



Recommendation ITU-R P.1238-9
(06/2017)

**Propagation data and prediction
methods for the planning of indoor
radiocommunication systems and radio local
area networks in the frequency
range 300 MHz to 100 GHz**

P Series
Radiowave propagation



International
Telecommunication
Union

Documents

Document Sharing Hub

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Annex 1 of Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from <http://www.itu.int/ITU-R/go/patents/en> where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

Series of ITU-R Recommendations

(Also available online at <http://www.itu.int/publ/R-REC/en>)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
BT	Broadcasting service (television)
F	Fixed service
M	Mobile, radiodetermination, amateur and related satellite services
P	Radiowave propagation
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

Note: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.

Electronic Publication
Geneva, 2017

© ITU 2017

All rights reserved. No part of this publication may be reproduced, by any means whatsoever, without written permission of ITU.

RECOMMENDATION ITU-R P.1238-9

Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 100 GHz

(Question ITU-R 211/3)

(1997-1999-2001-2003-2005-2007-2009-2012-2015-2017)

Scope

This Recommendation provides guidance on indoor propagation over the frequency range from 300 MHz to 100 GHz. Information is given on:

- path loss models;
- delay spread models;
- effects of polarization and antenna radiation pattern;
- effects of transmitter and receiver siting;
- effects of building materials furnishing and furniture;
- effects of movement of objects in the room;
- statistical model in static usage.

The ITU Radiocommunication Assembly,

considering

- a) that many new short-range (operating range less than 1 km) personal communication applications are being developed which will operate indoors;
- b) that there is a high demand for radio local area networks (RLANs) and wireless private business exchanges (WPBXs) as demonstrated by existing products and intense research activities;
- c) that it is desirable to establish RLAN standards which are compatible with both wireless and wired communications;
- d) that short-range systems using very low power have many advantages for providing services in the mobile and personal environments such as RF sensor networks and wireless devices operated in TV white space bands;
- e) that knowledge of the propagation characteristics within buildings and the interference arising from multiple users in the same area is critical to the efficient design of systems;
- f) that there is a need both for general (i.e. site-independent) models and advice for initial system planning and interference assessment, and for deterministic (or site-specific) models for some detailed evaluations,

noting

- a) that Recommendation ITU-R P.1411 provides guidance on outdoor short-range propagation over the frequency range 300 MHz to 100 GHz, and should be consulted for those situations where both indoor and outdoor conditions exist;
- b) that Recommendation ITU-R P.2040 provides guidance on the effects of building material properties and structures on radiowave propagation,

that the information and methods in Annex 1 be adopted for the assessment of the propagation characteristics of indoor radio systems between 300 MHz and 100 GHz.

1 Introduction

Because of the complex nature of these factors, if the specific planning of an indoor radio system were to be undertaken, detailed knowledge of the particular site would be required, e.g. geometry, materials, furniture, expected usage patterns, etc. However, for initial system planning, it is necessary to estimate the number of base stations to provide coverage to distributed mobile stations within the area and to estimate potential interference to other services or between systems. For these system planning cases, models that generally represent the propagation characteristics in the environment are needed. At the same time the model should not require a lot of input information by the user in order to carry out the calculations.

This Annex presents mainly general site-independent models and qualitative advice on propagation impairments encountered in the indoor radio environment. Where possible, site-specific models are also given. In many cases, the available data on which to base models was limited in either frequency or test environments; it is hoped that the advice in this Annex will be expanded as more data are made available. Similarly, the accuracy of the models will be improved with experience in their application, but this Annex represents the best advice available at this time.

2 Propagation impairments and measures of quality in indoor radio systems

Propagation impairments in an indoor radio channel are caused mainly by:

- reflection from, and diffraction around, objects (including walls and floors) within the rooms;
- transmission loss through walls, floors and other obstacles;
- channelling of energy, especially in corridors at high frequencies;
- motion of persons and objects in the room, including possibly one or both ends of the radio link.

and give rise to impairments such as:

- path loss – not only the free-space loss but additional loss due to obstacles and transmission through building materials, and possible mitigation of free-space loss by channelling;
- temporal and spatial variation of path loss;
- multipath effects from reflected and diffracted components of the wave;
- polarization mismatch due to random alignment of mobile terminal.

Indoor wireless communication services can be characterized by the following features:

- high/medium/low data rate;
- coverage area of each base station (e.g. room, floor, building);
- mobile/portable/fixed;
- real time/non-real time/quasi-real time;
- network topology (e.g. point-to-point, point-to-multipoint, each-point-to-each-point).

It is useful to define which propagation characteristics of a channel are most appropriate to describe its quality for different applications, such as voice communications, data transfer at different speeds, image transfer and video services. Table 1 lists the most significant characteristics of typical services.

TABLE 1
Typical services and propagation impairments

Services	Characteristics	Propagation impairments of concern
Wireless local area network	High data rate, single or multiple rooms, portable, non-real time, point-to-multipoint or each-point-to-each-point	Path loss – temporal and spatial distribution Multipath delay Ratio of desired-to-undesired mode strength
WPBX	Medium data rate, multiple rooms, single floor or multiple floors, real time, mobile, point-to-multipoint	Path loss – temporal and spatial distribution
Indoor paging	Low data rate, multiple floors, non-real time, mobile, point-to-multipoint	Path loss – temporal and spatial distribution
Indoor wireless video	High data rate, multiple rooms, real time, mobile or portable, point-to-point	Path loss – temporal and spatial distribution Multipath delay

3 Path loss models

The use of this indoor transmission loss model assumes that the base station and portable terminal are located inside the same building. The indoor base to mobile/portable radio path loss can be estimated with either site-general or site-specific models.

3.1 Site-general models

The models described in this section are considered to be site-general as they require little path or site information. The indoor radio path loss is characterized by both an average path loss and its associated shadow fading statistics. Several indoor path loss models account for the attenuation of the signal through multiple walls and/or multiple floors. The model described in this section

accounts for the loss through multiple floors to allow for such characteristics as frequency reuse between floors. The distance power loss coefficients given below include an implicit allowance for transmission through walls and over and through obstacles, and for other loss mechanisms likely to be encountered within a single floor of a building. Site-specific models would have the option of explicitly accounting for the loss due to each wall instead of including it in the distance model.

The basic model has the following form:

$$L_{total} = L(d_o) + N \log_{10} \frac{d}{d_o} + L_f(n) \quad \text{dB} \quad (1)$$

where:

- N : distance power loss coefficient
- f : frequency (MHz)
- d : separation distance (m) between the base station and portable terminal (where $d > 1$ m)
- d_o : reference distance (m)
- $L(d_o)$: path loss at d_o (dB), for a reference distance d_o at 1 m, and assuming free-space propagation $L(d_o) = 20 \log_{10} f - 28$ where f is in MHz
- L_f : floor penetration loss factor (dB)
- n : number of floors between base station and portable terminal ($n \geq 0$), $L_f = 0$ dB for $n = 0$.

Typical parameters, based on various measurement results, are given in Tables 2 and 3. Although these tables are for mainly up to 100 GHz corresponding to the scope of this Recommendation, the power loss coefficients at 300 GHz are also provided for possible future extension of frequency usage in indoor environments. Additional general guidelines are given at the end of the section.

TABLE 2
Power loss coefficients, N , for indoor transmission loss calculation

Frequency (GHz)	Residential	Office	Commercial	Factory	Corridor	Data Centre
0.8	—	22.5 ⁽¹⁴⁾	—	—	—	—
0.9	—	33	20	—	—	—
1.25	—	32	22	—	—	—
1.9	28	30	22	—	—	—
2.1	—	25.5 ⁽⁴⁾	20	21.1	17 ⁽⁹⁾	—
2.2	—	20.7 ⁽¹⁴⁾	—	—	—	—
2.4	28	30	—	—	—	—
2.625	—	44 ⁽⁵⁾	—	33 ⁽⁶⁾	—	—
3.5	—	27	—	—	—	—
4	—	28	22	—	—	—
4.7	—	19.8 ⁽¹⁴⁾	—	—	—	—
5.2	30 ⁽²⁾ 28 ⁽³⁾	31	—	—	—	—

TABLE 2 (end)

Frequency (GHz)	Residential	Office	Commercial	Factory	Corridor	Data Centre
5.8	–	24	–	–	–	–
26	–	19.5 ⁽¹⁴⁾	–	–	–	–
28	–	18.4 ⁽¹²⁾ 29.9 ⁽¹²⁾	27.6 ⁽⁸⁾ 17.9 ^(12, 13) 24.8 ^(12, 13)	–	–	–
37	–	15.6 ⁽¹⁴⁾	–	–	–	–
38	–	20.3 ⁽¹²⁾ 29.6 ⁽¹²⁾	18.6 ^(12, 13) 25.9 ^(12, 13)	–	–	–
51-57	–	15 ⁽¹⁰⁾	–	–	13 ⁽¹⁰⁾ 16.3 ^(4, 10)	–
60	–	22 ⁽¹⁾	17 ⁽¹⁾	–	16 ^{(1) (7)(9)}	–
67-73	–	19 ⁽¹¹⁾	–	–	16 ⁽¹¹⁾ 17.6 ^(4, 11)	–
70	–	22 ⁽¹⁾	–	–	–	–
300	–	20 ⁽¹⁵⁾	–	–	19.5 ^(9, 15)	20.2 ⁽¹⁵⁾

- ⁽¹⁾ 60 GHz and 70 GHz values assume propagation within a single room or space, and do not include any allowance for transmission through walls. Gaseous absorption around 60 GHz is also significant for distances greater than about 100 m which may influence frequency reuse distances (see Recommendation ITU-R P.676).
- ⁽²⁾ Apartment: Single or double storey dwellings for several households. In general most walls separating rooms are concrete walls.
- ⁽³⁾ House: Single or double storey dwellings for a household. In general most walls separating rooms are wooden walls.
- ⁽⁴⁾ Computer room where there are many computers around the room.
- ⁽⁵⁾ Transmitter and receiver are on the same floor and both antennas are set at ceiling height of 2.7 m.
- ⁽⁶⁾ Path between transmitter and receiver is semi-shielded by metal materials and both antennas height is 1.5 m.
- ⁽⁷⁾ Transmit and receive antennas have 15.4° beam width.
- ⁽⁸⁾ Railway station (170 m × 45 m × 21 m(H)) and Airport terminal (650 m × 82 m × 20 m(H)): NLoS case, 60° half-power beam width antenna for transmitter is set at the height of 8 m, and 10° beam width for receiver is set at 1.5 m on the floor. The value was obtained from the maximum path gain among various Tx and Rx antenna orientations.
- ⁽⁹⁾ Transmitter and receiver are on LoS corridor.
- ⁽¹⁰⁾ Transmit antenna beamwidth 56.3°, synthesised 360° in azimuth at receiver with 19.7° beamwidth in elevation.
- ⁽¹¹⁾ Transmit antenna beamwidth 40°, synthesised 360° in azimuth at receiver with 14.4° beamwidth in elevation.
- ⁽¹²⁾ The upper number is for LoS cases and the lower number is for NLoS cases.
- ⁽¹³⁾ The environments are same to (8) and a Tx antenna with 60° beamwidth is set at the height of 8 m and a Rx with an omni-directional antenna is set at the height of 1.5 m.
- ⁽¹⁴⁾ Open office (50 m × 16 m × 2.7 m (H)): LoS case. Averaged results with Tx heights of 2.6 and 1.2 m. Rx height was 1.5 m height. Both Tx and Rx are omni-directional antennas.
- ⁽¹⁵⁾ Transmit and received antennas have 10° beamwidth.

TABLE 3

Floor penetration loss factors, L_f (dB) with n being the number of floors penetrated, for indoor transmission loss calculation ($n \geq 1$)

Frequency (GHz)	Residential	Office	Commercial
0.9	–	9 (1 floor) 19 (2 floors) 24 (3 floors)	–
1.8-2	4 n	15 + 4 ($n - 1$)	6 + 3 ($n - 1$)
2.4	10 ⁽¹⁾ (apartment) 5 (house)	14	–
3.5	–	18 (1 floor) 26 (2 floors)	–
5.2	13 ⁽¹⁾ (apartment) 7 ⁽²⁾ (house)	16 (1 floor)	–
5.8	–	22 (1 floor) 28 (2 floors)	–

(1) Per concrete wall.

(2) Wooden mortar.

For the various frequency bands where the power loss coefficient is not stated for residential buildings, the value given for office buildings could be used.

It should be noted that there may be a limit on the isolation expected through multiple floors. The signal may find other external paths to complete the link with less total loss than that due to the penetration loss through many floors.

When the external paths are excluded, measurements at 5.2 GHz have shown that at normal incidence the mean additional loss due to a typical reinforced concrete floor with a suspended false ceiling is 20 dB, with a standard deviation of 1.5 dB. Lighting fixtures increased the mean loss to 30 dB, with a standard deviation of 3 dB, and air ducts under the floor increased the mean loss to 36 dB, with a standard deviation of 5 dB. These values, instead of L_f , should be used in site-specific models such as ray-tracing.

The indoor shadow fading statistics are log-normal and standard deviation values (dB) are given in Table 4.

TABLE 4

Shadow fading statistics, standard deviation (dB), for indoor transmission loss calculation

Frequency (GHz)	Residential	Office	Commercial
0.8	–	3.4 ⁽⁴⁾	–
1.8-2	8	10	10
2.2	–	2.3 ⁽⁴⁾	–
3.5	–	8	–
4.7	–	2.7 ⁽⁴⁾	–

TABLE 4 (end)

Frequency (GHz)	Residential	Office	Commercial
5.2	—	12	—
5.8	—	17	—
26	—	2.8 ⁽⁴⁾	—
28	—	3.4 ⁽²⁾ 6.6 ⁽²⁾	6.7 ⁽¹⁾ 1.4 ^(2, 3) 6.4 ^(2, 3)
37	—	2.4 ⁽⁴⁾	—
38	—	4.6 ⁽²⁾ 6.8 ⁽²⁾	1.6 ^(2, 3) 5.5 ^(2, 3)
51-57	—	2.7	—
67-73	—	2.1	—

- (1) Railway station (170 m × 45 m × 21 m(H)) and Airport terminal (650 m × 82 m × 20 m(H)): NLoS case, 60° half-power beam width antenna for transmitter is set at the height of 8 m, and 10° beam width for receiver is set at 1.5 m on the floor. The value was obtained from the maximum path gain among various Tx and Rx antenna orientations.
- (2) The upper number is for LoS case and the lower number is for NLoS case.
- (3) The environments are same to (1) and a Tx antenna with 60° beamwidth is set at the height of 8 m and a Rx with an omni-directional antenna is set at the height of 1.5 m.
- (4) Open office (50 m × 16 m × 2.7 m (H)): LoS case. Averaged results with Tx heights of 2.6 and 1.2 m. Rx height was 1.5 m height. Both Tx and Rx are omni-directional antennas.

Although available measurements have been made under various conditions which make direct comparisons difficult and only select frequency bands have been reported upon, a few general conclusions can be drawn, especially for the 900-2000 MHz band.

- Paths with a line-of-sight (LoS) component are dominated by free-space loss and have a distance power loss coefficient of around 20.
- Large open rooms also have a distance power loss coefficient of around 20; this may be due to a strong LoS component to most areas of the room. Examples include rooms located in large retail stores, sports arenas, open-plan factories, and open-plan offices.
- Corridors exhibit path loss less than that of free-space, with a typical distance power coefficient of around 18. Grocery stores with their long, linear aisles exhibit the corridor loss characteristic.
- Propagation around obstacles and through walls adds considerably to the loss which can increase the power distance coefficient to about 40 for a typical environment. Examples include paths between rooms in closed-plan office buildings.
- For long unobstructed paths, the first Fresnel zone breakpoint may occur. At this distance, the distance power loss coefficient may change from about 20 to about 40.
- The decrease in the path loss coefficient with increasing frequency for an office environment (Table 2) is not always observed or easily explained. On the one hand, with increasing frequency, loss through obstacles (e.g. walls, furniture) increases, and diffracted signals contribute less to the received power; on the other hand, the Fresnel zone is less obstructed at higher frequencies, leading to lower loss. The actual path loss is dependent on these opposing mechanisms.