RECOMMENDATION ITU-R P.1407-1

Multipath propagation and parameterization of its characteristics

(Question ITU-R 203/3)

(1999-2003)

The ITU Radiocommunication Assembly,

considering

a) the necessity of estimating the effects of multipath on services employing digital systems;

b) that it is desirable to standardize the terminology and expressions used to characterize multipath,

recommends

1 that, to describe the concepts of multipath in a consistent manner, the terms and definitions given in Annex 1 should be employed.

Annex 1

1 Introduction

In radio systems with low antenna heights, there are often multiple indirect paths between the transmitter and receiver due to reflections from surrounding objects, in addition to the direct path when there is line-of-sight. Such multipath propagation is particularly significant in urban environments, where the sides of buildings and paved road surfaces provide strong reflections. As a result, the received signal consists of the summation of several components having various amplitudes, phase angles and directions of arrival.

The resulting spatial variability of signal strength can be viewed as having two regimes:

a) rapid fading which varies over distances of the order of a wavelength due primarily to changes in phase angles of different signal components;

b) slow fading which varies over larger distances due primarily to changes in shadowing loss by surrounding objects.

In addition, the various signal components can be Doppler shifted by different amounts due to the movement of the mobile or of reflecting objects such as vehicles.

The multipath mobile channel can be characterized in terms of its impulse response which varies at a rate dependent on the speed of the mobile and/or the scatterers. Therefore, a receiver has to be able to cope with the signal distortion arising from echoes in the channel as well as the rapid changes in the nature of this distortion. Such characteristics of the mobile radio channel are described by the power delay profiles and the Doppler spectra which are obtained from wideband channel sounding measurements.

Signals transmitted to and from moving vehicles in urban or forested environments exhibit extreme variations in amplitude due to multiple scattering. Fades of 30 dB or more below the mean level are common. The instantaneous field strength when measured over distances of a few tens of wavelengths is approximately Rayleigh-distributed. The mean values of these small sector distributions vary widely from area to area, depending on the height, density and distribution of hills, trees, buildings and other structures.

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.

Definitions of small sector (or small-scale) channel parameters are given in § 2 and 3. Statistics of small-scale parameters are subsequently used to produce cumulative distribution functions (CDF). Medium-scale CDF covers a particular route of measurement, which is of the order of tens to hundreds of metres. The combined data set from a number of medium-scale routes is considered to be large-scale or global characterization which is representative of the surveyed environment e.g. hilly terrain, urban, suburban, indoor large rooms, corridors, etc.

A time-varying linear channel can be characterized by a linear transversal filter. The output of this filter contains a sum of delayed, attenuated and Doppler shifted versions of the input signal. The channel is then represented by the delay-Doppler-spread function, sometimes referred to as the scattering function. This function represents the multipath phenomenon in the three dimensions of excess delay, Doppler frequency and power density. This formulation is particularly suitable for realizing a hardware simulator in the form of a dynamic transversal filter.

2 Multipath parameters

The appropriate parameters for the statistical description of multipath effects are given below and can be computed either from instantaneous power delay profiles or from profiles averaged over a few wavelengths.

The *average delay* is the power weighted-average of the excess delays measured and is given by the first moment of the impulse response.

The *r.m.s. delay spread* is the power weighted standard deviation of the excess delays and is given by the second moment of the impulse response. It provides a measure of the variability of the mean delay.

The *delay window* is the length of the middle portion of the power profile containing a certain percentage of the total energy found in that impulse response.

The *delay interval* is defined as the length of the impulse response between two values of excess delay which mark the first time the amplitude of the impulse response exceeds a given threshold, and the last time it falls below it.

The *correlation bandwidth* is defined as the frequency for which the autocorrelation function of the transfer function falls below a given threshold.

With reference to Fig. 1, the total power, P_m, of the power delay profile is:

$$P_m = \int_{t_0}^{t_3} P(t)\,\mathrm{d}\,t \tag{1}$$

where:

$P(t)$: power density of the impulse response

t: delay with respect to a time reference

t_0: instant when $P(t)$ exceeds the cut-off level for the first time

t_3: instant when $P(t)$ exceeds the cut-off level for the last time.

The average delay, T_D, is given by the first moment of the impulse response:

$$T_D = \frac{\int_0^{\tau_e} \tau P(\tau)\;\mathrm{d}\,\tau}{\int_0^{\tau_e} P(\tau)\;\mathrm{d}\,\tau} - \tau_a \tag{2a}$$

where:

τ: excess time delay variable and is equal to $t - t_0$

τ_a: arrival time of the first received multipath component (first peak in the profile)

$\tau_e = t_3 - t_0$.

In discrete form equation (2a) becomes:

$$T_D = \frac{\sum_{i=1}^{N} \tau_i P(\tau_i)}{\sum_{i=1}^{N} P(\tau_i)} - \tau_M \tag{2b}$$

where $i = 1$ and N are the indices of the first and the last samples of the delay profile above the threshold level, respectively, and M is the index of the first received multipath component (first peak in the profile).

The delays may be determined from the following relationship:

$$t_i(\mu\mathrm{s}) = 3.3 r_i \qquad \mathrm{km}$$

where r_i is the sum of the distances from the transmitter to the multipath reflector, and from the reflector to the receiver, or is the total distance from the transmitter to receiver for t_{LOS}.

The r.m.s. delay spread, S, is defined by the square root of the second central moment:

$$S = \sqrt{\frac{\int_0^{\tau_e} (\tau - T_D - \tau_a)^2 P(\tau)\,\mathrm{d}\tau}{\int_0^{\tau_e} P(\tau)\,\mathrm{d}\tau}} \tag{3}$$

or, in discrete form:

$$S = \sqrt{\frac{\sum_{i=1}^{N} (\tau_i - T_D - \tau_M)^2 P(\tau_i)}{\sum_{i=1}^{N} P(\tau_i)}} \tag{4}$$

The delay window, W_q, is the length of the middle portion of the impulse response containing a certain percentage, q, of the total power:

$$W_q = (t_2 - t_1) \tag{5}$$

whereby the boundaries t_1 and t_2 are defined by:

$$\int_{t_1}^{t_2} P(t)\,\mathrm{d}t = \frac{q}{100} \int_{t_0}^{t_3} P(t)\,\mathrm{d}t = \frac{q}{100} P_m \tag{6}$$

and the energy outside of the window is split into two equal parts $\left(\frac{100 - q}{200}\right) P_m$.

The delay interval, I_{th}, is defined as the time difference between the instant t_4 when the amplitude of the impulse response first exceeds a given threshold P_{th}, and the instant t_5 when it falls below that threshold for the last time:

$$I_{th} = (t_5 - t_4) \tag{7}$$

The Fourier transform of the power density of the impulse response provides the autocorrelation $C(f)$ of the transfer function:

$$C(f) = \int_0^{\tau_e} P(\tau)\ \exp(-j\,2\,\pi f \tau)\,\mathrm{d}\tau \tag{8}$$

For a Rician channel, equation (8) underestimates the correlation bandwidth. For such channels it is more accurate to estimate the correlation bandwidth from the spaced frequency correlation function, which is obtained from the time variant complex transfer function by computing the correlation coefficient for different frequency spacings.

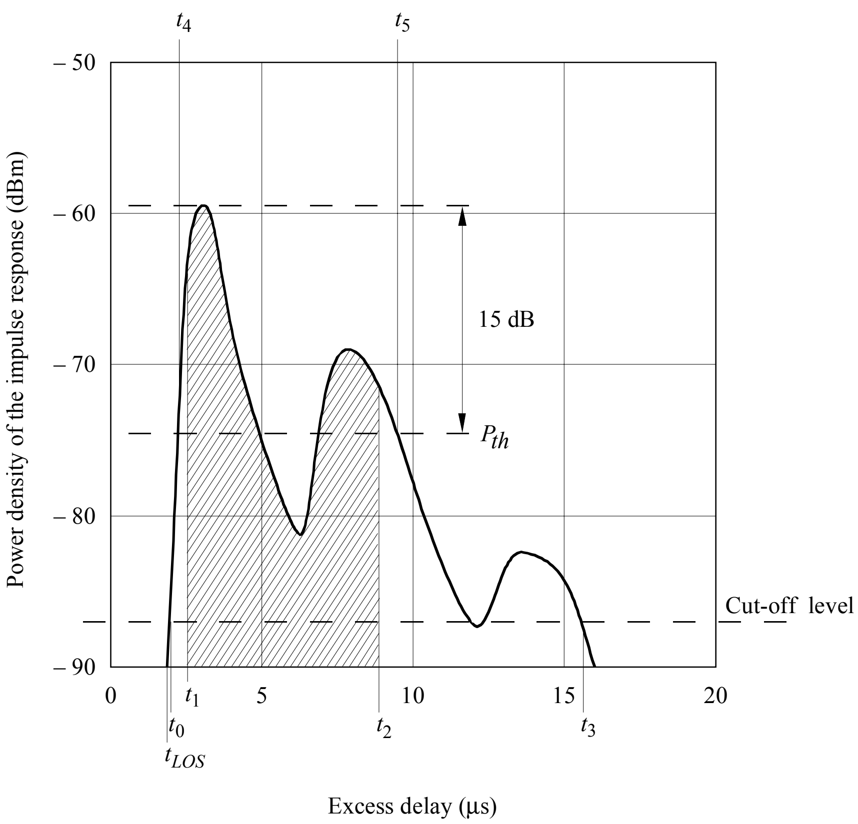
The correlation bandwidth B_x is defined as the frequency for which $|C(f)|$ equals x% of $C(f = 0)$.

Delay windows for 50%, 75% and 90% power, delay intervals for thresholds of 9, 12 and 15 dB below the peak and correlation bandwidth for 50% and 90% of correlation are recommended for analysis of data. It is worth noting that the effects of noise and spurious signals in the system (from RF to data processing) can be very significant. Therefore, it is important to determine the noise and/or spurious threshold of the systems accurately and to allow a safety margin on top of that. A safety margin of 3 dB is recommended, and in order to ensure the integrity of results, it is recommended that a minimum peak-to-spurious ratio of, for example, 15 dB (excluding the 3 dB safety margin) is used as an acceptance criterion before an impulse response is included in the statistics.

An example of the use of some of these terms is given in Fig. 1.

FIGURE 1

Example of an averaged delay power profile



The delay window, W_{90}, containing 90% of the received energy, is marked by hatching. The delay interval, I_{15}, containing the signal above the level "15 dB below the peak value", lies within t_4 and t_5

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3 Parameters of direction of arrival

Let the received power in the direction θ be $P(\theta)$ W, where θ in radians is measured from the direction of the principal signal (assumed to be stationary within the duration of the measurement). Then, the r.m.s. angular spread σ_θ of the direction of arrival is defined as follows:

$$\sigma_\theta = \sqrt{\frac{1}{P_0}\int_{-\pi}^{\pi}(\theta-\bar{\theta})^2 P(\theta)\,d\theta} \tag{9}$$

where:

$$P_0 = \int_{-\pi}^{\pi} P(\theta)\,d\theta \tag{10}$$

and

$$\bar{\theta} = \frac{1}{P_0}\int_{-\pi}^{\pi}\theta\,P(\theta)\,d\theta \tag{11}$$

where all integrals are evaluated for values above the noise floor of the measurement.