FACULDADE INTEGRADA
DA GRANDE FORTALEZA

FGF

DESENVOLVIMENTO PARA DISPOSITIVOS MOVEIS

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Aula 05

Objetivo

- Apresentar os principais modelos de propagação.

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MODELOS DE PROPAGAÇÃO

The free space propagation model is used to predict received signal strength when the transmitter and receiver have a clear, unobstructed line-of-sight path between them. Satellite communication systems and microwave line-of-sight radio links typically undergo free space propagation. As with most large-scale radio wave propagation models, the free space model predicts that received power decays as a function of the T-R separation distance raised to some power (i.e. a power law function). The free space power received by a receiver antenna which is separated from a radiating transmitter antenna by a distance d, is given by the Friis free space equation,

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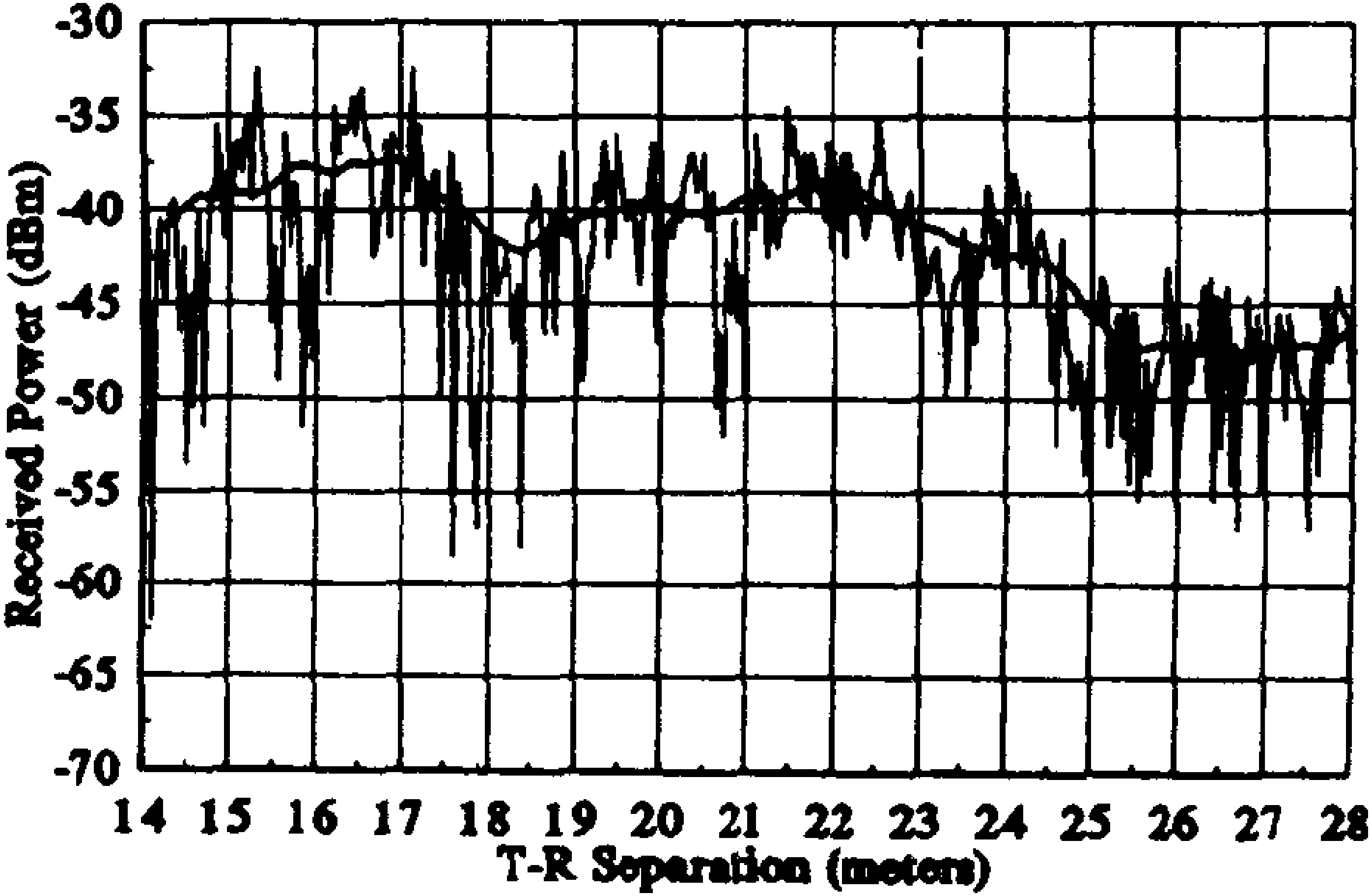

MODELOS DE PROPAGAÇÃO

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \tag{3.1}$$

where P_t is the transmitted power, $P_r(d)$ is the received power which is a function of the T-R separation, G_t is the transmitter antenna gain, G_r is the receiver antenna gain, d is the T-R separation distance in meters, L is the system loss factor not related to propagation ($L \geq 1$), and λ is the wavelength in meters. The gain of an antenna is related to its effective aperture, A_e, by

$$G = \frac{4\pi A_e}{\lambda^2} \tag{3.2}$$

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The effective aperture A_e is related to the physical size of the antenna, and λ is related to the carrier frequency by

$$\lambda = \frac{c}{f} = \frac{2\pi c}{\omega_c} \tag{3.3}$$

where f is the carrier frequency in Hertz, ω_c is the carrier frequency in radians per second, and c is the speed of light given in meters/s. The values for P_t and P_r must be expressed in the same units, and G_t and G_r are dimensionless quantities. The miscellaneous losses L ($L \geq 1$) are usually due to transmission line attenuation, filter losses, and antenna losses in the communication system. A value of $L = 1$ indicates no loss in the system hardware.

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The Friis free space equation of (3.1) shows that the received power falls off as the square of the T-R separation distance. This implies that the received power decays with distance at a rate of 20 dB/decade.

An *isotropic* radiator is an ideal antenna which radiates power with unit gain uniformly in all directions, and is often used to reference antenna gains in wireless systems. The *effective isotropic radiated power (EIRP)* is defined as

$$EIRP = P_t G_t \tag{3.4}$$

and represents the maximum radiated power available from a transmitter in the direction of maximum antenna gain, as compared to an isotropic radiator.

In practice, *effective radiated power (ERP)* is used instead of EIRP to denote the maximum radiated power as compared to a half-wave dipole antenna (instead of an isotropic antenna). Since a dipole antenna has a gain of 1.64 (2.15 dB above an isotrope), the ERP will be 2.15 dB smaller than the EIRP for the same transmission system. In practice, antenna gains are given in units of dBi (dB gain with respect to an isotropic source) or dBd (dB gain with respect to a half-wave dipole) [Stu81].

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The *path loss*, which represents signal attenuation as a positive quantity measured in dB, is defined as the difference (in dB) between the effective transmitted power and the received power, and may or may not include the effect of the antenna gains. The path loss for the free space model when antenna gains are included is given by

$$PL\,(\mathrm{dB}) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right] \tag{3.5}$$

When antenna gains are excluded, the antennas are assumed to have unity gain, and path loss is given by

$$PL\,(\mathrm{dB}) = 10\log\frac{P_t}{P_r} = -10\log\left[\frac{\lambda^2}{(4\pi)^2 d^2}\right] \tag{3.6}$$

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The Friis free space model is only a valid predictor for P_r for values of d which are in the far-field of the transmitting antenna. The far-field, or *Fraunhofer region*, of a transmitting antenna is defined as the region beyond the far-field distance d_f, which is related to the largest linear dimension of the transmitter antenna aperture and the carrier wavelength. The Fraunhofer distance is given by

$$d_f = \frac{2D^2}{\lambda} \tag{3.7.a}$$

where D is the largest physical linear dimension of the antenna. Additionally, to be in the far-field region, d_f must satisfy

$$d_f \gg D \tag{3.7.b}$$

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$$d_f \gg \lambda \tag{3.7.c}$$

Furthermore, it is clear that equation (3.1) does not hold for $d = 0$. For this reason, large-scale propagation models use a close-in distance, d_0, as a known received power reference point. The received power, $P_r(d)$, at any distance $d > d_0$, may be related to P_r at d_0. The value $P_r(d_0)$ may be predicted from equation (3.1), or may be measured in the radio environment by taking the average received power at many points located at a close-in radial distance d_0 from the transmitter. The reference distance must be chosen such that it lies in the far-field region, that is, $d_0 \geq d_f$, and d_0 is chosen to be smaller than any practical distance used in the mobile communication system. Thus, using equation (3.1), the received power in free space at a distance greater than d_0 is given by

$$P_r(d) = P_r(d_0)\left(\frac{d_0}{d}\right)^2 \qquad d \geq d_0 \geq d_f \tag{3.8}$$

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In mobile radio systems, it is not uncommon to find that P_r may change by many orders of magnitude over a typical coverage area of several square kilometers. Because of the large dynamic range of received power levels, often dBm or dBW units are used to express received power levels. Equation (3.8) may be expressed in units of dBm or dBW by simply taking the logarithm of both sides and multiplying by 10. For example, if P_r is in units of dBm, the received power is given by

$$P_r(d)\ \text{dBm} = 10\log\left[\frac{P_r(d_0)}{0.001\ \text{W}}\right] + 20\log\left(\frac{d_0}{d}\right) \qquad d \geq d_0 \geq d_f \qquad (3.9)$$

where $P_r(d_0)$ is in units of watts.

The reference distance d_0 for practical systems using low-gain antennas in the 1-2 GHz region is typically chosen to be 1 m in indoor environments and 100 m or 1 km in outdoor environments, so that the numerator in equations (3.8) and (3.9) is a multiple of 10. This makes path loss computations easy in dB units.

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Example 3.1

Find the far-field distance for an antenna with maximum dimension of 1 m and operating frequency of 900 MHz.

Solution to Example 3.1

Given:

Largest dimension of antenna, $D = 1$ m

Operating frequency $f = 900$ MHz, $\lambda = c/f = \dfrac{3 \times 10^8 \text{ m/s}}{900 \times 10^6 \text{ Hz}}$ m

Using equation (3.7.a), far-field distance is obtained as

$$d_f = \frac{2(1)^2}{0.33} = 6 \text{ m}$$

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If a transmitter produces 50 watts of power, express the transmit power in units of (a) dBm, and (b) dBW. If 50 watts is applied to a unity gain antenna with a 900 MHz carrier frequency, find the received power in dBm at a free space distance of 100 m from the antenna. What is P_r (10 km) ? Assume unity gain for the receiver antenna.

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Given:
Transmitter power, $P_t = 50$ W.
Carrier frequency, $f_c = 900$ MHz

Using equation (3.9),
(a) Transmitter power,

$$P_t(\text{dBm}) = 10\log[P_t(\text{mW})/(1\text{ mW})]$$
$$= 10\log[50\times10^3] = 47.0\text{ dBm.}$$

(b) Transmitter power,

$$P_t(\text{dBW}) = 10\log[P_t(\text{W})/(1\text{ W})]$$
$$= 10\log[50] = 17.0\text{ dBW.}$$

The received power can be determined using equation (3.1).

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} = \frac{50(1)(1)(1/3)^2}{(4\pi)^2(100)^2(1)} = 3.5\times10^{-6}\text{ W} = 3.5\times10^{-3}\text{ mW}$$

$$P_r(\text{dBm}) = 10\log P_r(\text{mW}) = 10\log\left(3.5\times10^{-3}\text{ mW}\right) = -24.5\text{ dBm.}$$

The received power at 10 km can be expressed in terms of dBm using equation (3.9), where $d_0 = 100$ m and $d = 10$ km

$$P_r(10\text{ km}) = P_r(100) + 20\log\left[\frac{100}{10000}\right] = -24.5\text{ dBm} - 40\text{ dB}$$

$$= -64.5\text{ dBm.}$$

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cell type	typical cell radius	typical position of base station antenna
macro-cell (large cell)	1km to 30 km	outdoor; mounted above medium roof-top level, heights of all surrounding buildings are below base station antenna height
small macro-cell	0.5 km to 3 km	outdoor; mounted above medium roof-top level, heights of some surrounding buildings are above base station antenna height
micro-cell	up to 1 km	outdoor; mounted below medium roof top level
pico-cell / in-house	up to 500 m	indoor or outdoor (mounted below roof-top level)

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COST 231 - Hata-Model

Path loss estimation is performed by empirical models if land cover is known only roughly, and the parameters required for semi-deterministic models cannot be determined. Four parameters are used for estimation of the propagation loss by Hata's well-known model: frequency f, distance d, base station antenna height h_{Base} and the height of the mobile antenna h_{Mobile}. In Hata´s model, which is based on Okumura´s various correction functions [50], the basic transmission loss, L_b, in urban areas is:

$$L_b = 69.55 + 26.16 \cdot \log \frac{f}{MHz} - 13.82 \cdot \log \frac{h_{Base}}{m} - a(h_{Mobile}) + \left(44.9 - 6.55 \cdot \log \frac{h_{Base}}{m}\right) \cdot \log \frac{d}{km} \quad ^{1)} \qquad (4.4.1)$$

where:

1) "log" means "$\log_{10}$"

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$$a(h_{Mobile}) = (1.1 \cdot \log \frac{f}{MHz} - 0.7)\frac{h_{Mobile}}{m} - (1.56 \cdot \log \frac{f}{MHz} - 0.8) \qquad (4.4.2)$$

The model is restricted to:

f :	150 ... 1000 MHz
h_{Base} :	30 ...200 m
h_{Mobile}:	1 ...10 m
d :	1 ...20 km

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COST 231 has extended Hata´s model to the frequency band $1500 \leq f(\mathrm{MHz}) \leq 2000$ by analysing Okumura´s propagation curves in the upper frequency band. This combination is called "COST-Hata-Model" [51]:

$$L_b = 46.3 + 33.9\log\frac{f}{\mathrm{MHz}} - 13.82\log\frac{h_{Base}}{m} - a(h_{Mobile})$$

$$+(44.9 - 6.55\log\frac{h_{Base}}{m})\log\frac{d}{km} + C_m \qquad (4.4.3)$$

where $a(h_{Mobile})$ is defined in equation (4.4.2) and

$$C_m = \begin{cases} 0\ \mathrm{dB} & \text{for medium sized city and suburban} \\ & \text{centres with medium tree density} \\ 3\ \mathrm{dB} & \text{for metropolitan centres} \end{cases} \qquad (4.4.4)$$

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The COST-Hata-Model is restricted to the following range of parameters:

f:	1500 ... 2000 MHz
h_{Base}:	30 ... 200 m
h_{Mobile}:	1 ... 10 m
d:	1 ... 20 km

The application of the COST-Hata-Model is restricted to large and small macro-cells, i. e. base station antenna heights above roof-top levels adjacent to the base station. Hata´s formula and its modification must not be used for micro-cells.

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Indoor Propagation Models

4.7.2 Empirical narrow-band models

Three types of empirical indoor models have been investigated.

The ***one-slope model*** *(1SM)* assumes a linear dependence between the path loss (dB) and the logarithmic distance

$$L = L_0 + 10n \cdot \log(d) \quad (4.7.1)$$

where

L_0 = the path loss at 1 meter distance,

n = power decay index,

d = distance between transmitter and receiver in metres.

This model is easy to use, because only the distance between transmitter and receiver appears as an input parameter. However, the dependency of these parameters on environment category (Tab. 2.3.1) has to be taken into account.

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Indoor Propagation Models

The multi-wall model [135]-[139] gives the path loss as the free space loss added with losses introduced by the walls and floors penetrated by the direct path between the transmitter and the receiver. It has been observed that the total floor loss is a non-linear function of the number of penetrated floors. This characteristic is taken into account by introducing an empirical factor b [139]. The ***multi-wall model*** *(MWM)* can then be expressed in form

$$L = L_{FS} + L_c + \sum_{i=1}^{I} k_{wi} L_{wi} + k_f^{\left[\frac{k_f + 2}{k_f + 1} - b\right]} L_f \qquad (4.7.2)$$

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where

L_{FS} = free space loss between transmitter and receiver,

L_C = constant loss,

k_{wi} = number of penetrated walls of type i,

k_f = number of penetrated floors,

L_{wi} = loss of wall type i

L_f = loss between adjacent floors,

b = empirical parameter,

I = number of wall types.

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Indoor Propagation Models

Wall type	Description
Light wall (L_{w1})	A wall that is not bearing load: e.g. plasterboard, particle board or thin (<10 cm), light concrete wall.
Heavy wall (L_{w2})	A load-bearing wall or other thick (>10 cm) wall, made of e.g. concrete or brick.

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Indoor Propagation Models

Environment	One slope model (1SM)		Multi-wall model (MWM)				Linear model (LAM)
	L_0 [dB]	n	L_{w1} [dB]	L_{w2} [dB]	L_f [dB]	b	a
Dense one floor two floors multi floor	 33.3 [3)] 21.9 [4)] 44.9 [4)]	 4.0 [3)] 5.2 [4)] 5.4 [4)]	3.4 [1)]	6.9 [1)]	18.3 [2)]	0.46 [9)]	0.62 [10)] 2.8 [4)]
Open	42.7 [5)]	1.9 [5)]	3.4 [1)]	6.9 [1)]	18.3 [2)]	0.46 [9)]	0.22 [8)]
Large	37.5 [6)]	2.0 [6)]	3.4 [1)]	6.9 [1)]	18.3 [2)]	0.46 [9)]	
Corridor	39.2 [7)]	1.4 [7)]	3.4 [1)]	6.9 [1)]	18.3 [2)]	0.46 [9)]	

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Indoor Propagation Models

The third considered propagation model is the ***linear attenuation model (LAM)***, which assumes that the excess path loss (dB) is linearly dependent on the distance (m), where α (dB/m) is the attenuation coefficient:

$$L = L_{FS} + \alpha d \tag{4.7.3}$$

In some studies wall loss terms are added to the linear model which improves the performance to some extent since degrees of freedom is increased [140]. In the following the LAM is used in the simple form of (4.7.3).

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Bibliografia

- COST Action 231. Digital mobile radio towards future generation systems: Final Report. Published: 1999-04-29. Corporate author(s): Directorate-General for the Information Society and Media (European Commission) , European Commission