 dBi
NF	12 dB
Rain zone	K

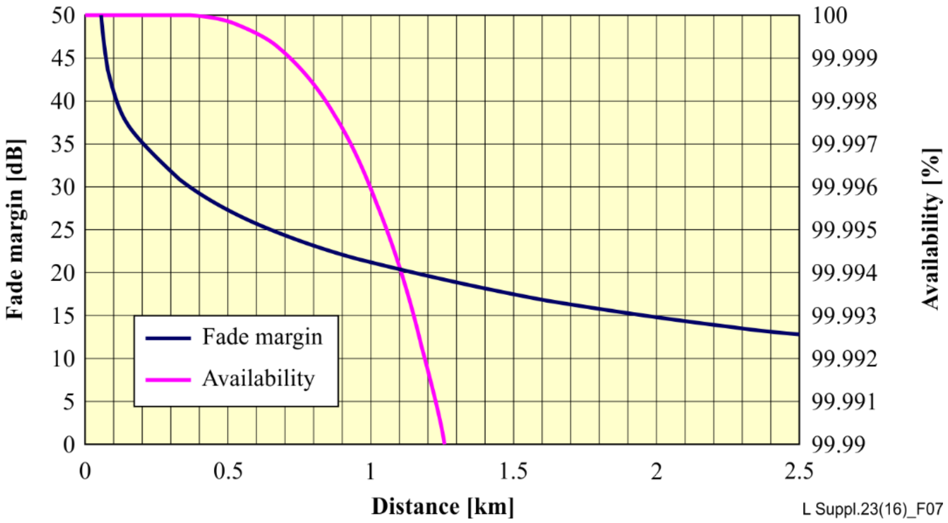

Figure 7 – Example of link budget calculation at 80 GHz: Fade margin and availability versus distance

Appendix I

Technical characteristics of the 6-42 GHz band wireless link

The typical technical and operational characteristics of microwave systems operating in some administrations in the 6-42 GHz band are summarized in Table I.1 below.

Figure I.1 contains photos of split type microwave radio equipment. Figure I.1 (a) shows an IDU, and (b) shows an outdoor unit (ODU) with an antenna.

Table I.1 – Typical technical and operational characteristics of microwave systems

RF frequency	6 to 42 GHz
Modulation	QPSK to 2048 QAM
Nodal	4-way
Interface	E1 / FE / GbE
Synchronization	Sync Ethernet / IEEE 1588 v2
Ambient temperature	IDU: –5 to +50°C ODU: –33 to +50°C
Power supply voltage	–48 V DC
Power consumption	ODU: 30 W (6-11 GHz) / 23 W (13-42 GHz)
	IDU: 55 W (1+0) / 65 W (1+1)
Dimensions	ODU: 237 × 237 × 101 mm / 3.5 kg (6-8 GHz)
	239 × 247 × 68 mm / 3.0 kg (10-38 GHz)
	IDU: 482 × 44 × 240 mm / 3 kg (1+0)

(a) IDU (b) ODU and Antenna

Figure I.1 – Example of network elements for the 6-42 GHz band wireless link

Appendix II

Technical characteristics of the E-band (71-76 GHz, 81-86 GHz) wireless link

The typical technical and operational characteristics of millimeter-wave systems operating in some administrations in the E-band are summarized in Table II.1 below.

In the E-band, very wide bandwidth, more than 250 MHz is available. Therefore, the E-band system can achieve higher capacity.

Figure II.1 is a photo of the E-band radio equipment (all outdoor type) with an antenna.

Table II.1 – Typical technical and operational characteristics of millimeter-wave systems

Frequency range	71-76 / 81-86 GHz frequency division duplex (FDD)
Modulation	QPSK/ 16/ 32/ 64/ 128/ 256 QAM (Hitless ACM)
Channel separation	250 MHz (ETSI/ ANSI)
Interfaces	2 × GbE (Electrical or Optical)
Maximum link capacity	1600 Mbps
QoS	8 classes queue strict priority / deficit weighted round-robin (DWRR)
Synchronization	Synchronous Ethernet
Ethernet OAM	IEEE 802.1ag/ ITU-T G.1731/ IEEE 802.3ah
Radio configuration	1+0/ 1+1/ 2+0
Antenna	Direct mount (0.3-0.6 m dia.)
Ambient temperature	–33 to +50°C
Power line voltage	–40.5 to 57 V DC or PoE
Power consumption	50 W typ.
Dimension and weight	270(W) × 270(H) × 100(D) mm <5.5 kg

Figure II.1 – Example of E-band (71-76 GHz, 81-86 GHz) wireless link

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