RECOMMENDATION ITU-R F.1102-2

Characteristics of fixed wireless systems operating in frequency bands above about 17 GHz

(Question ITU-R 107/9)

(1994-2002-2005)

Scope

This Recommendation provides characteristics of fixed wireless systems operating in frequency bands above about 17 GHz. The Annex 1 contains possible applications, hop length consideration, basic functions of transmitters and receivers, and other technical/operational characteristics required for the implementation of fixed wireless systems in this frequency range.

The ITU Radiocommunication Assembly,

considering

a) that frequency bands above about 17 GHz are allocated to the fixed and other services;

b) that the propagation characteristics above about 17 GHz are predominantly governed by precipitation fading and absorption and only suited to short range radio system applications;

c) that differing applications of various administrations may require different radio-frequency channel arrangements;

d) that several services with various transmission signal characteristics and capacities may be in simultaneous use in the same frequency band;

e) that the various applications may require differing channel bandwidths;

f) that new applications and network configurations are being used in high density deployment of fixed wireless systems in bands above about 17 GHz,

recommends

1 that system design should take into consideration the effects of precipitation outage which critically determines hop length;

2 that the frequency bands above about 17 GHz be used for short range applications which will allow equipment to be compact with smaller antennas;

3 that to allow the use of mixed services, whilst achieving spectral economy, the radio-frequency channel arrangements should be based on homogeneous patterns in accordance with Recommendation ITU-R F.746;

4 that both digital and wideband analogue modulation techniques are applicable;

5 that Annex 1 be referred to for guidance in system design.

Annex 1

Characteristics of fixed wireless systems operating in frequency bands above about 17 GHz

1 Introduction

In the frequency bands above about 17 GHz some allocations are provided for the fixed service on a worldwide basis. At these frequencies, outage is due primarily to precipitation fading lasting in excess of 10 s. Hence parameters of particular importance to the implementation of such systems are availability and transmitter-to-receiver path length (hop length) that may be achieved. These parameters are considered in this Annex for systems that are typically used in the local network.

2 Application considerations

2.1 Local access/networks

The frequency bands above about 17 GHz are being used mainly for short haul links. Compact and highly reliable radio equipment can support voice, data, video, and broadband data transmission.

The main applications are:

– interconnection of LANs;
  – interconnection between LANs (IEEE 802.3/Ethernet and IEEE 802.5/Token Ring) with a transmission capacity of the order of 10 Mbit/s;
  – interconnection between LANs (Ethernet including RLANs IEEE 802.11a/IEEE 802.11b/HiperLAN2/HiSWANa) with a transmission capacity of the order of 100 Mbit/s;
– video transmission;
– subscriber links;
– digital primary group or higher speed data links from end office to user buildings;
– cellular phone applications;
– interconnection between cellular phone exchanges and base stations;
– relief applications;
– transportable radio equipment used for backup links when optical fibre systems or other terrestrial circuits have failed;
– ring closure or point-to-point connection in the synchronous digital hierarchy (SDH) access network;
– high density access networks in, for example, subscriber-based applications.

Table 1 categorizes the above applications.

TABLE 1

A categorization of applications

	Physical link configuration	**Transmission capacity**	**Content of signal**	**Hop length**
LAN interconnection	User to user building	Order of 10 Mbit/s	Data	Several tens of metres to km
Subscriber links	From end office to user building	Analogue or primary rate digital group or higher PDH capacity	Data or video	Several km to tens of km
Inter-cell telephone applications	Between cellular system telephone exchange and radio base station	2 Mbit/s up to STM-1	Voice or data	Several km to tens of km
Transportable equipment for relief operations (see Note 1)	Backup for optical fibre links	Analogue or primary rate digital group – or higher PDH capacity or SDH	Voice, data or video	Several km to tens of km
SDH access network	ADMs ring closure/interconnection or tributary extension	SDH hierarchy	Virtual containers (Vc)	Several km to tens of km
High density subscriber-based access	Direct access to subscriber	Up to STM-1	Data and voice	Fraction of a km up to a few km
Vertically-connected wireless link	From user building to subscriber	Order of 100 Mbit/s	Data and video	Several tens of m

ADM: Add/drop multiplexer

PDH: Plesiochronous digital hierarchy

STM-1: Synchronous transfer mode 1

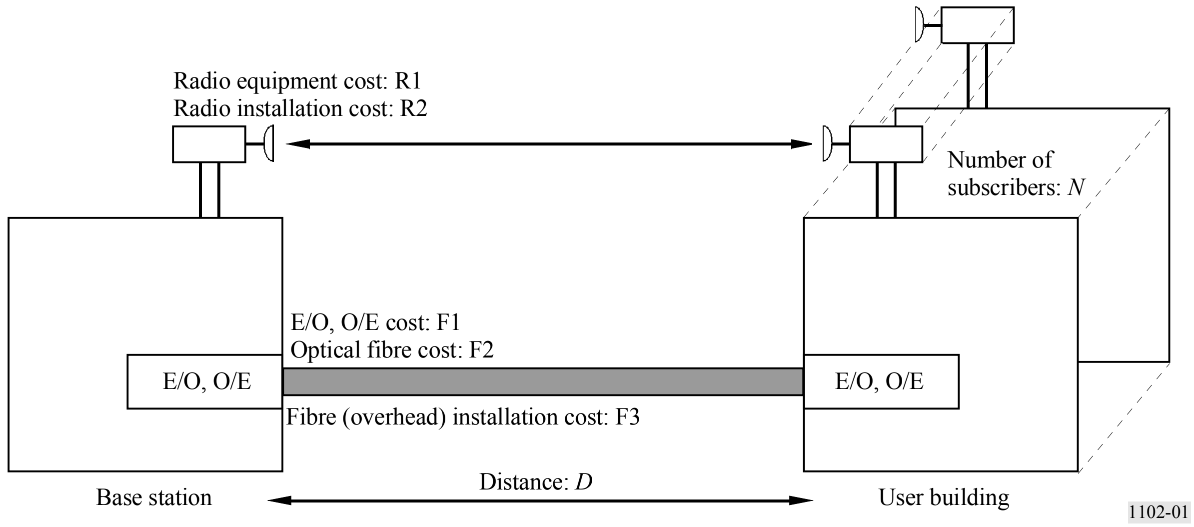
NOTE 1 – See Recommendation ITU-R F.1105.

2.2 Cost comparison between fibre and radio links in the access portion

An optical fibre system requires construction work continuously along the cable route. On the other hand, radio systems require such work only at the transmitting and receiving stations. For this reason, the greater the distance between locations, the greater the cost for a fibre system will increase. Costs are compared in the following simple model shown in Fig. 1.

FIGURE 1

Assumed model



Cost R for introducing a radio system is given by:

$$R = (R1 + R2)\ N$$

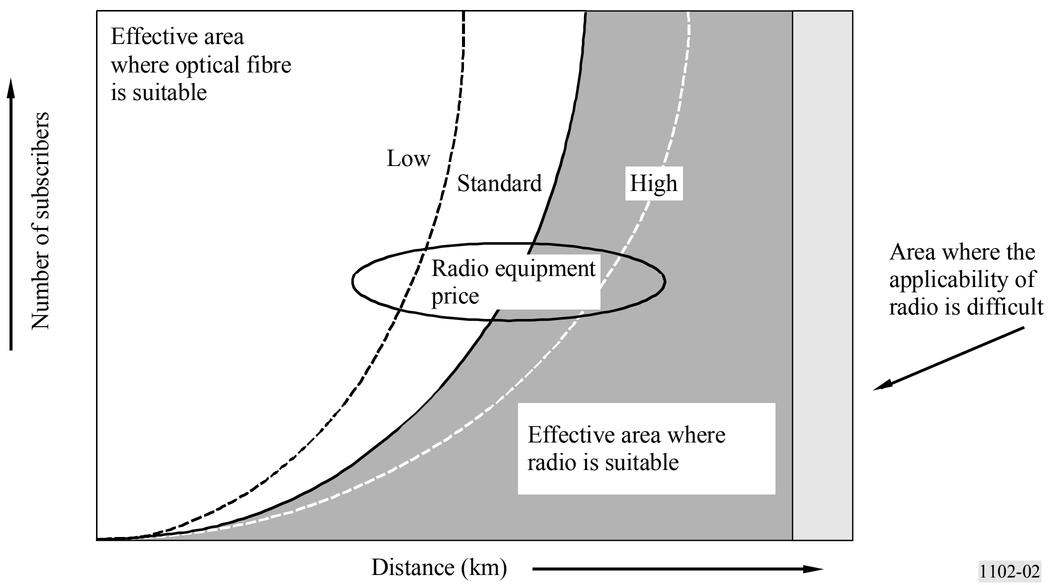
Cost F for introducing an optical fibre system is given by:

$$F = F1\ N + (F2 + F3)\ N\ D$$

Figure 2 shows the result of cost comparison. According to Fig. 2, with the same number of subscribers, any increase in distance decreases the cost of radio with respect to that for a fibre system. Further, with the same distance, radio systems are advantageous when the number of subscribers is small. Moreover, the applicable area for radio expands sharply when the distance becomes greater.

FIGURE 2

Results of cost comparison between fibre and radio



If only cost is taken into consideration, the greater the distance, the more the applicable area of radio will expand. However, it is necessary to take into account the fact that the propagation distance of radio systems using frequency bands above about 17 GHz is limited by rain attenuation. The provision of multiple-hop short-range links would therefore tip the balance towards the favour of fibre systems, but generally within the local loop multiple-hop systems are rare. In practice a mixture of fibre and radio would be used depending on which system is the most cost effective and practical for that particular part of the application.

2.3 Rapid deployment

One of the characteristics of radio systems is the speed at which they can be commissioned. Fibre systems require installation of fibres between the locations where communications are to be implemented, resulting in a long construction period until lines can be placed in service. In particular, the construction period increases sharply when optical fibre is laid underground when compared to pole-mounted installation. Further, there may be cases when fibre installation is impossible because of inability to obtain the right of way. The use of radio links to facilitate cable television system installation in such situations is a known implementation of this property. However, the lead-in time for radio systems is very short since it requires installation only at the locations where communications are to be implemented. This makes it possible to open circuits within a few hours. Although link planning, licensing and site clearance procedures increase the lead-in time in practice, the lead-in time is still likely to be significantly shorter than that for a fibre link.

In radio systems, it is necessary to confirm the line-of-sight condition. Studies concerning computer-based line of sight confirmation preparing databases of geographical features and buildings are being made, and a quick antenna alignment procedure may be helpful.

The relative ease of redeploying radio equipment is one of its attractive characteristics. Transportable radio systems are more suitable for rapid communications relief during times of disaster, link and fibre failures and the like.

3 Hop length considerations

No universal hop length/frequency characteristic can be constructed, however the following parameters contribute to the availability objectives on hop length:

– *Free space specific attenuation:* A_0 (dB/km)

  – Frequency dependent, from Recommendation ITU-R P.525.

– *O_2 and H_2O specific gaseous absorption attenuation:* A_α (dB/km)

  – Frequency dependent in the relevant frequency ranges from Recommendation ITU-R P.676.

– *Antenna isotropic gain:* Gi (dB)

  – Constant depending on geometrical size of antennas, with no theoretical upper bound, but practically limited, to allow feasible boresight alignment, by field operability of the 3 dB main beam angle width (normally not narrower than 1°).

This leads to a practical limit of $G \cong 44$ dBi.

– *Transmit power:* P_T (dBm)

  – Related to the available technology for RF carrier generation/amplification and to the linearity requirement of the modulation format.

– *Bit error ratio (BER) threshold:* P_{Th} (dBm)

  – Relative to the relevant BER at which the availability objective is defined. This parameter is related to the receiver noise figure, the transmitted bit rate and the carrier-to-noise performance of the modulation format.

– *Rain attenuation for the objective time percentage:* $R|_{\%}$ (dB)

  – Estimated on the basis of rain-rate intensity for the relevant unavailability time percentage through the method reported in Recommendations ITU-R P.530 and ITU-R P.838, using statistics obtained from Recommendation ITU-R P.837.

The above parameters may be subdivided into two blocks (see Note 1):

– A fixed, implementation dependent, constant "hop gain" (HG):

$$HG = 2Gi + |P_{Th}| + P_T \qquad \text{dB} \qquad (1)$$

– A rain-rate/frequency dependent "hop attenuation" ($HA|_{\%}$) for a given time percentage over the length ℓ (km) of the hop as foreseen by Recommendation ITU-R P.530:

$$HA|_{\%} = R|_{\%} + (A_0 + A_{\alpha})\ \ell \qquad \text{dB} \qquad (2)$$

Using the above approach, graphs like those reported in Figs. 3, 4 and 5 (computed as an example for the climatic zones B, G and K with frequency and percentage of unavailability (U%) as parameters) may be derived, from which the maximum hop length for the given implementation/ frequency/climatic zone/objective time-percentage may be obtained.

NOTE 1 – Since, in general, radio systems above about 17 GHz are supplied with integral antennas, in these assumptions feeder losses are neglected; in the case of feeder connection between equipment and antenna, the feeder losses will decrease the hop gain (HG).

4 Digital radio implementations

The application requirements, spectrum availability, propagation conditions and available technology above about 17 GHz result in equipment implementations that differ substantially from those that predominate below about 17 GHz. Nevertheless, there is no abrupt transition but a gradual one starting from the band 13 GHz.

The predominant distinctive characteristics of digital radio applications above about 17 GHz are:

– a wide range of transmission capacities;

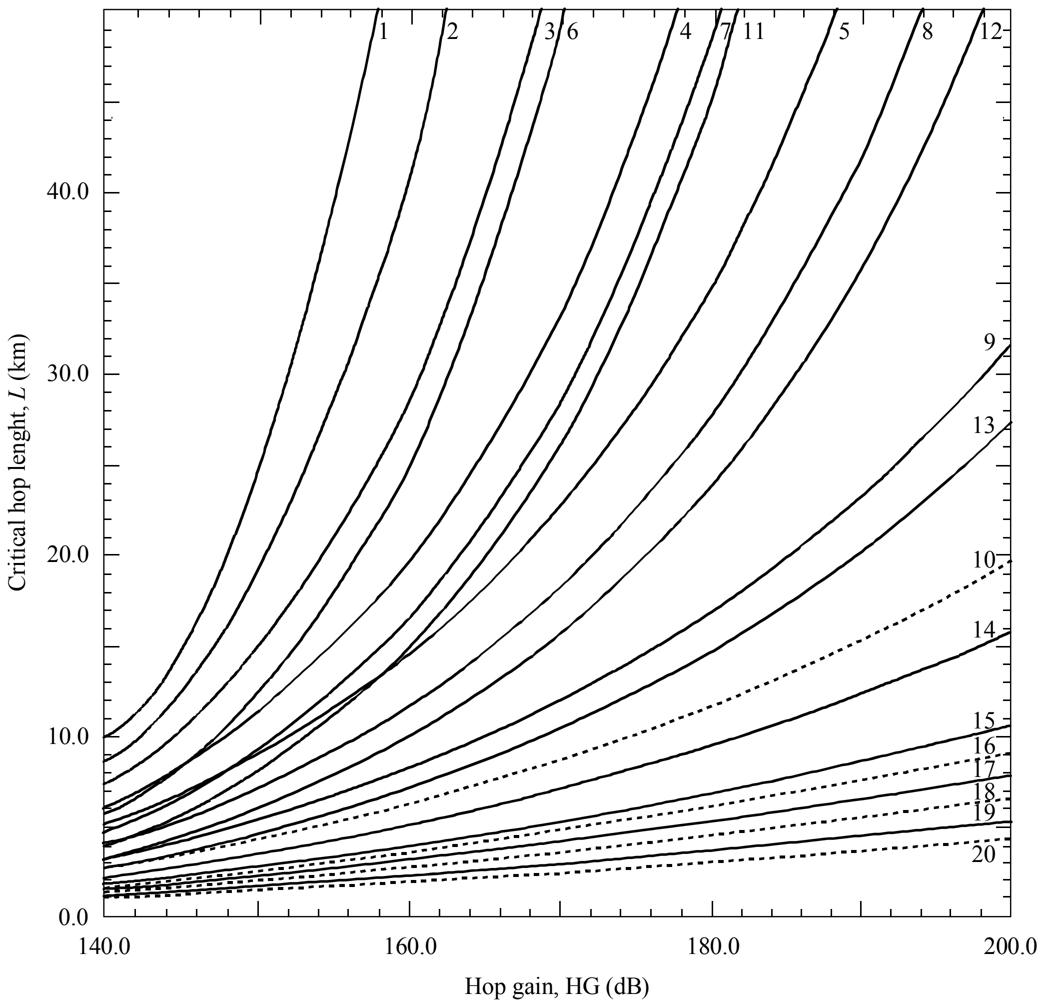
– partitioning of equipment into an outdoor unit consisting of radio front-end attached to antenna, and an indoor unit containing the baseband sub-assemblies and in many cases the

IF sub-assemblies as well. This virtually avoids waveguide feeder losses which could be prohibitive and provides great equipment mounting flexibility through low-loss interconnection at baseband and/or IF;

– new applications trending towards higher order modulations and higher technical spectral efficiencies.

FIGURE 3

Critical hop length vs. hop gain for climatic zone B, horizontal polarization



Curve	*f* (GHz)	*U* %	Curve	*f* (GHz)	*U* %
1	18	0.1	11	38	0.1
2	18	0.03	12	38	0.03
3	18	0.01	13	38	0.01
4	18	0.003	14	38	0.003
5	18	0.001	15	38	0.001
6	28	0.1	16	55	0.1
7	28	0.03	17	55	0.03
8	28	0.01	18	55	0.01
9	28	0.003	19	55	0.003
10	28	0.001	20	55	0.001

U: unavailability (%)

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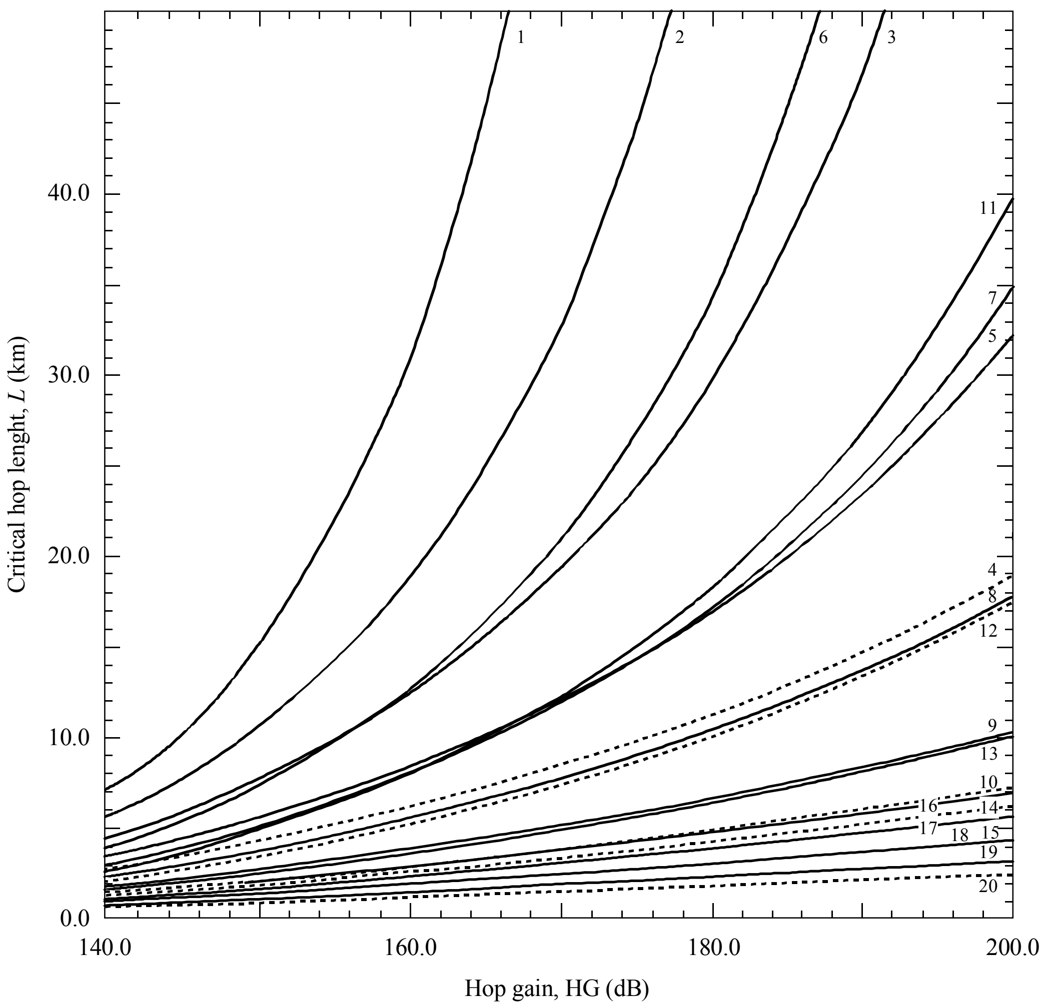
FIGURE 4

Critical hop length vs. hop gain for climatic zone G, horizontal polarization



Curve	f (GHz)	U %	Curve	f (GHz)	U %
1	18	0.1	11	38	0.1
2	18	0.03	12	38	0.03
3	18	0.01	13	38	0.01
4	18	0.001	14	38	0.001
5	18	0.003	15	38	0.003
6	28	0.1	16	55	0.1
7	28	0.03	17	55	0.03
8	28	0.01	18	55	0.01
9	28	0.001	19	55	0.001
10	28	0.003	20	55	0.003

U: unavailability (%)

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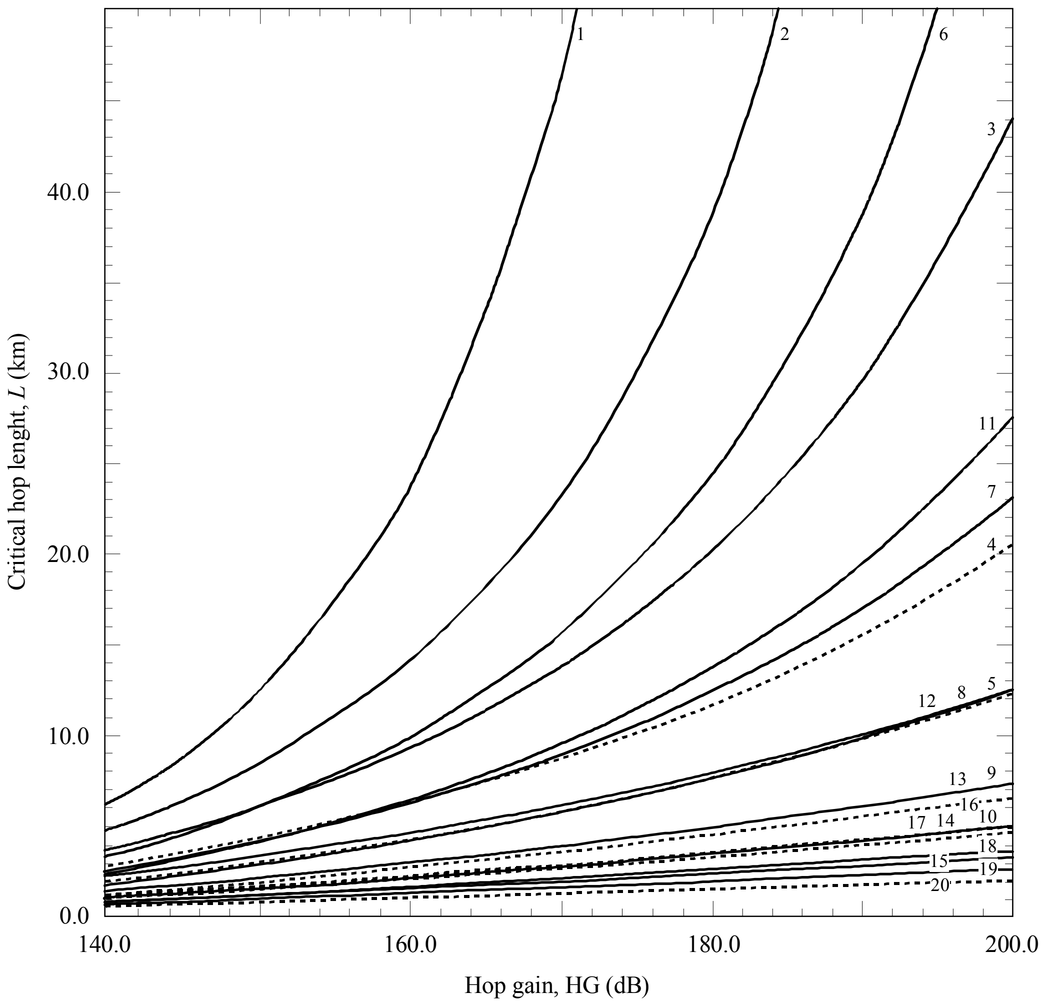
FIGURE 5

Critical hop length vs. hop gain for climatic zone K, horizontal polarization



Curve	*f* (GHz)	*U* %	Curve	*f* (GHz)	*U* %
1	18	0.1	11	38	0.1
2	18	0.03	12	38	0.03
3	18	0.01	13	38	0.01
4	18	0.001	14	38	0.001
5	18	0.003	15	38	0.003
6	28	0.1	16	55	0.1
7	28	0.03	17	55	0.03
8	28	0.01	18	55	0.01
9	28	0.001	19	55	0.001
10	28	0.003	20	55	0.003

U: unavailability (%)

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4.1 Design trade-offs

Design trade-offs are rather complex due to the multiple interdependencies. However, to simplify the task, the trade-off criteria can be subdivided in various ways, depending on specific optimization goals.

For example, it is meaningful to distinguish between service quality and user friendliness criteria, as exemplified in Table 2.

TABLE 2

Service quality	User friendliness
Transmission performance System gain Spectral efficiency Power efficiency	Application versatility Maintainability Size and weight Environmental robustness

These trade-off criteria can be rearranged, as needed. For example, for a selected combination of transmission capacity and performance, the primary service quality trade-off is between system gain and spectral efficiency. If enhancement options are available, such as error correction, the trade-off criteria sub-set expands and increases design flexibility.

Some additional design trade-off criteria may belong to both categories. For example, MTBF affects both service quality and user friendliness.

In many instances the knowledgeable user will be able to recognize the basic design trade-offs from the equipment data sheet, but additional information may be needed in some cases to fully assess the equipment under consideration.

The equipment designer, on the other hand, has the demanding task of translating the transmission performance objectives into the corresponding set of equipment design objectives. This matter is addressed in ITU-T Recommendation M.2100.

4.2 Baseband signal processing

Radio implementations for frequency bands above about 17 GHz commonly incorporate the necessary baseband signal processing functions in the indoor unit.

This includes group multiplexing at capacities above the PDH primary group or SDH functionalities. Order wire functions are most commonly included; the specific implementations vary considerably.

Error correction is used to improve the transmission performance and the system gain.

4.3 Carrier generation and stabilization

In principle, direct, fundamental frequency generation is preferred for simplicity. However, the availability of active microwave devices for direct generation decreases with increasing frequency, and the cost increases. At some point, which depends on the status of technological development, it becomes preferable to generate a sub-harmonic and to multiply it to the carrier frequency.

The choice of carrier frequency stabilization method depends on the application. Lowest cost radio implementations with the most relaxed frequency tolerances can be satisfied with free-running, resonator stabilized oscillators. Adding temperature control assures tighter yet moderate frequency tolerances for somewhat more demanding applications. The most demanding application category in terms of frequency stability requires crystal controlled oscillators. For both radio manufacturers and users the preferred implementation is with a frequency synthesizer.

4.4 Carrier modulation formats

The use of simpler modulation formats, (2- or 4-state) assures higher system gains, which is important for long hops due to the predominance of precipitation fading in the frequency range above about 17 GHz. However, the trend is the use of higher state modulation formats in conjunction with shorter hops to achieve higher density networks, for technical and/or regulatory reasons.

An overview of the digital modulation formats is presented in Annex 1 of Recommendation ITU-R F.1101.

4.5 Basic radio transmit/receive functions

The implementation of the transmit and receive functions results from the design trade-offs which are based on the considerations presented under § 4.1. The encountered differences in hardware implementations for the same application reflect the manufacturers' different market orientations, product assortments, in-house technological capabilities, component suppliers and, last but not least, subjective design preferences.

The basic radio design differences for the same application are in the choice between direct and indirect transmitter carrier modulation, and in the number of receiver IF conversions. In principle, the simpler the modulation format, the easier it is to implement direct carrier modulation. The number of receiver IF conversions is primarily derived from selectivity requirements, integrated circuit component availability and the required RF channel agility (e.g. with a synthesizer).

Most digital radio applications above about 17 GHz are in local distribution systems and require few repeaters, if any. Back-to-back connection of terminals is straightforward, but passive or active RF repeaters are available and represent a cost effective solution where no drop/insert capability is needed. Active RF repeaters may or may not use frequency conversion, as required.

4.6 Supervisory functions and protection arrangements

Successive generations of digital radio implementations incorporate ever more sophisticated supervisory functions and network management capability, such as BER monitoring, local and remote loopback, and local display of remote monitoring. Portable, hand-held terminals exist as alternative dedicated implementations. PCs and laptop computers using proprietary software are in use for centralized network management.

Protection arrangements are provided as needed to give the desired reliability and/or availability. Examples of those possible arrangements are:

– route diversity;

– monitored hot standby;

– monitored hot standby with frequency, polarization or space diversity.

4.7 New applications for high-density, high availability, subscriber-based networks

Recent developments in the use of digital radio systems to provide direct subscriber access for high availability networks in competition with fibre access, has led to the development of network architectures that place different demands on the characteristics of the individual transmitters and receivers used in the network. Conventional parameters used in the design of individual hops typically have made use of sufficient fade margin to overcome the variations that result from propagation conditions, rain attenuation, and other propagation phenomena that occur over typical paths optimized for the maximum hop length. In the new high-density networks, where frequency reuse becomes one of the more significant considerations, there is a need to reduce transmitted power to the minimum necessary to achieve the desired availability, in order to minimize the effects of intrasystem interference. In high-density networks, individual hop lengths are reduced to the minimum permissible to achieve the desired availability with the minimum transmitted power. To some extent because the hop lengths are reduced, the effects of propagation are also minimized, such that rain attenuation becomes less of an impairment. The net result is that the individual paths can be designed with significantly reduced fade margins. Also, in order to minimize the susceptibility to interference, the subscriber terminals use higher gain antennas and lower receiver noise figures, which also permit lower transmit levels. This consideration is also very important for networks serving customers with expectations for high availability. These new characteristics, which are applied to maximize the frequency reuse, give rise to a greater potential for receiving interference that could enter the receiver directly into the boresite of the subscriber antenna.

4.8 Conclusion

The growing demand for digital radio systems above about 17 GHz stimulates continuous development of new equipment generations that provide improved service quality and user friendliness at ever lower costs. In addition, cost effective implementations are becoming available for ever higher frequency bands.

This progress is made possible by continuous technological developments in active microwave devices, particularly FETs, MMICs, and integrated circuit implementations of the IF, baseband and auxiliary functions.