

## RECOMMENDATION ITU-R P.1816

**The prediction of the time and the spatial profile for broadband land mobile services using UHF and SHF bands**

(Question ITU-R 211/3)

(2007)

**Scope**

The purpose of this Recommendation is to provide guidance on the prediction of the time and the spatial profile for broadband land mobile services using the frequency range 0.7 GHz to 9 GHz for distances from 0.5 km to 3 km in both urban and suburban environments.

The ITU Radiocommunication Assembly,

*considering*

- a) that there is a need to give guidance to engineers in the planning of broadband mobile services in the UHF and SHF bands;
- b) that the time-spatial profile can be important for evaluating the influence of multipath propagation;
- c) that the time-spatial profile can best be modelled by considering the propagation conditions such as building height, antenna height, distance between base station and mobile station, and bandwidth of receiver,

*noting*

- a) that the methods of Recommendation ITU-R P.1546 are recommended for point-to-area prediction of field strength for the broadcasting, land mobile, maritime and certain fixed services in the frequency range 30 MHz to 3 000 MHz and for the distance range 1 km to 1 000 km;
- b) that the methods of Recommendation ITU-R P.1411 are recommended for the assessment of the propagation characteristics of short-range (up to 1 km) outdoor systems between 300 MHz and 100 GHz;
- c) that the methods of Recommendation ITU-R P.1411 are recommended for estimating the average shape of the delay profile for the line-of-sight (LoS) case in an urban high-rise environment for micro-cells and pico-cells;
- d) that the methods of Recommendation ITU-R P.1407 are recommended for specifying the terminology of multipath and for calculating the delay spread and the arrival angular spread by using the delay profile and the arrival angular profile, respectively;
- e) that the methods of Recommendation ITU-R M.1225 are recommended for evaluating the IMT-2000 system performance affected by multipath propagation,

*recommends*

- 1** that the content of Annex 1 should be used for estimating the long-term average delay profile for broadband mobile services in urban and suburban areas using the UHF and SHF bands;
- 2** that the content of Annex 2 should be used for estimating the long-term power angular profile for broadband mobile services in urban and suburban areas using the UHF and SHF bands.

## Annex 1

### 1 Introduction

The importance of the delay profile is indicated in Recommendation ITU-R P.1407 as follows.

Multipath propagation characteristics are a major factor in controlling the quality of digital mobile communications. Physically, multipath propagation characteristics imply multipath number, amplitude, path-length difference (delay), and arrival angle. These can be characterized by the transfer function of the propagation path (amplitude-frequency characteristics), and the correlation bandwidth.

As mentioned, the delay profile is a fundamental parameter for evaluating the multipath characteristics. Once the profile is modelled, multipath parameters such as delay spread and correlation bandwidth can be derived from the profile.

Propagation parameters related to the path environment affect the shape of the profile. A profile is formed by multiple waves that have different amplitudes and different delay times. It is known that long delayed waves have low amplitude because of the long path travelled. The averaged delay profile (long term delay profiles) can be approximated as an exponential function in short-range LoS paths. This approximation is used in Recommendation ITU-R P.1411 for estimating the multipath characteristics in a street micro cell. For non-LoS paths, the averaged delay profiles can be approximated as an exponential function (dB).

Both the number and the period of arriving waves in a delay profile depend on the receiving bandwidth because the time resolution is limited by the frequency bandwidth of the receiver. In order to estimate the delay profile, the limitation of frequency bandwidth should be considered. This limitation is closely related to the method used to divide the received power into multiple waves.

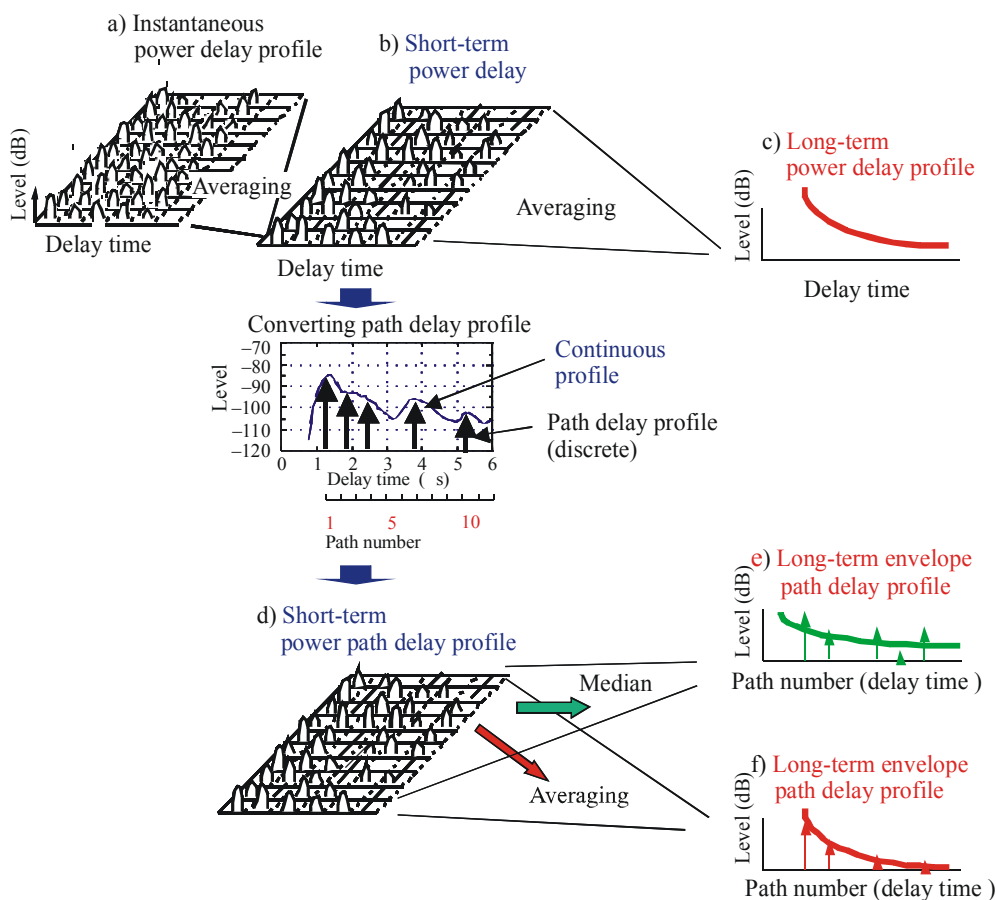
In order to take the frequency bandwidth or path resolution into consideration, the delay profile consisting of discrete paths is defined as the path delay profile.

Various delay profiles and their processing methods are defined in Fig. 1. As shown in Fig. 1, short-term power delay profiles are obtained by spatial averaging the instantaneous power delay profiles over several tens of wavelengths in order to suppress the variation of rapid fading; long-term power delay profiles are obtained by spatial averaging the short-term power delay profiles at the approximately same distance from the base station in order to also suppress the variation due to shadowing.

Furthermore, with regarding to the long-term path delay profile, two different profiles can be defined. One, the envelope path delay profile, is based on the median value of each delay path on the delay path profiles; it expresses the shape of the profile at the area being considered as shown in Fig. 1. The other is the power path delay profile based on the power average value of each delay path on the path delay profiles.

FIGURE 1

## Definition of various delay profiles



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## 2 Definition of delay profiles and parameters

### 2.1 Power delay profile – This is defined as the power delay profile with a continuous excess delay time

*Instantaneous power delay profile:* Power density of the impulse response at one moment at one point.

*Short-term power delay profile:* The delay profile obtained by spatial averaging the instantaneous power delay profile at each location within the range where multipath components do not vary.

*Long-term power delay profile:* The delay profile obtained by spatial averaging the short-term power delay profiles at approximately the same distance from the base station.

### 2.2 Path delay profile – This is defined as the delay profile with a discrete excess delay time normalized by time resolution $1/B$ . This includes the short-term and the long-term power path delay profiles, and the long-term envelope path delay profile

*Short-term power path delay profile:* The short-term power delay profile with a discrete excess delay time normalized by time resolution  $1/B$ .

*Long-term envelope path delay profile:* The delay profile is the median value of the short-term power path delay profiles at the approximately the same distance from the base station; it expresses the shape of the delay profile at the area considered.

*Long-term power path delay profile:* The delay profile obtained by averaging the short-term power path delay profiles at approximately the same distance from the base station; it expresses the general characteristics of the delay profile at the area considered.

### 2.3 Parameters

- $i$ : excess delay time normalized by time resolution  $1/B$  corresponding to bandwidth  $B$  and  $i = 0, 1, 2, \dots$  (here  $i = 0$  means the first arrival path without excess delay time and  $i = k$  means excess delay time of  $k/B$  ( $\mu\text{s}$ ))
- $\langle H \rangle$ : average building height: 5-50 m: height above the mobile station ground level (m)
- $h_b$ : base station antenna height: 20-150 m: height above the mobile station ground level (m)
- $d$ : distance from the base station: 0.5-3 km (km)
- $B$ : bandwidth or chip rate: 0.5-50 MHz (MHz)
- $f$ : carrier frequency: 0.7-9 GHz (GHz)
- $Loss(d)$ : general propagation loss formula such as Recommendation ITU-R P.1546 for example (dB)
- $\Delta L$ : the level difference between the peak path's power and cut-off power. The cut-off power is described in Recommendation ITU-R P.1407 as  $L_0$  (dB)
- $N_{path}(d, \Delta L)$ : the number of observable paths taking  $\Delta L$  into consideration.

## 3 Envelope path delay profile

### 3.1 Envelope path delay profile normalized by the first arrival path power in urban and suburban areas

The envelope path delay profile  $E(i, d)$  normalized by the first arrival path power at distance  $d$  is given as follows:

$$E(i, d) = \alpha(d) \log(1+i) \quad \text{dB} \quad (1)$$

where:

$$\alpha(d) = -\{19.1 + 9.68 \log(h_b / \langle H \rangle)\} B^{\{-0.36 + 0.12 \log(h_b / \langle H \rangle)\}} d^{\{-0.38 + 0.21 \log(B)\}} \quad (2)$$

### 3.2 Envelope path delay profile normalized by power of all delay paths in urban and suburban areas

The envelope path delay profile  $E_N(i, d)$  normalized by summing the power of all delay paths,  $A_E(d)$ , at distance  $d$  is given as follows:

$$E_N(i, d) = E(i, d) - A_E(d) \quad \text{dB} \quad (3)$$

where:

$$A_E(d) = 10 \log \left( \sum_{i=0}^{\infty} 10^{E(i,d)/10} \right) \approx 10 \log \left( \sum_{i=0}^{N_{path}-1} 10^{E(i,d)/10} \right) \quad \text{dB} \quad (4)$$

$A_E(d)$  can be approximated as the following simple function with  $N_{path}$  as a parameter.

$$A_E(d) \approx 10^{\{10.3 + 10.93 \log(\log N_{path}) + (3.57 + 5.17 \log(\log N_{path}))(\alpha(d)/10)\}/10} \quad (5)$$

On the other hand, the number of observable paths taking  $\Delta L$  into account is given as follows:

$$N_{path}(d, \Delta L) = 10^{-\Delta L / \alpha(d)} \quad (6)$$

#### 4 Power path delay profile

The conversion factor  $c(i)$  that yields the power from the shape of the path delay profile to the power path delay profile is given as follows:

$$c(i) = \begin{cases} 1 & (i=0) \\ \min(0.63, \{0.59e^{-0.0172B} + (0.0172 + 0.0004B) < H >\} e^{-\{0.077 - 0.00096B\} - (0.0014 - 0.000018B) < H >\} i}) & (i \geq 1) \end{cases} \quad (7)$$

where  $\min(x, y)$  selects the minimum value of  $x$  and  $y$ .

##### 4.1 Power path delay profile normalized by the first path's power

The power path delay profile normalized by the first path's power,  $P(i, d)$ , can be calculated by using the shape of the path delay profile and conversion factor  $c(i)$  as follows:

$$P(i, d) = E(i, d) + 10 \log(c(i)) \quad \text{dB} \quad (8)$$

##### 4.2 Power path delay profile normalized by summing the power of all delay paths

The power path delay profile  $P_N(i, d)$  normalized by summing the power of all delay paths,  $A_P(d)$  at distance  $d$  is given as follows:

$$P_N(i, d) = P(i, d) - A_P(d) \quad \text{dB} \quad (9)$$

where:

$$A_P(d) = 10 \log \left( \sum_{i=0}^{\infty} 10^{P(i,d)/10} \right) \approx 10 \log \left( \sum_{i=0}^{N_{path}-1} 10^{P(i,d)/10} \right) \quad \text{dB} \quad (10)$$

## 5 Path delay profile for loss representation in urban and suburban areas

### 5.1 Envelope path delay profile for loss representation in urban and suburban areas

The shape of the path delay profile  $L(i, d)$  for loss representation is given by using a general path loss method  $Loss(d)$  as follows:

$$L(i, d) = Loss(d) - E_N(i, d) \quad \text{dB} \quad (11)$$

## 5.2 Power path delay profile for loss presentation in urban and suburban areas

The power path delay profile  $L_p(i,d)$  for loss presentation is given by using a general path loss method  $Loss(d)$  as follows:

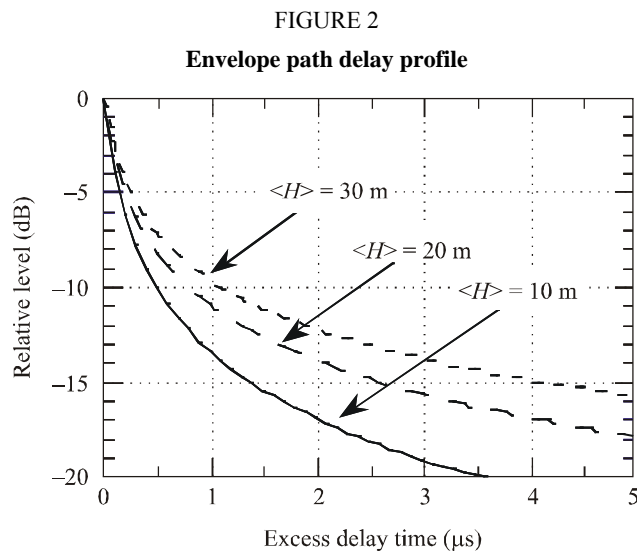
$$L_p(i,d) = Loss(d) - P_N(i,d) \quad \text{dB} \quad (12)$$

## 6 Examples

### 6.1 Envelope path delay profile in urban and suburban areas

#### 6.1.1 Envelope path delay profile normalized by the first arrival path's power

When base station antenna height  $h_b$ , distance from the base station  $d$  and bandwidth (chip rate)  $B$  are 50 m, 1.5 km and 10 Mchip, respectively, the envelope path delay profile  $E(i,d)$  follows that shown in Fig. 2, where the parameter is the average building height  $\langle H \rangle$ .



$B = 10 \text{ MHz}$   
 $h_b = 50 \text{ m}$   
 $d = 1.5 \text{ km}$

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#### 6.1.2 Envelope path delay profile normalized by power of all delay paths

When base station antenna height  $h_b$ , distance from the base station,  $d$ , and  $N_{path}$  are 50 m, 1.5 km and 20, respectively,  $A(d)$  given in equations (4) and (5) is as shown in Fig. 3, where the parameter is the bandwidth  $B$ .

When base station antenna height  $h_b$ , distance from the base station  $d$  and bandwidth (chip rate)  $B$  are 50 m, 1.5 km and 10 Mchip, respectively, the normalized envelope path delay profile  $E_N(i,d)$  in equation (3) is as shown in Fig. 4, where the parameter is average building height  $\langle H \rangle$ .

FIGURE 3  
 $A(\alpha)$  values

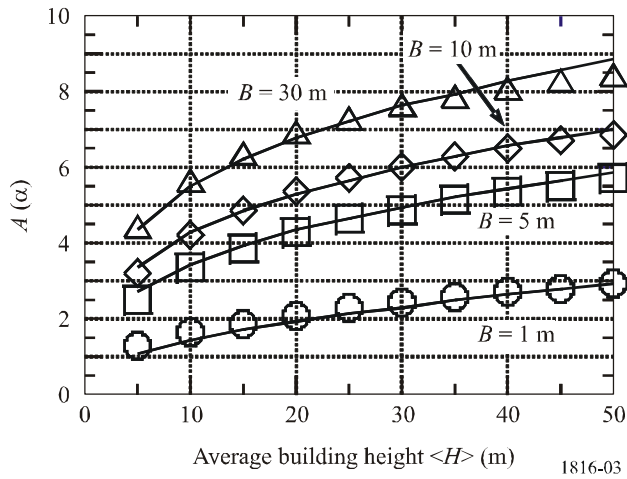
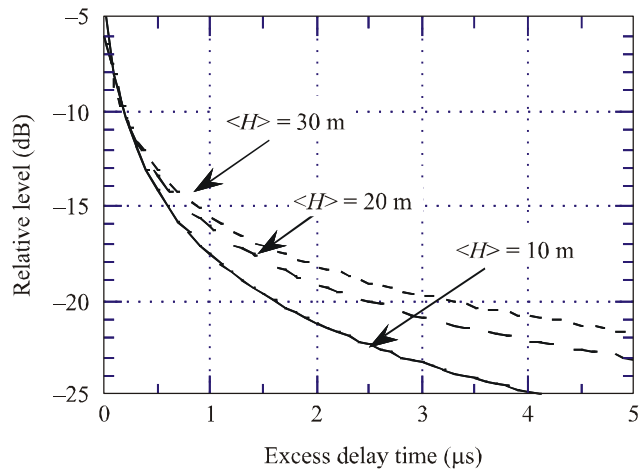


FIGURE 4

Normalized envelope path delay profile



$B = 10$  MHz  
 $h_b = 50$  m  
 $d = 1.5$  km  
 $N_{path} = 20$

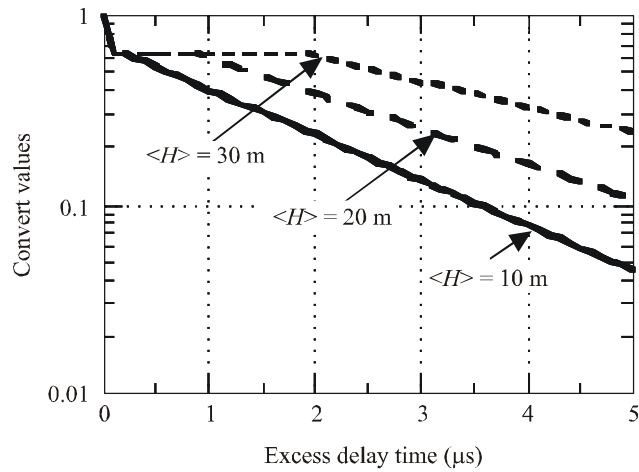
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## 6.2 Power path delay profile in urban and suburban areas

When base station antenna height  $h_b$ , distance from the base station  $d$  and bandwidth (chip rate)  $B$  are 50 m, 1.5 km and 10 Mchip, respectively, the conversion factor,  $c(k)$ , from the shape of the path delay profile to the power path delay profile follows that shown in Fig. 5, where the parameter is the average building height  $\langle H \rangle$ .

FIGURE 5

## Conversion factor


 $B = 10\text{ MHz}$ 
 $h_b = 50\text{ m}$ 
 $d = 1.5\text{ km}$ 

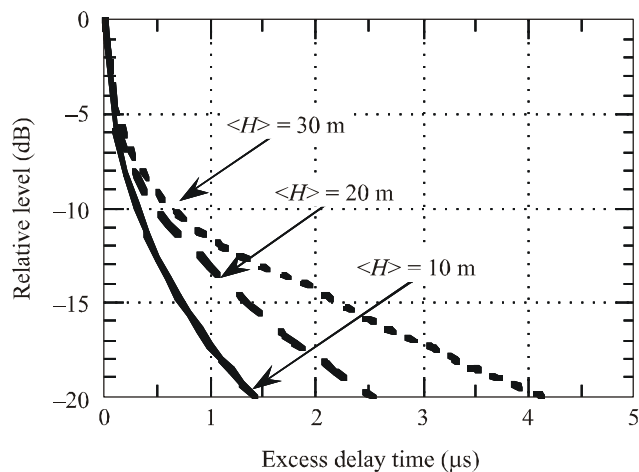
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### 6.2.1 Power path delay profile normalized by the first path's power

When base station antenna height  $h_b$ , distance from the base station  $d$  and bandwidth (chip rate)  $B$  are 50 m, 1.5 km and 10 Mchip, respectively, the power path delay profile normalized by the first path's power,  $P(i,d)$ , follows that shown in Fig. 6, where the parameter is the average building height  $\langle H \rangle$ .

FIGURE 6

## Power path delay profile

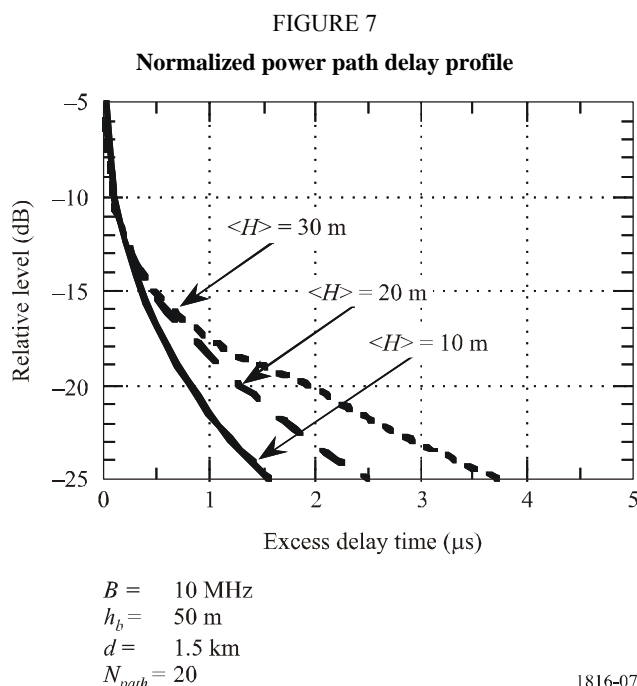

 $B = 10\text{ MHz}$ 
 $h_b = 50\text{ m}$ 
 $d = 1.5\text{ km}$ 

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### 6.2.2 Power path delay profile normalized by summing all delay path's power

When base station antenna height  $h_b$ , distance from the base station  $d$ , bandwidth (chip rate)  $B$  and  $N_{path}$  are 50 m, 1.5 km and 10 Mchip and 20, respectively, the power path delay profile normalized by summing the power of all delay paths,  $P_N(i,d)$ , follows that shown in Fig. 7, where the parameter is the average building height  $\langle H \rangle$ .



### 6.3 Path delay profile in loss presentation in urban and suburban areas

For the propagation loss prediction formula  $Loss(d)$ , we use the Okumura-Hata formula for a large city as follows:

$$Loss(d) = 69.55 + 26.16 \log f - 13.82 \log h_b + (44.9 - 6.55 \log h_b) \log d - a(h_m) \quad \text{dB} \quad (13)$$

where:

$$a(h_m) = 3.2 \{ \log(11.75 h_m) \}^2 - 4.97$$

$d$ : distance from the base station (km)

$h_m$ : mobile station antenna height (m)

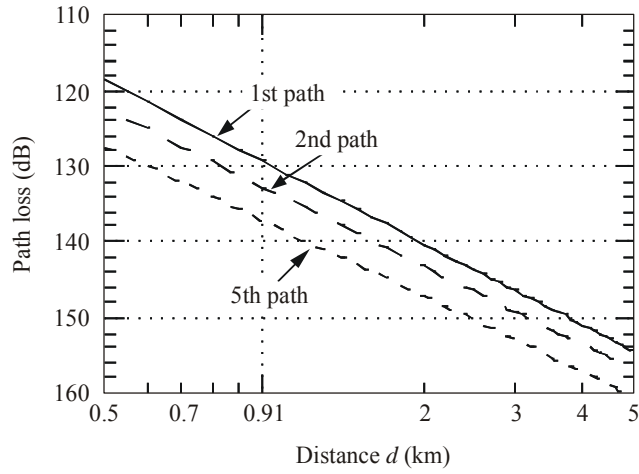
$f$ : carrier frequency (MHz).

#### 6.3.1 Envelope path delay profile in loss presentation

When base station antenna height  $h_b$ , average building height  $\langle H \rangle$ , and bandwidth  $B$ , carrier frequency  $f$ , mobile station antenna height  $h_m$  and  $N_{path}$  are 50 m, 20 m, 10 Mchips, 1 000 MHz, 1.5 m and 20, respectively, the path loss of envelope path delay profile  $L(i,d)$  in equation (11) is as shown in Fig. 8 for the cases of  $i = 0, 1$  and  $4$  which correspond to the 1st path, 2nd path and 5th path, respectively.

FIGURE 8

Propagation loss of each path following the envelope path delay profile using Okumura-Hata formula



$f = 1\ 000\ \text{MHz}$   
 $B = 10\ \text{MHz}$   
 $h_b = 50\ \text{m}$   
 $\langle H \rangle = 20\ \text{m}$   
 $h_m = 1.5\ \text{m}$   
 $N_{path} = 20$

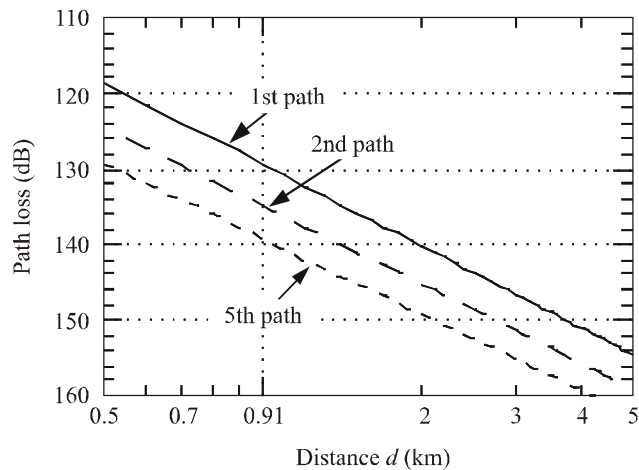
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### 6.3.2 Power path delay profile in loss presentation

When base station antenna height  $h_b$ , average building height  $\langle H \rangle$ , bandwidth  $B$ , carrier frequency  $f$ , mobile station antenna height  $h_m$  and  $N_{path}$  are 50 m, 20 m, 10 Mchips, 1 000 MHz, 1.5 and 20 m respectively, the path loss of power path delay profile  $L_p(i,d)$  in equation (12) is as shown in Fig. 9 for the cases of  $i = 0, 1$  and 4 which correspond to the 1st path, 2nd path and 5th path, respectively.

FIGURE 9

Propagation loss of each path following the power path delay profile using Okumura-Hata formula



$f = 1\ 000\ \text{MHz}$   
 $B = 10\ \text{MHz}$   
 $h_b = 50\ \text{m}$   
 $\langle H \rangle = 20\ \text{m}$   
 $h_m = 1.5\ \text{m}$   
 $N_{path} = 20$

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## Annex 2

### 1 Introduction

The importance of the arrival angular profile is indicated in Recommendation ITU-R P.1407 as follows.

Multipath propagation characteristics are a major factor in controlling the quality of digital mobile communications. Physically, multipath propagation characteristics imply multipath number, amplitude, path-length difference (delay), and arrival angle. These can be characterized by the transfer function of the propagation path (amplitude-frequency characteristics), and the correlation bandwidth.

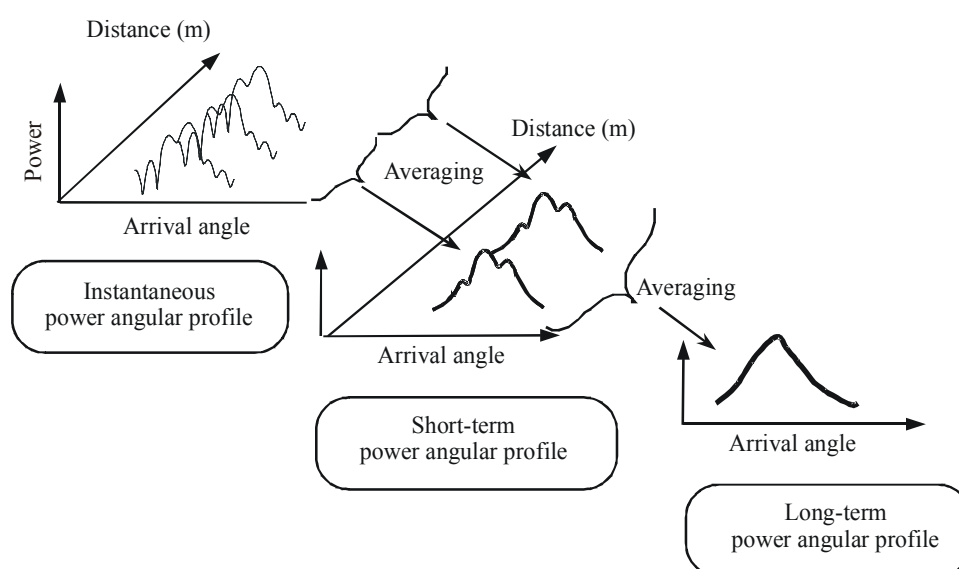
As mentioned, the arrival angular profile is a fundamental parameter for evaluating the multipath characteristics. Once the profile is modelled, multipath parameters such as arrival angular spread and spatial correlation distance can be derived from the profile.

Propagation parameters related to the path environment affect the shape of the profile. A profile is formed by multiple waves that have different amplitudes and different arrival angle. It is known that waves with large arrival angles have low amplitude because of the long path travelled. The arrival angular profile is approximated as Gaussian or Laplacian (both side exponential) functions in previous works.

In Recommendation ITU-R P.1407, various power arrival angular profiles are defined as Fig. 10. The power arrival angular profile is shortened to the power angular profile after this. As shown in Fig. 10, short-term power angular profiles are obtained by spatial averaging the instantaneous power angular profiles over several tens of wavelengths in order to suppress the variation of rapid fading; long-term power angular profiles are obtained by spatial averaging the short-term power angular profiles at approximately the same distance from the base station in order to suppress the variation due to shadowing.

FIGURE 10

Definition of various power angular profiles



## 2 Definition of power angular profiles and parameters

### 2.1 Power angular profile – This is defined as the power angular profile with a continuous arrival angle

*Instantaneous power angular profile:* Power density of the impulse response at one moment at one point.

*Short-term power angular profile:* The angular profile obtained by spatial averaging the instantaneous power angular profile at each location within the range where multipath components do not vary.

*Long-term power angular profile:* The angular profile obtained by spatial averaging the short-term power angular profiles at approximately the same distance from the base station.

### 2.2 Parameters

$h_b$ : base station antenna height (20-150 m: height above the mobile station ground level), (m)

$\langle H \rangle$ : average building height (5-50 m: height above the mobile station ground level), (m)

$d$ : distance from the base station (0.5-3 km), (km)

$f$ : carrier frequency (0.7-9 GHz), (GHz)

$\Delta L$ : the level difference between the peak power and cut-off power (dB).

## 3 Long-term power angular profile

### 3.1 Long-term power angular profile

The long-term power angular profile  $p_a(\theta)$  normalized by  $0^\circ$  arrival path is approximately given by a power function as follows:

$$p_a(\theta) = (|\theta| + a)^{-\beta} / a^{-\beta} = (|\theta| / a + 1)^{-\beta} \quad (14)$$

where  $a$ ,  $\beta$  are constants and are represented as functions of the distance,  $d$ , base station antenna height,  $h_b$ , and the average building height,  $\langle H \rangle$  as follows:

$$a = -0.2d + 2.1 \left\{ \left( \frac{\langle H \rangle}{h_b} \right)^{0.23} \right\} \quad (15)$$

$$\beta = (-0.015 \langle H \rangle + 0.63)d - 0.16 + 0.76 \log(h_b)$$

The maximum arrival angle  $a_M$  (degrees) is represented as follows:

$$a_M = -\gamma \cdot d + \eta \quad (16)$$

$\gamma$  and  $\eta$  are constants and represented as functions of base station antenna height,  $h_b$ , the average building height,  $\langle H \rangle$ , and the threshold level  $\Delta L$  (dB) as follows:

$$\gamma = \begin{cases} (-7.67 + 0.98\Delta L) \cdot \exp\left(\frac{\langle H \rangle}{h_b} \cdot (2.66 - 0.18\Delta L)\right) & (\Delta L \leq 15) \\ 7 & (\Delta L > 15) \end{cases} \quad (17)$$

$$\eta = (-35.8 + 41.1 \log(\Delta L)) \cdot \exp\left(\frac{\langle H \rangle}{h_b} \cdot (1.76 - 0.034\Delta L)\right)$$

### 3.2 The spatial correlation function

The spatial correlation function  $R_f(\Delta l)$  and the spatial correlation coefficient  $R(\Delta l)$  with antenna distance of  $\Delta l$ , are given respectively as follows:

$$R_f(\Delta l) = \int_{-\frac{a_M}{180}}^{+\frac{a_M}{180}} \frac{\pi}{180} p_a\left(\theta_r \cdot \frac{180}{\pi}\right) \exp\left(j \frac{2\pi\Delta l \sin \theta_r}{\lambda}\right) \cdot \frac{180}{\pi} d\theta_r \tag{18}$$

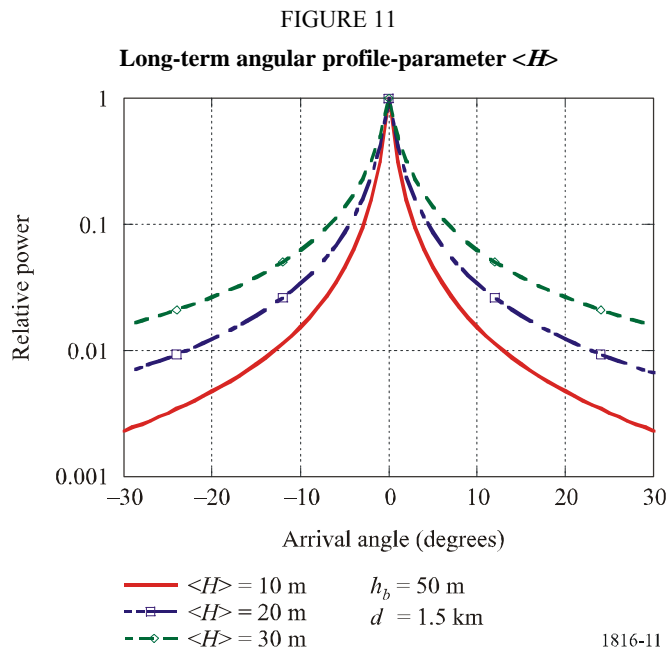
$$R(\Delta l) = R_f(\Delta l) / R_f(0)$$

where  $\lambda$  is the wavelength and  $\theta_r$  is the angle(rad).

From the empirical studies, equations (14) and (16) are applied for carrier frequencies between 0.7 GHz and 9 GHz.

### 4 Example

When base station antenna height,  $h_b$ , and distance from the base station,  $d$ , are 50 m and 1.5 km respectively, the long-term power angular profile  $p_a(\theta)$  is as shown in Fig. 11, where the parameter is the average building height  $\langle H \rangle$ .



Also, when we apply equation (16) with  $\Delta L$  is 15 dB, the long-term power angular profile becomes like Fig. 12 and the spatial correlation coefficient calculated based on Fig. 12 is shown as Fig. 13.

FIGURE 12

Long-term angular profile with  $\Delta L$  is 15 dB – parameter  $\langle H \rangle$

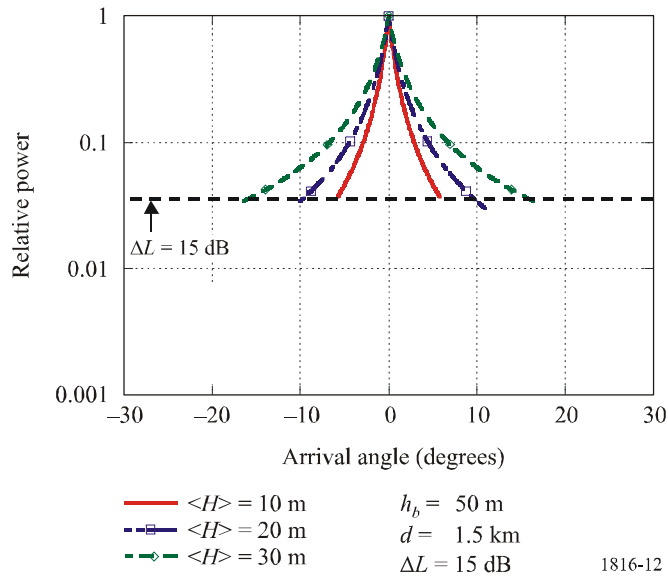


FIGURE 13

The spatial correlation function – parameter  $\langle H \rangle$

