

Recommendation ITU-R P.1238-12

(08/2023)

P Series: Radiowave propagation

**Propagation data and prediction
methods for the planning of indoor
radiocommunication systems and radio
local area networks in the frequency
range 300 MHz to 450 GHz**

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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.

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RECOMMENDATION ITU-R P.1238-12

Propagation data and prediction methods for the planning of indoor radiocommunication systems and radio local area networks in the frequency range 300 MHz to 450 GHz*

(Question ITU-R 211/3)

(1997-1999-2001-2003-2005-2007-2009-2012-2015-2017-2019-2021-2023)

Scope

This Recommendation provides guidance on indoor propagation over the frequency range from 300 MHz to 450 GHz. Information is given on:

- basic transmission 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.

Keywords

Indoor propagation, basic transmission loss, delay spread

Abbreviations/Glossary

CP	Circular polarization
FDTD	Finite difference time domain
HH	Horizontal to horizontal
HPBW	Half power beamwidth
LoS	Line-of-sight
LP	Linear polarization
MIMO	Multiple input multiple output
MT	Mobile terminal
N/A	Not available
NLoS	Non-line-of-sight
PDF	Probability density function
r.m.s.	Root mean square
RF	Radio frequency
RLAN	Radio local area networks

* Further measurement results are required to validate the models above 100 GHz in this Recommendation, as proposed in Question ITU-R 211-7/3.

Rx	Receiver
TV	Television
Tx	Transmitter
UTD	Uniform theory of diffraction
VV	Vertical to vertical
WLAN	Wireless local area networks
WPBX	Wireless private business exchanges
XPR	Cross polarization discrimination ratio

Related ITU Recommendations, Reports

Recommendation ITU-R P.676

Recommendation ITU-R P.1407

Recommendation ITU-R P.1411

Recommendation ITU-R P.2040

Report ITU-R P.2406

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;
- c) that Report ITU-R P.2406 provides additional background information on how the measurement data and models were obtained and derived in the Recommendation,

recommends

that the information and methods in Annex 1 should be used for the assessment of the propagation characteristics of indoor radio systems between 300 MHz and 450 GHz.

Annex 1

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1 Introduction

Propagation prediction for indoor radio systems differs in some respects from that for outdoor systems. The ultimate purposes, as in outdoor systems, are to ensure efficient coverage of the required area (or to ensure a reliable path, in the case of point-to-point systems), and to avoid interference, both within the system and to other systems. However, in the indoor case, the extent of coverage is well-defined by the geometry of the building, and the limits of the building itself will affect the propagation. In addition to frequency reuse on the same floor of a building, there is often a desire for frequency reuse between floors of the same building, which adds a third dimension to the interference issues. Finally, the very short range, particularly where millimetre wave frequencies are used, means that small changes in the immediate environment of the radio path may have substantial effects on the propagation characteristics.

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. 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:

- basic transmission loss – not only the free space basic transmission loss but additional loss due to obstacles and transmission through building materials, and possible mitigation of free space basic transmission loss by channelling;
- temporal and spatial variation of basic transmission 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	Basic transmission 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	Basic transmission loss – temporal and spatial distribution
Indoor paging	Low data rate, multiple floors, non-real time, mobile, point-to-multipoint	Basic transmission loss – temporal and spatial distribution
Indoor wireless video	High data rate, multiple rooms, real time, mobile or portable, point-to-point	Basic transmission loss – temporal and spatial distribution Multipath delay

3 Basic transmission 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 basic transmission loss can be estimated with either site-general or site-specific models.

3.1 Site-general models

The site-general model is applicable to situations where both the transmitting and receiving stations are located on the same floor. The median basic transmission loss is given by:

$$L_b(d, f) = 10\alpha \log_{10}(d) + \beta + 10\gamma \log_{10}(f) \quad \text{dB} \quad (1)$$

with an additive zero mean Gaussian random variable $N(0, \sigma)$ with a standard deviation σ (dB), where:

- d : 3D direct distance between the transmitting and receiving stations (m)
- f : operating frequency (GHz)
- α : coefficient associated with the increase of the basic transmission loss with distance
- β : coefficient associated with the offset value of the basic transmission loss
- γ : coefficient associated with the increase of the basic transmission loss with frequency.

For non-line-of-sight (NLoS) Monte Carlo simulations, the excess basic transmission loss with respect to free-space basic transmission loss, L_{FS} ($L_{FS} = 20 \log_{10}(4 \times 10^9 \pi d f / c)$ where c is the speed of light in metres per second), will not exceed $10 \log_{10}(10^{0.1A} + 1)$ (dB), where A is a random variable with a normal distribution $N(\mu, \sigma)$, with mean $\mu = L_b(d, f) - L_{FS}$ and standard deviation of σ .

The recommended coefficient values for indoor propagation environments are provided in Table 2.

TABLE 2
Basic transmission loss coefficients

Environment	LoS/NLoS	Frequency range (GHz)	Distance range (m)	α	β	γ	σ
Office	LoS	0.3–83.5	2–27	1.46	34.62	2.03	3.76
	NLoS	0.3–82.0	4–30	2.46	29.53	2.38	5.04
Corridor	LoS	0.3–83.5	2–160	1.63	28.12	2.25	4.07
	NLoS	0.625–83.5	4–94	2.77	29.27	2.48	7.63
Industrial	LoS	0.625–70.28	2–102	2.34	24.26	2.06	2.67
	NLoS	0.625–70.28	5–110	3.66	22.42	1.34	9.00
Conference/lecture room	LoS	0.625–82.0	2–21	1.61	28.82	2.37	3.28
	NLoS	7.075–82.0	4–25	2.07	28.13	2.67	3.67

3.2 Site-specific models

For estimating the basic transmission loss or field strength, site-specific models are also useful. Models for indoor field strength prediction based on the uniform theory of diffraction (UTD) and ray-tracing techniques are available. Detailed information of the building structure is necessary for the calculation of the indoor field strength. These models combine empirical elements with the theoretical electromagnetic approach of UTD. The method takes into account direct, single-diffracted and single-reflected rays, and can be extended to multiple diffraction or multiple reflection as well as to combinations of diffracted and reflected rays. By including reflected and diffracted rays, the basic transmission loss prediction accuracy is significantly improved.

For directional antenna usage, the indoor basic-transmission loss is characterized by both an average basic transmission loss and its associated shadow fading statistics. Several indoor basic transmission loss models account for the attenuation of the signal through multiple walls and/or multiple floors. The model-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. Uniform theory of diffraction (UTD) and ray-tracing techniques would have the option of explicitly accounting for the loss due to each wall instead of including it in the distance model.

The median basic transmission loss for directional transmitter antennas with a 40° beamwidth to an omnidirectional receiver antenna located on the same floor within a single room or space, and does not include any allowance for transmission through walls, and has the form as the site-general model given in equation (1) with parameters given in Table 3.

TABLE 3

Basic transmission loss coefficients for directional to omni-directional

Environment	LoS/NLoS	Distance range (m)	Frequency range (GHz)	α	β	γ	σ
Corridor	LoS	4-21	0.6-73 ⁽¹⁾	1.43	29.3	2.38	2.92
	NLoS	5.8-23		3.19	16.9	2.71	4.28
Office	LoS	4.9-21.5		1.29	32	2.32	2.75
	NLoS	14.2-29.2		3.46	14.1	2.61	3.04
Industrial	LoS	5.8-25.7		1.84	24.6	2.43	2.29
	NLoS	6.5-25.9		2.92	22.3	3.34	6.14

⁽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 Rec. ITU-R P.676).

The site-specific basic transmission loss model also can use the following form:

$$L_{total} = L(d_o) + N \log_{10} \frac{d}{d_o} + L_f(n) \quad (2)$$

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)
- $L(d_o)$: basic transmission 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 4 and 5. Additional general guidelines are given at the end of the section.

TABLE 4

Power loss coefficients, N , for indoor transmission loss calculation

Frequency (GHz)	Office	Commercial	Factory	Corridor	Data Centre
28		27.6 ⁽¹⁾ 17.9 ^{(2), (3)} 24.8 ^{(2), (3)}	—	—	—
38		18.6 ^{(2), (3)} 25.9 ^{(2), (3)}	—	—	—
250	20.1 ⁽⁵⁾	—	—	19.0 ^{(2), (5)}	—
275	20 ⁽⁵⁾	—	—	19.2 ^{(2), (5)}	—
300	20 ⁽⁴⁾	—	—	19.5 ^{(2), (4)}	20.2 ⁽⁴⁾
325	19.8 ⁽⁶⁾	—	—	19.6 ^{(2), (6)}	—
340	20.8 ⁽⁷⁾	—	—	19.9 ^{(2), (7)}	—
410	20.6 ⁽⁵⁾	—	—	20.1 ^{(2), (5)}	—

- ⁽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 cases and the lower number is for NLoS cases.
- ⁽³⁾ The environments are same to (2) 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⁾ Transmit and received antennas have 10° beamwidth.
- ⁽⁵⁾ Transmit and received antennas have 8° beamwidth.
- ⁽⁶⁾ Transmit and received antennas have 7° beamwidth.
- ⁽⁷⁾ Transmit and received antennas have 9° beamwidth.

TABLE 5

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)	—