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Radiocommunication Sector of ITU

Recommendation ITU-R P.1411-9
(06/2017)

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

P Series
Radiowave propagation



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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.1411-9

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

(Question ITU-R 211/3)

(1999-2001-2003-2005-2007-2009-2012-2013-2015-2017)

Scope

This Recommendation provides guidance on outdoor short-range propagation over the frequency range 300 MHz to 100 GHz. Information is given on path loss models for line-of-sight (LoS) and non-line-of-sight (NLoS) environments, building entry loss, multipath models for both environments of street canyon and over roof-tops, number of signal components, polarization characteristics and fading characteristics. This Recommendation can also be used in compatibility studies.

The ITU Radiocommunication Assembly,

considering

- a) that many new short-range (operating range less than 1 km) mobile and personal communication applications are being developed;
- b) that there is a high demand for radio local area networks (RLANs) and wireless local loop systems;
- c) that short-range systems using very low power have many advantages for providing services in the mobile and wireless local loop environment;
- d) that knowledge of the propagation characteristics and the interference arising from multiple users in the same area is critical to the efficient design of systems;
- e) 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.1238 provides guidance on indoor 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.1546 provides guidance on propagation for systems that operate over distances of 1 km and greater, and over the frequency range 30 MHz to 3 GHz;
- c) that Recommendation ITU-R P.2040 provides guidance on the effects of building material properties and structures on radiowave propagation;
- d) that Recommendation ITU-R P.[BEL] provides statistical models for building entry loss,

recommends

that the information and methods in Annex 1 should be adopted for the assessment of the propagation characteristics of short-range outdoor radio systems between 300 MHz and 100 GHz where applicable.

Annex 1

1 Introduction

Propagation over paths of length less than 1 km is affected primarily by buildings and trees, rather than by variations in ground elevation. The effect of buildings is predominant, since most short-path radio links are found in urban and suburban areas. The mobile terminal is most likely to be held by a pedestrian or located in a vehicle.

This Recommendation defines categories for short propagation paths, and provides methods for estimating path loss, delay spread, angular spread, and cross correlation over these paths.

The propagation models of these methods are symmetric in the sense that they treat radio terminals at both ends of a path in the same manner. From the model's perspective, it does not matter which terminal is the transmitter and which is the receiver. Hence the terms "Station 1" and "Station 2" are used to denote the terminals at the start and end of the propagation path, respectively.

2 Physical operating environments and definition of cell types

Environments described in this Recommendation are categorized solely from the radio propagation perspective. Radiowave propagation is influenced by the environment, i.e. building structures and heights, the usage of the mobile terminal (pedestrian/vehicular) and the positions of the antennas. Five different environments are identified, considered to be the most typical. Hilly areas, for example, are not considered, as they are less typical in metropolitan areas. Table 1 lists the five environments. Recognizing that there is a wide variety of environments within each category, it is not intended to model every possible case but to give propagation models that are representative of environments frequently encountered.

TABLE 1

Physical operating environments – Propagation impairments

Environment	Description and propagation impairments of concern
Urban very high-rise	– Busiest urban deep canyon, characterized by streets lined with high-density buildings with several tens of floors which results in an urban deep canyon – High dense buildings and skyscrapers interleave with each other which yields to the rich scattering propagation paths in NLoS – Rows of tall buildings provide the possibility of very long path delays – Heavy traffic vehicles and high flowrate visitors in the area act as reflectors adding Doppler shift to the reflected waves – Trees beside the streets provide dynamic shadowing
Urban high-rise	– Urban canyon, characterized by streets lined with tall buildings of several floors each – Building height makes significant contributions from propagation over roof-tops unlikely – Rows of tall buildings provide the possibility of long path delays – Large numbers of moving vehicles in the area act as reflectors adding Doppler shift to the reflected waves

TABLE 1 (*end*)

Environment	Description and propagation impairments of concern
Urban low-rise/Suburban	– Typified by wide streets – Building heights are generally less than three stories making diffraction over roof-top likely – Reflections and shadowing from moving vehicles can sometimes occur – Primary effects are long delays and small Doppler shifts
Residential	– Single and double storey dwellings – Roads are generally two lanes wide with cars parked along sides – Heavy to light foliage possible – Motor traffic usually light
Rural	– Small houses surrounded by large gardens – Influence of terrain height (topography) – Heavy to light foliage possible – Motor traffic sometimes high

For each of the five different environments two possible scenarios for the mobile are considered. Therefore the users are subdivided into pedestrian and vehicular users. For these two applications the velocity of the mobile is quite different yielding different Doppler shifts. Table 2 shows typical velocities for these scenarios.

TABLE 2

Physical operating environments – Typical mobile velocity

Environment	Velocity for pedestrian users (m/s)	Velocity for vehicular users
Urban very high-rise/Urban high-rise	1.5	Typical downtown speeds around 50 km/h (14 m/s)
Urban low-rise/Suburban	1.5	Around 50 km/h (14 m/s) Expressways up to 100 km/h (28 m/s)
Residential	1.5	Around 40 km/h (11 m/s)
Rural	1.5	80-100 km/h (22-28 m/s)

The type of propagation mechanism that dominates depends also on the height of the base station antenna relative to the surrounding buildings. Table 3 lists the typical cell types relevant for outdoor short-path propagation.

TABLE 3

Definition of cell types

Cell type	Cell radius	Typical position of base station antenna
Micro-cell	0.05 to 1 km	Outdoor; mounted above average roof-top level, heights of some surrounding buildings may be above base station antenna height
Dense urban micro-cell	0.05 to 0.5 km	Outdoor; mounted below average roof-top level
Pico-cell	Up to 50 m	Indoor or outdoor (mounted below roof-top level)

(Note that “dense urban micro-cell” is not explicitly defined in Radiocommunication Study Group 5 Recommendation.)

3 Path categories

3.1 Definition of propagation situations

Three levels of the location of the station can be considered in this Recommendation. They are 1) over the roof-top (designated as L1 in Fig. 1); 2) below roof-top but above head level (L2); and 3) at or below head level (L3). Comprehensively, six different kinds of links can be considered depending on the locations of the stations, each of which may be LoS or NLoS.

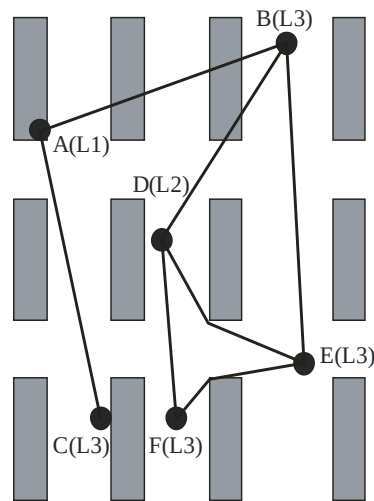
Typical propagation situations in urban or suburban areas are depicted in Fig. 1. When one station (A) is mounted above roof-top level and another station (B or C) is located at head level, the corresponding cell is a micro-cell. The path can be LoS (A to C) or NLoS (A to B). The propagation between the stations A and B is mainly over the roof-tops. When one station (D) is mounted below roof-top level but above head level and another station (E or F) is located at head level in an urban or suburban environment, the corresponding cell is a micro- or pico-cellular environment. In these cell types, propagation is mainly within street canyons. For mobile-to-mobile links, both ends of the link can be assumed to be at head level. The path can be LoS (B to E) or NLoS (E to F).

3.1.1 Propagation over rooftops, non-line-of-sight (NLoS)

The typical NLoS case (link A-B in Fig. 1) is described in Fig. 2. In the following, this case is called NLoS1.

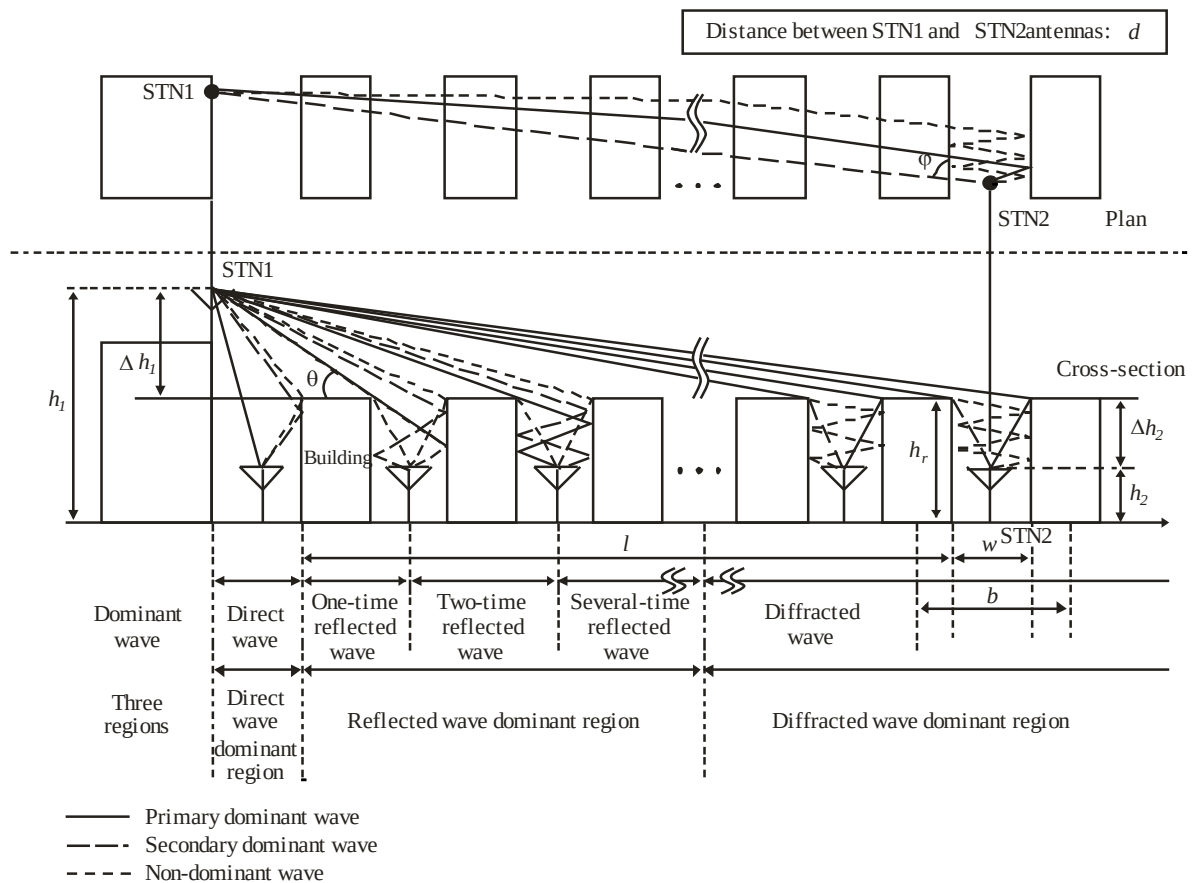
Figure 1: Typical propagation situations in urban or suburban areas

FIGURE 1
Typical propagation situation in urban areas



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FIGURE 2
Definition of parameters for the NLoS1 case



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The relevant parameters for this situation are:

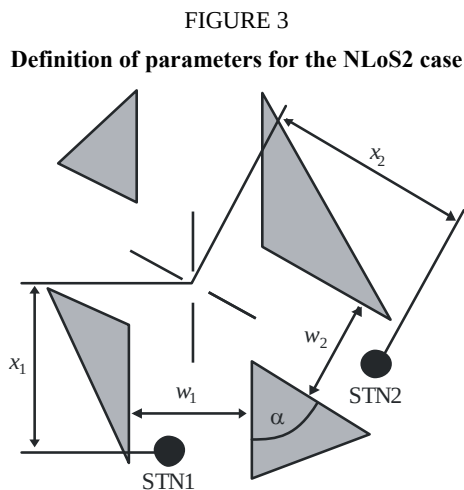
h_r : average height of buildings (m)

- w : street width (m)
 b : average building separation (m)
 φ : street orientation with respect to the direct path (degrees)
 h_1 : Station 1 antenna height (m)
 h_2 : Station 2 antenna height (m)
 l : length of the path covered by buildings (m)
 d : distance from Station 1 to Station 2.

The NLoS1 case frequently occurs in residential/rural environments for all cell-types and is predominant for micro-cells in urban low-rise/suburban environments. The parameters h_r , b and l can be derived from building data along the line between the antennas. However, the determination of w and φ requires a two-dimensional analysis of the area around the mobile. Note that l is not necessarily normal to the building orientation.

3.1.2 Propagation along street canyons, NLoS

Figure 3 depicts the situation for a typical dense urban micro-cellular NLoS-case (link D-E in Fig. 1). In the following, this case is called NLoS2.



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The relevant parameters for this situation are:

- w_1 : street width at the position of the Station 1 (m)
 w_2 : street width at the position of the Station 2 (m)
 x_1 : distance Station 1 to street crossing (m)
 x_2 : distance Station 2 to street crossing (m)
 α : is the corner angle (rad).

NLoS2 is the predominant path type in urban high-rise environments for all cell-types and occurs frequently in dense urban micro- and pico-cells in urban low-rise environments. The determination of all parameters for the NLoS2 case requires a two-dimensional analysis of the area around the mobile.

3.1.3 Line-of-sight (LoS) paths

The paths A-C, D-F, and B-E in Fig. 1 are examples of LoS situations. The same models can be applied for these types of LoS path.

3.2 Data requirements

For site-specific calculations in urban areas, different types of data can be used. The most accurate information can be derived from high-resolution data where information consists of:

- building structures;
- relative and absolute building heights;
- vegetation information.

Data formats can be both raster and vector. The location accuracy of the vector data should be of the order of 1 to 2 m. The recommended resolution for the raster data is 1 to 10 m. The height accuracy for both data formats should be of the order of 1 to 2 m.

If no high-resolution data are available, low-resolution land-use data (50 m resolution) are recommended. Depending on the definition of land-use classes (dense urban, urban, suburban, etc.) the required parameters can be assigned to these land-use classes. These data can be used in conjunction with street vector information in order to extract street orientation angles.

4 Path loss models

For typical scenarios in urban areas, some closed-form algorithms can be applied. These propagation models can be used both for site-specific and site-general calculations. The corresponding propagation situations are defined in § 3.1. The type of the model to be applied may depend also on the frequency range e.g. UHF, SHF and EHF (millimetre-wave). For site-specific calculations, different models have to be applied for UHF propagation and for millimetre-wave propagation. In the UHF frequency range, LoS and NLoS situations are considered. In mm-wave propagation, LoS is considered only. Additional attenuation by oxygen and hydrometeors should be considered in the millimetre-wave frequency range.

4.1 Models for propagation within street canyons

4.1.1 Site-general model

This site-general model is applicable to situations where both the transmitting and receiving stations are located below-rooftop, regardless of their antenna heights. The site-general model is provided by the following equation:

$$PL(d, f) = 10\alpha \log_{10}(d) + \beta + 10\gamma \log_{10}(f) + N(0, \sigma) \text{ dB} \quad (1)$$

where:

- d : 3D direct distance between the transmitting and receiving stations (m)
- f : operating frequency (GHz)
- α : coefficient associated with the increase of the path loss with distance
- β : coefficient associated with the offset value of the path loss
- γ : coefficient associated with the increase of the path loss with frequency
- $N(0, \sigma)$: a zero mean Gaussian random variable with a standard deviation σ (dB).

The recommended values for LoS (e.g. D-F in Fig. 1) and NLoS (e.g. D-E in Fig. 1) situations to be used for below-rooftop propagation in urban and suburban environments are provided in Table 4.

TABLE 4
Path loss coefficients for below-rooftop propagation

Frequency range (GHz)	Distance range (m)	Type of environment	LoS / NLoS	α	β	γ	σ
0.8-73	5-660	Urban high-rise, Urban low-rise / Suburban	LoS	2.12	29.2	2.11	5.06
0.8-38	30-715	Urban high-rise	NLoS	4.00	10.2	2.36	7.60
10-73	30-250	Urban low-rise / Suburban	NLoS	5.06	-4.68	2.02	9.33

4.1.2 Site-specific model for LoS situation

This situation is depicted as the paths between A and C, D and F, or B and E in Fig. 1.

UHF propagation

In the UHF frequency range, basic transmission loss, as defined by Recommendation ITU-R P.341, can be characterized by two slopes and a single breakpoint. An approximate lower bound $L_{LoS,l}$ is given by:

$$L_{LoS,l} = L_{bp} + \begin{cases} 20 \log_{10} \left(\frac{d}{R_{bp}} \right) & \text{for } d \leq R_{bp} \\ 40 \log_{10} \left(\frac{d}{R_{bp}} \right) & \text{for } d > R_{bp} \end{cases} \quad (2)$$

where R_{bp} is the breakpoint distance in m and is given by:

$$R_{bp} \approx \frac{4h_1h_2}{\lambda} \quad (3)$$

where λ is the wavelength (m). The lower bound is based on the two-ray plane earth reflection model.

An approximate upper bound $L_{LoS,u}$ is given by:

$$L_{LoS,u} = L_{bp} + 20 + \begin{cases} 25 \log_{10} \left(\frac{d}{R_{bp}} \right) & \text{for } d \leq R_{bp} \\ 40 \log_{10} \left(\frac{d}{R_{bp}} \right) & \text{for } d > R_{bp} \end{cases} \quad (4)$$

L_{bp} is a value for the basic transmission loss at the break point, defined as:

$$L_{bp} = \left| 20 \log_{10} \left(\frac{\lambda^2}{8\pi h_1 h_2} \right) \right| \quad (5)$$

The upper bound has the fading margin of 20 dB. In equation (4), the attenuation coefficient before the breakpoint is set to 2.5 because a short distance leads to a weak shadowing effect.

According to the free-space loss curve, a median value $L_{LoS,m}$ is given by:

$$L_{LoS,m} = L_{bp} + 6 + \begin{cases} 20 \log_{10} \left(\frac{d}{R_{bp}} \right) & \text{for } d \leq R_{bp} \\ 40 \log_{10} \left(\frac{d}{R_{bp}} \right) & \text{for } d > R_{bp} \end{cases} \quad (6)$$

SHF propagation up to 15 GHz

At SHF, for path lengths up to about 1 km, road traffic will influence the effective road height and will thus affect the breakpoint distance. This distance, R_{bp} , is estimated by:

$$R_{bp} = 4 \frac{(h_1 - h_s)(h_2 - h_s)}{\lambda} \quad (7)$$

where h_s is the effective road height due to such objects as vehicles on the road and pedestrians near the roadway. Hence h_s depends on the traffic on the road. The h_s values given in Tables 5 and 6 are derived from daytime and night-time measurements, corresponding to heavy and light traffic conditions, respectively. Heavy traffic corresponds to 10-20% of the roadway covered with vehicles, and 0.2-1% of the footpath occupied by pedestrians. Light traffic is 0.1-0.5% of the roadway and less than 0.001% of the footpath occupied. The roadway is 27 m wide, including 6 m wide footpaths on either side.

TABLE 5

The effective height of the road, h_s (heavy traffic)

Frequency (GHz)	h_1 (m)	h_s (m)	
		$h_2 = 2.7$	$h_2 = 1.6$
3.35	4	1.3	(2)
	8	1.6	(2)
8.45	4	1.6	(2)
	8	1.6	(2)
15.75	4	1.4	(2)
	8	(1)	(2)

(1) The breakpoint is beyond 1 km.

(2) No breakpoint exists.

TABLE 6

The effective height of the road, h_s (light traffic)

Frequency (GHz)	h_1 (m)	h_s (m)	
		$h_2 = 2.7$	$h_2 = 1.6$
3.35	4	0.59	0.23
	8	(1)	(1)
8.45	4	(2)	0.43
	8	(2)	(1)
15.75	4	(2)	0.74
	8	(2)	(1)

(1) No measurements taken.

(2) The breakpoint is beyond 1 km.

When $h_1, h_2 > h_s$, the approximate values of the upper and lower bounds of basic transmission loss for the SHF frequency band can be calculated using equations (2) and (4), with L_{bp} given by:

$$L_{bp} = \left\lceil 20 \log_{10} \left\{ \frac{\lambda^2}{8\pi(h_1 - h_s)(h_2 - h_s)} \right\} \right\rceil \quad (8)$$

On the other hand, when $h_1 \leq h_s$ or $h_2 \leq h_s$ no breakpoint exists. When two terminals are close ($d < R_s$), the basic propagation loss is similar to that of the UHF range. When two terminals are far, the propagation characteristic is such that the attenuation coefficient is cubed. Therefore, the approximate lower bound for $d \geq R_s$ is given by:

$$L_{LoS,l} = L_s + 30 \log_{10} \left(\frac{d}{R_s} \right) \quad (9)$$

The approximate upper bound for $d \geq R_s$ is given by:

$$L_{LoS,u} = L_s + 20 + 30 \log_{10} \left(\frac{d}{R_s} \right) \quad (10)$$

The basic propagation loss L_s is defined as:

$$L_s = \left| 20 \log_{10} \left(\frac{\lambda}{2\pi R_s} \right) \right| \quad (11)$$

R_s in equations (9) to (11) has been experimentally determined to be 20 m.

Based on measurements, a median value is given by:

$$L_{LoS,m} = L_s + 6 + 30 \log_{10} \left(\frac{d}{R_s} \right) \quad (12)$$

Millimetre-wave propagation

At frequencies above about 10 GHz, the breakpoint distance R_{bp} in equation (3) is far beyond the expected maximum cell radius (500 m). This means that no fourth-power law is expected in this frequency band. Hence the power distance decay-rate will nearly follow the free-space law with a path-loss exponent of about 1.9-2.2.

With directional antennas, the path loss when the boresights of the antennas are aligned is given by

$$L_{LoS} = L_0 + 10n \log_{10} \frac{d}{d_0} + L_{gas} + L_{rain} \text{ dB} \quad (13)$$

where n is the path loss exponent, d is the distance between Station 1 and Station 2 and L_0 is the path loss at the reference distance d_0 . For a reference distance d_0 at 1 m, and assuming free-space propagation $L_0 = 20 \log_{10} f - 28$ where f is in MHz. L_{gas} and L_{rain} , are attenuation by atmospheric gases and by rain which can be calculated from Recommendation ITU-R P.676 and Recommendation ITU-R P.530, respectively.

Values of path loss exponent n are listed in Table 7.

TABLE 7

Directional path loss coefficients for millimetre-wave propagation

Frequency (GHz)	Type of environment	Half power beam width (degree)		Path loss exponent
		Tx Ant	Rx Ant	n
28	Urban very high-rise	30	10	2.21
	Urban low-rise	30	10	2.06
60	Urban low rise	15.4	15.4	1.9

4.1.3 Site-specific model for NLoS situations

This situation is depicted as the paths between D and E in Fig. 1.

4.1.3.1 Frequency range from 800 to 2 000 MHz

For NLoS2 situations where both antennas are below roof-top level, diffracted and reflected waves at the corners of the street crossings have to be considered (see Fig. 3).

$$L_{NLoS2} = -10 \log_{10} (10^{-L_r/10} + 10^{-L_d/10}) \quad \text{dB} \quad (14)$$

where:

L_r : reflection path loss defined by:

$$L_r = 20 \log_{10} (x_1 + x_2) + x_1 x_2 \frac{f(\alpha)}{w_1 w_2} + 20 \log_{10} \left(\frac{4\pi}{\lambda} \right) \quad \text{dB} \quad (15)$$

where:

$$f(\alpha) = \frac{3.86}{\alpha^{3.5}} \quad \text{dB} \quad (16)$$

where $0.6 < \alpha \text{ [rad]} < \pi$.

L_d : diffraction path loss defined by:

$$L_d = 10 \log_{10} [x_1 x_2 (x_1 + x_2)] + 2D_a - 0.1 \left(90 - \alpha \frac{180}{\pi} \right) + 20 \log_{10} \left(\frac{4\pi}{\lambda} \right) \quad \text{dB} \quad (17)$$

$$D_a = \left(\frac{40}{2\pi} \right) \left[\arctan \left(\frac{x_2}{w_2} \right) + \arctan \left(\frac{x_1}{w_1} \right) - \frac{\pi}{2} \right] \quad \text{dB} \quad (18)$$

4.1.3.2 Frequency range from 2 to 38 GHz

The propagation model for the NLoS2 situations as described in § 3.1.2 with the corner angle $\alpha = \pi/2$ rad is derived based on measurements at a frequency range from 2 to 38 GHz, where $h_1, h_2 < h_r$ and w_2 is up to 10 m (or sidewalk). The path loss characteristics can be divided into two parts: the corner loss region and the NLoS region. The corner loss region extends for d_{corner} from the point which is 1 m down the edge of the LoS street into the NLoS street. The corner loss (L_{corner}) is expressed as the additional attenuation over the distance d_{corner} . The NLoS region lies beyond the corner loss region, where a coefficient parameter (β) applies. This is illustrated by the typical curve shown in Fig. 4. Using x_1, x_2 , and w_1 , as shown in Fig. 3, the overall path loss (L_{NLoS2}) beyond the corner region ($x_2 > w_1/2 + 1$) is found using:

$$L_{NLoS2} = L_{LoS} + L_c + L_{att} \quad (19)$$

$$L_c = \begin{cases} \frac{L_{corner}}{\log_{10}(1 + d_{corner})} \log_{10}(x_2 - w_1/2) & w_1/2 + 1 < x_2 \leq w_1/2 + 1 + d_{corner} \\ L_{corner} & x_2 > w_1/2 + 1 + d_{corner} \end{cases} \quad (20)$$

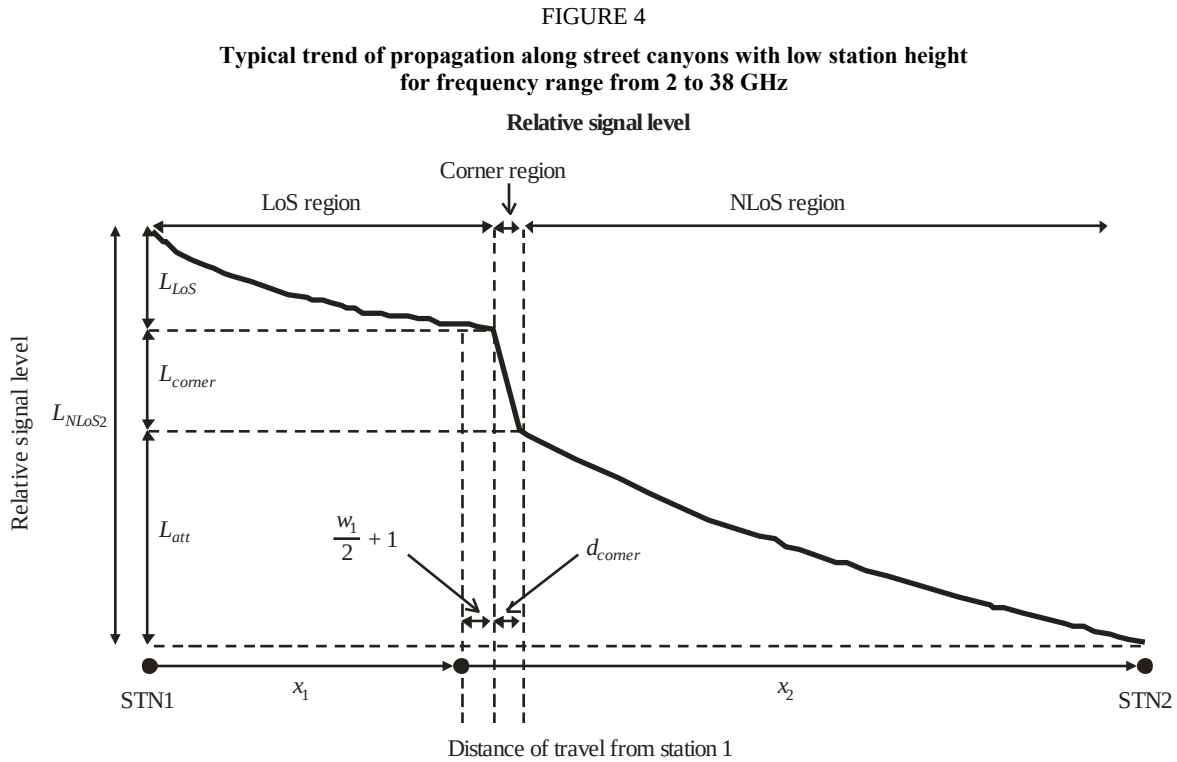
$$L_{att} = \begin{cases} 10\beta \log_{10} \left(\frac{x_1 + x_2}{x_1 + w_1/2 + d_{corner}} \right) & x_2 > w_1/2 + 1 + d_{corner} \\ 0 & x_2 \leq w_1/2 + 1 + d_{corner} \end{cases} \quad (21)$$

where L_{LoS} is the path loss in the LoS street for x_1 (> 20 m), as calculated in § 4.1.2. In equation (20), L_{corner} is given as 20 dB in an urban environment and 30 dB in a residential environment. And d_{corner} is 30 m in both environments.

In equation (21), $\beta = 6$ in urban and residential environments for wedge-shaped buildings at four corners of the intersection as illustrated in case (1) of Fig. 5. If a particular building is chamfered at the intersection in urban environments as illustrated in case (2) of Fig. 5, β is calculated by equation (22). Because the specular reflection paths from chamfered-shape buildings significantly affect path loss in NLoS region, the path loss for case (2) is different from that for case (1).

$$\beta = 4.2 + (1.4 \log_{10} f - 7.8)(0.8 \log_{10} x_1 - 1.0) \quad (22)$$

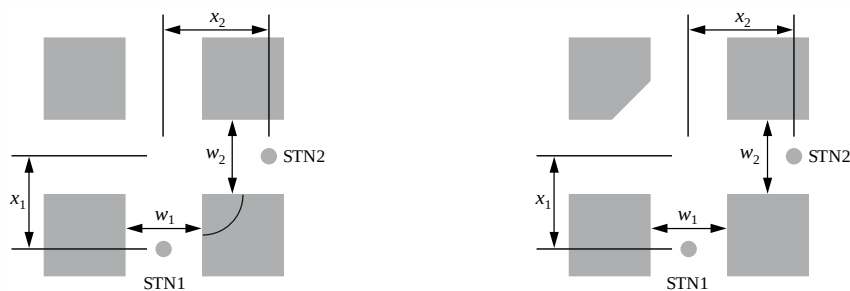
where f is frequency in MHz.



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FIGURE 5

Case (1) Wedge shaped buildings layout Case (2) Chamfered shape buildings layout



P.1411-05

In a residential environment, the path loss does not increase monotonically with distance, and thus the coefficient parameter may be lower than the value in an urban environment, owing to the presence of alleys and gaps between the houses.

With a high base station antenna in the small macro-cell, the effects of diffraction over roof-tops are more significant. Consequently, the propagation characteristics do not depend on the corner loss.

4.2 Models for propagation over roof-tops

4.2.1 Site-general model

This site-general model is applicable to situations where one of the stations is located above-rooftop and the other station is located below-rooftop, regardless of their antenna heights. The site-general model is the same as equation (1) described for the site-general model for propagation below-rooftop (within street canyons).

The recommended values for LoS (e.g. A-C in Fig. 1) and NLoS (e.g. A-B in Fig. 1) situations to be used for above-rooftop propagation in urban and suburban environments are provided in Table 8.

TABLE 8

Path loss coefficients for above-rooftop propagation

Frequency range (GHz)	Distance range (m)	Type of environment	LoS / NLoS	α	β	γ	σ
2.2-73	55-1200	Urban high-rise, Urban low-rise / Suburban	LoS	2.29	28.6	1.96	3.48
2.2-66.5	260-1200	Urban high-rise	NLoS	4.39	-6.27	2.30	6.89

4.2.2 Site-specific model

NLoS signals can arrive at the station by diffraction mechanisms or by multipath which may be a combination of diffraction and reflection mechanisms. This section develops models that relate to diffraction mechanisms.

Propagation for urban area

Models are defined for the paths A (h_1) to B (h_2) and D (h_1) to B (h_2) as depicted in Fig. 1. The models are valid for:

- h_1 : 4 to 50 m
- h_2 : 1 to 3 m
- f : 800 to 5 000 MHz
2 to 16 GHz for $h_1 < h_r$ and $w_2 < 10$ m (or sidewalk)
- d : 20 to 5 000 m.

(Note that although the model is valid up to 5 km, this Recommendation is intended for distances only up to 1 km.)

Propagation for suburban area

Model is defined for the path A (h_1) to B (h_2) as depicted in Fig. 1. The model is valid for:

- h_r : any height m
- Δh_1 : 1 to 100 m
- Δh_2 : 4 to 10 (less than h_r) m
- h_1 : $h_r + \Delta h_1$ m
- h_2 : $h_r - \Delta h_2$ m
- f : 0.8 to 38 GHz
- w : 10 to 25 m
- d : 10 to 5 000 m

(Note that although the model is valid up to 5 km, this Recommendation is intended for distances only up to 1 km.)

Millimetre-wave propagation

Millimetre-wave signal coverage is considered only for LoS and NLoS reflection situations because of the large diffraction losses experienced when obstacles cause the propagation path to become NLoS. For NLoS situations, multipath reflections and scattering will be the most likely signal propagation method. The frequency range (f) for the suburban area propagation model (§ 4.2.2.2) is applicable up to 38 GHz.

4.2.2.1 Urban area

The multi-screen diffraction model given below is valid if the roof-tops are all about the same height. Assuming the roof-top heights differ only by an amount less than the first Fresnel-zone radius over a path of length l (see Fig. 2), the roof-top height to use in the model is the average roof-top height. If the roof-top heights vary by much more than the first Fresnel-zone radius, a preferred method is to use the highest buildings along the path in a knife-edge diffraction calculation, as described in Recommendation ITU-R P.526, to replace the multi-screen model.

In the model for transmission loss in the NLoS1-case (see Fig. 2) for roof-tops of similar height, the loss between isotropic antennas is expressed as the sum of free-space loss, L_{bf} , the diffraction loss from roof-top to street L_{rts} and the reduction due to multiple screen diffraction past rows of buildings, L_{msd} .

In this model L_{bf} and L_{rts} are independent of the station antenna height, while L_{msd} is dependent on whether the station antenna is at, below or above building heights.