Παρουσιάσεις για το Μάθημα Ασύρματων και Κινητών Τηλεπικοινωνιών του ΔΜΠΣ στο ΕΚΠΑ

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Radio Signal Propagation

Radio Signal Propagation

- **Unlike wired communication channels that are stationary and predictable, wireless channels are extremely random and do not offer easy analysis.**
- **Radio Signal Propagation analysis has been focusing on predicting**
  - **the average signal strength at a given distance from the Tx , as well as (large scale propagation modeling)**
  - **The variability of the signal strength in close spatial proximity to a particular location (small scale propagation or fading modeling)**

Free Space Propagation Modeling

The Received Signal Level (RSL) varies

- **Proportionally to Tx power, antenna gains and wavelength**
- **Inversely proportionally to the distance between the {Tx, Rx}, and other miscellaneous losses in the communication system hardware**

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

$$G = \frac{4\pi A}{\lambda^2}, \qquad \lambda = c / f$$

- **A**: Effective aperture related to antenna physical size
- **L**: Miscellaneous losses in communication system

$$FSL_{dB} = 32.45 + 20\log D_{Km} + 20\log F_{MHz}$$

$$= 36.58 + 20\log D_{mi} + 20\log F_{MHz}$$

FSL: Free Space Loss

Path Loss

- **Path Loss (PL) represents signal attenuation as a positive quantity, usually measured in dB (i.e. 10log(x))**

$$PL(dB) = P_t(dB) - P_r(dB) = 10\log\left(\frac{P_t}{P_r}\right)$$

- **Due to the large dynamic range of received power levels, often dBm or dBW units are used to express received power levels in milliwatts or watts respectively**

$$1W \Leftrightarrow 10\log(1W) = 0dBW = 10\log(1000mW) = 30dBm$$

Path Loss Analysis - Example

Example:

In a wireless system, the Tx produces 50 watts of power, the antenna at 900 MHz carrier frequency, and both antennas have a unity gain.

- **What is the transmit power in (a) dBm or (b) dBW?**
- **What is received power in dBm at a free space distance of 100m from the antenna?**

Answers:

- **Pt = 50W = 47.0 dBm = 17.0 dBW**
- **Pr(dBm@100m) = -24.5 dBm**

Mechanisms affecting Free-Space Propagation

- ***Reflection:*** **Occurs when the e-m wave impinges upon an object with very large dimensions (wrt λ)**

- ***Diffraction:*** **Occurs when the radio line-of-sight (LOS) path (between the Tx and Rx) is obstructed by a surface with sharp edges, leading to «wave bending»**

- ***Scattering:*** **Due to many and small obstacles (Foliage, Street signs, lamp posts, etc)**

Path Loss Modeling

$$avg\ PL(d) \propto \left(\frac{d}{d_0}\right)^n$$

Measured signal levels (in dB) have a Gaussian distribution

(log-normal shadowing)

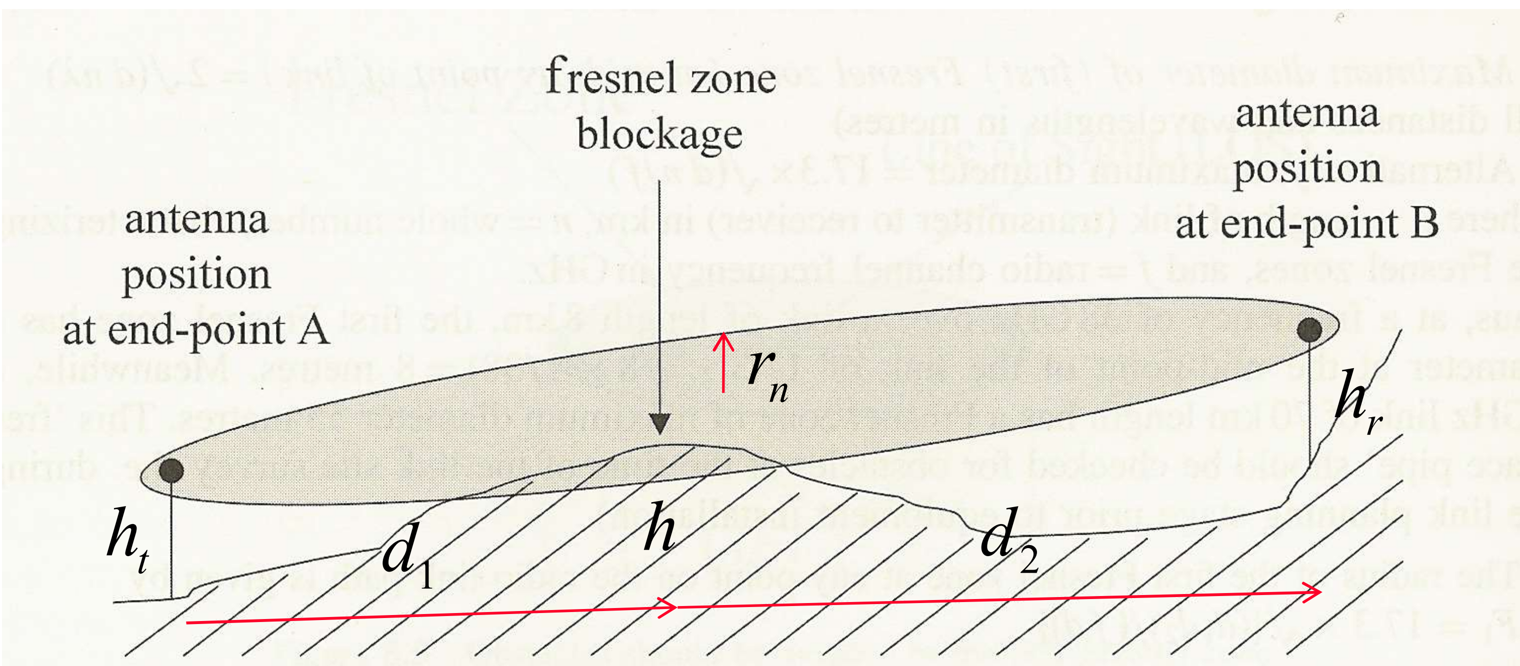
$$avg\ PL(dB) = avg\ PL(d_0) + 10n\log\left(\frac{d}{d_0}\right)$$

A reference distance close to Tx

Environment	Path Loss Exponent, n
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Fresnel Zones

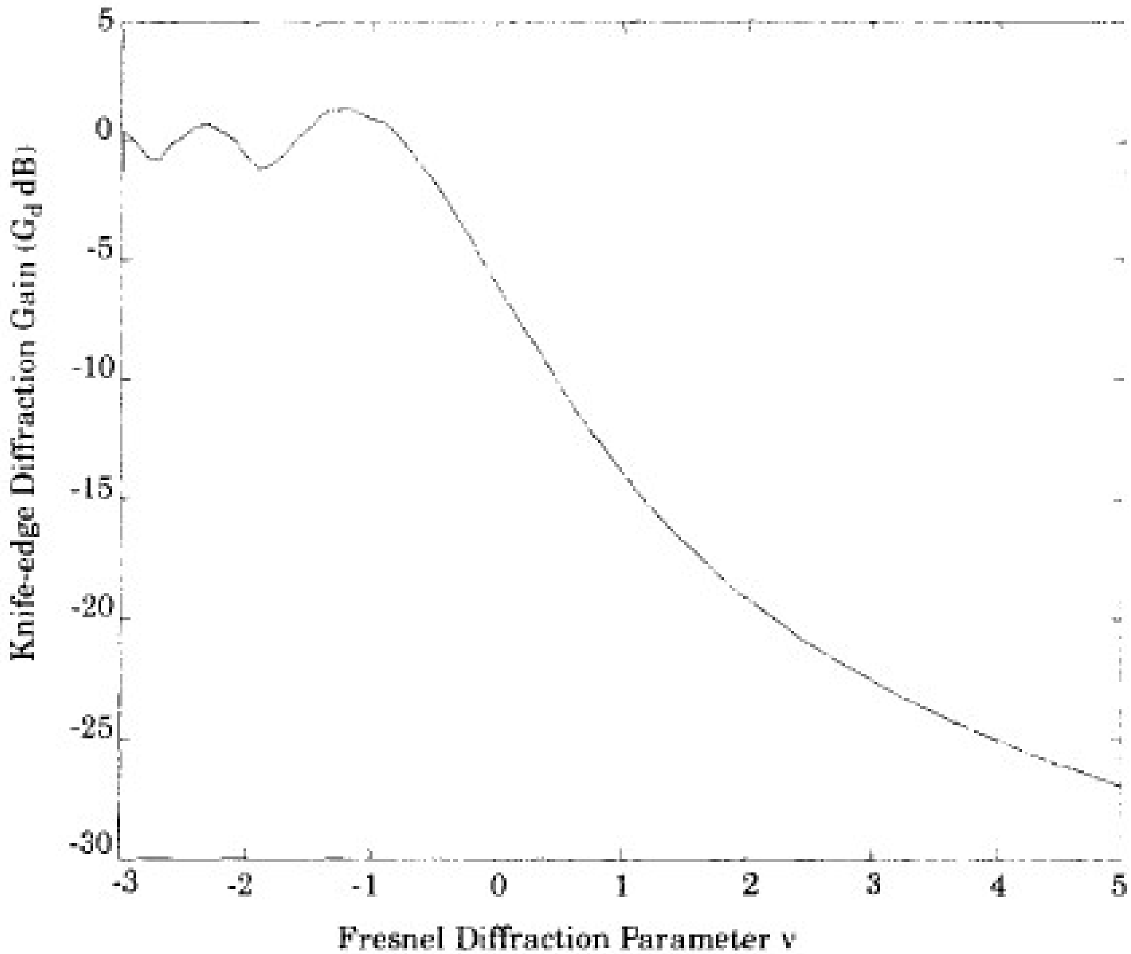
- **Fresnel zones represent successive regions where secondary waves have a path length from Tx to Rx greater from LOS path by n*λ/2, n=1,2,3,…**
- **Successive Fresnel zones alternatively provide constructive and destructive interference to the received signal**
- **Fresnel zone radii get max when the obstruction is in the middle of Tx-Rx path**
- **Rule of thumb: 1st Fresnel zone should be at least 55% clear**



$$r_n = \sqrt{\frac{n\lambda d_1 d_2}{d_1 + d_2}}$$

Fresnel Zones cont'd

- **Fresnel Diffraction parameter (v) may be used to determine the loss due to edge diffraction**



$$v = h\sqrt{\frac{2(d_1 + d_2)}{\lambda d_1 d_2}}$$

- **h: the obstructing object height above LOS (positive or negative)**

Propagation Modeling

The objective is to predict/ estimate the path loss statistics over an irregular terrain

- **Outdoor models**
  - **Okumura**
  - **Hata**
  - **COST-231 (Hata @ PCS frequencies)**
  - **Walfisch & Bertoni, Longley-Rice, Durkin**
- **Indoor models**
  - **Same floor soft/ hard partitions**
  - **Intra-floor partitions**
  - **Log-distance path loss**
  - **Ericsson multiple breakpoint**

Okumura Model

Median path Loss:

{Tx, Rx} Antenna Height
Gain Factors

$$L_{med}(dB) = L_{FreeSpace} + A(f,d) - G(h_{te}) - G(h_{re}) - G_{Area}$$

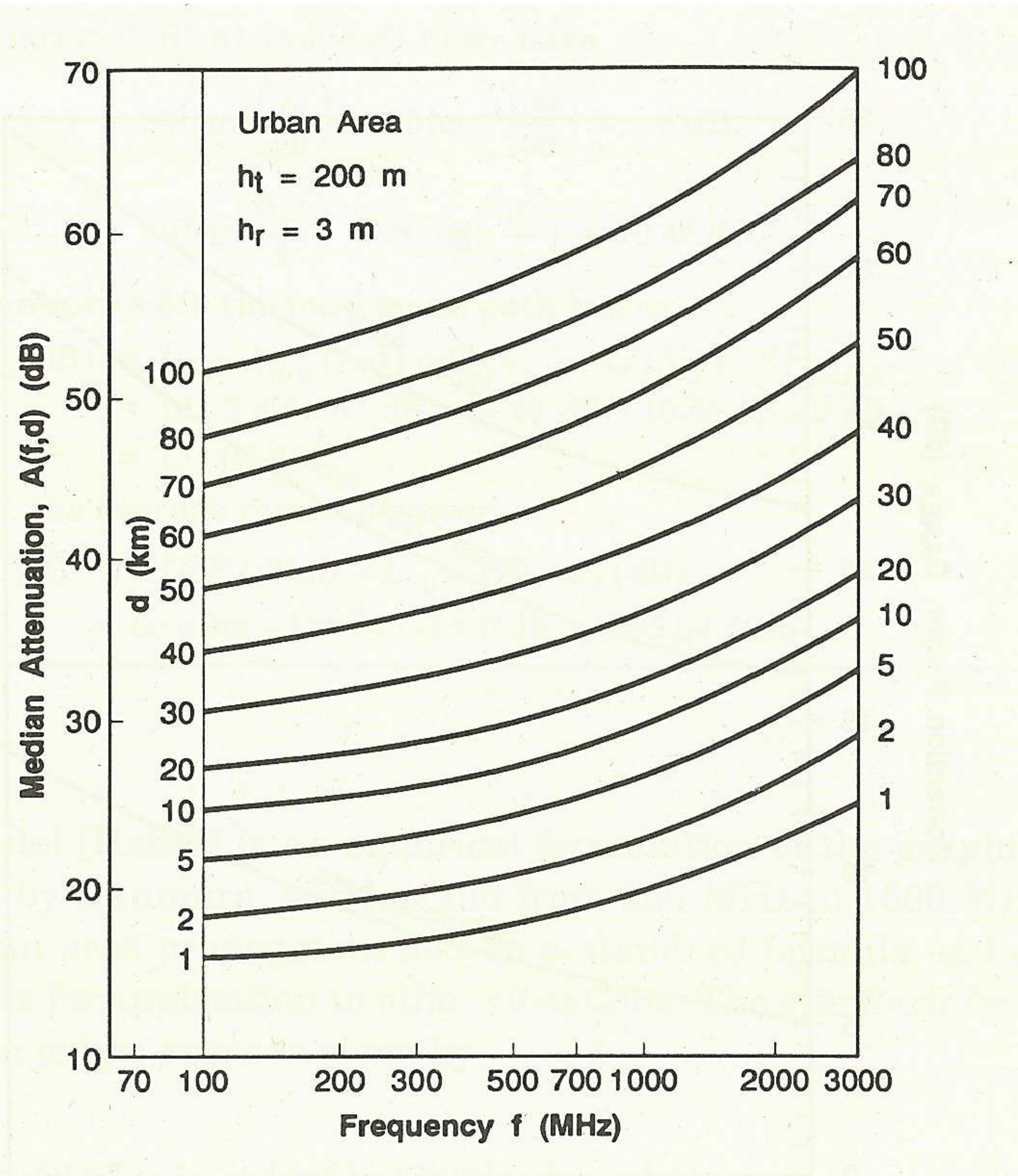
Median Attenuation

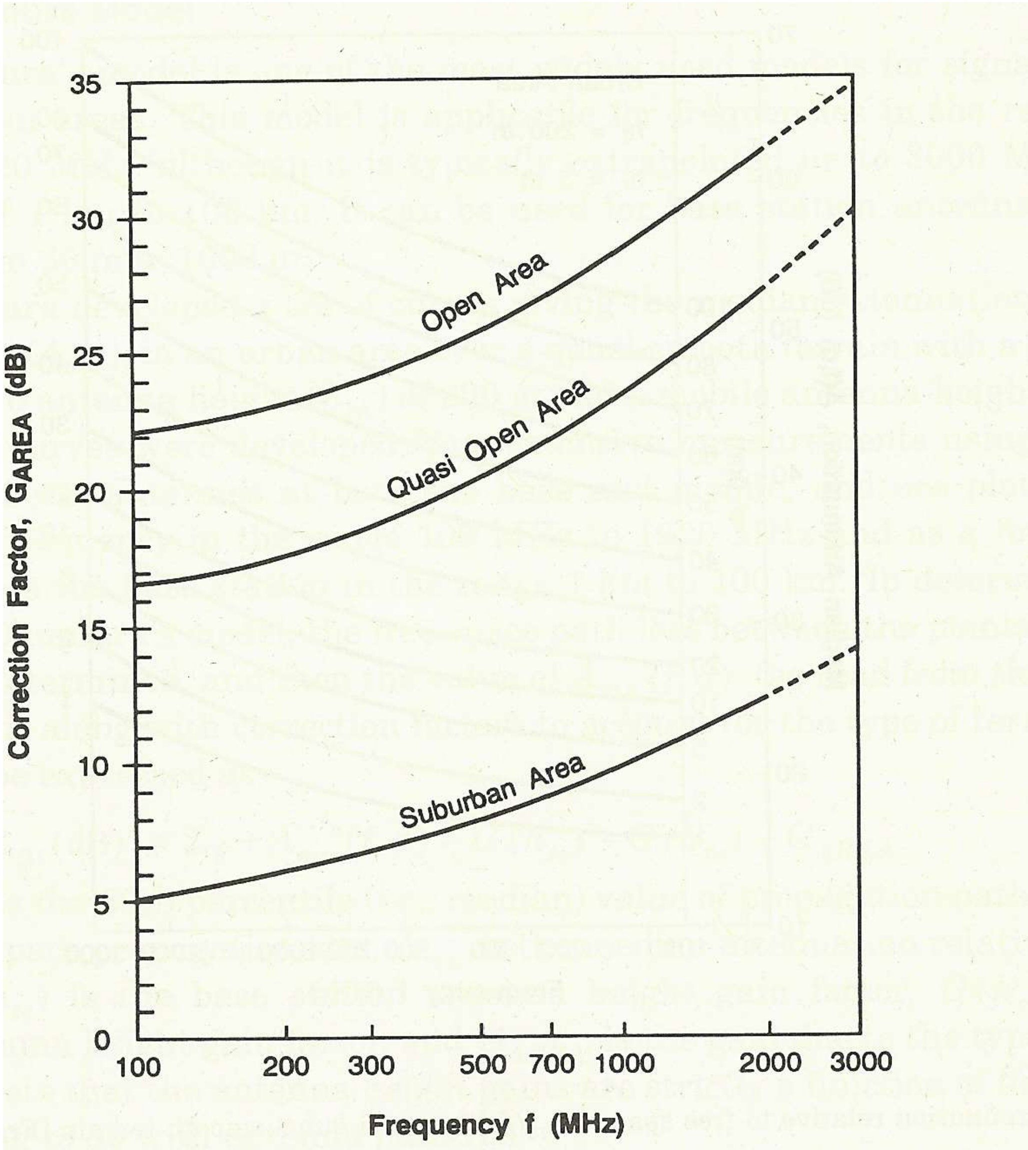
Environment specific
Correction Factor

$$G(h_{te}) = 20\log\left(\frac{h_{te}}{200}\right)$$

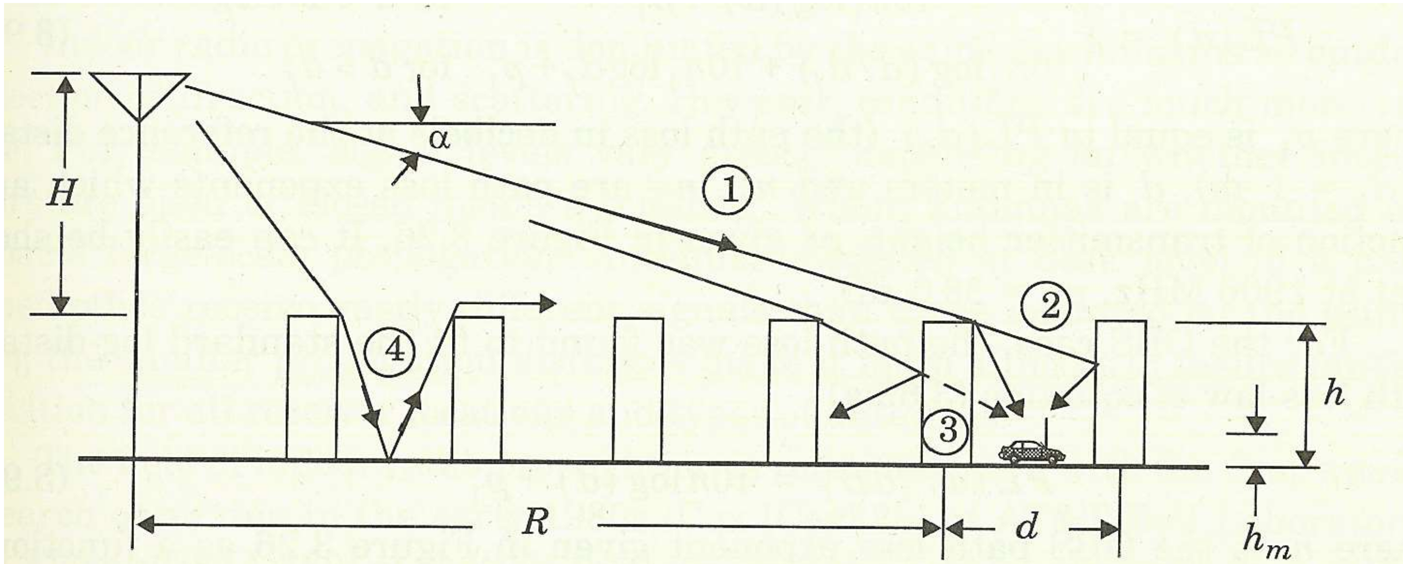
$$G(h_{re}) \sim \log\left(\frac{h_{re}}{3}\right)$$

Okumura Model





Walfisch & Bertoni Model



$$L(dB) = L_{FreeSpace} + L_{RooftopStreet} + L_{multiscreen}$$

{1,2} {3,4}

Indicative Average Loss Measurements

Radio Paths Obstructed by Common Building Material.

Material Type	Loss (dB)	Frequency	Reference
All metal	26	815 MHz	[Cox83b]
Aluminium siding	20.4	815 MHz	[Cox83b]
Foil insulation	3.9	815 MHz	[Cox83b]
Concrete block wall	13	1300 MHz	[Rap91c]
Loss from one floor	20-30	1300 MHz	[Rap91c]
Loss from one floor and one wall	40-50	1300 MHz	[Rap91c]
Fade observed when transmitter turned a right angle corner in a corridor	10-15	1300 MHz	[Rap91c]
Light textile inventory	3-5	1300 MHz	[Rap91c]
Chain-like fenced in area 20 ft high containing tools, inventory, and people	5-12	1300 MHz	[Rap91c]
Metal blanket — 12 sq ft	4-7	1300 MHz	[Rap91c]
Metallic hoppers which hold scrap metal for recycling - 10 sq ft	3-6	1300 MHz	[Rap91c]
Small metal pole — 6" diameter	3	1300 MHz	[Rap91c]
Metal pulley system used to hoist metal inventory — 4 sq ft	6	1300 MHz	[Rap91c]
Light machinery < 10 sq ft	1-4	1300 MHz	[Rap91c]
General machinery - 10 - 20 sq ft	5-10	1300 MHz	[Rap91c]
Heavy machinery > 20 sq ft	10-12	1300 MHz	[Rap91c]
Metal catwalk/stairs	5	1300 MHz	[Rap91c]
Light textile	3-5	1300 MHz	[Rap91c]
Heavy textile inventory	8-11	1300 MHz	[Rap91c]
Area where workers inspect metal finished products for defects	3-12	1300 MHz	[Rap91c]
Metallic inventory	4-7	1300 MHz	[Rap91c]
Large 1-beam — 16 - 20"	8-10	1300 MHz	[Rap91c]
Metallic inventory racks — 8 sq ft	4-9	1300 MHz	[Rap91c]
Empty cardboard inventory boxes	3-6	1300 MHz	[Rap91c]
Concrete block wall	13-20	1300 MHz	[Rap91c]
Ceiling duct	1-8	1300 MHz	[Rap91c]
2.5 m storage rack with small metal parts (loosely packed)	4-6	1300 MHz	[Rap91c]
4 m metal box storage	10-12	1300 MHz	[Rap91c]
5 m storage rack with paper products (loosely packed)	2-4	1300 MHz	[Rap91c]
5 m storage rack with large paper products (tightly packed)	6	1300 MHz	[Rap91c]
5 m storage rack with large metal parts (tightly packed)	20	1300 MHz	[Rap91c]
Typical N/C machine	8-10	1300 MHz	[Rap91c]
Semi-automated assembly line	5-7	1300 MHz	[Rap91c]
0.6 m square reinforced concrete pillar	12-14	1300 MHz	[Rap91c]
Stainless steel piping for cook-cool process	15	1300 MHz	[Rap91c]
Concrete wall	8-15	1300 MHz	[Rap91c]
Concrete floor	10	1300 MHz	[Rap91c]
Commercial absorber	38	9.6 GHz	[Vio88]
Commercial absorber	51	28.8 GHz	[Vio88]
Commercial absorber	59	57.6 GHz	[Vio88]
Sheetrock (3/8 in) — 2 sheets	2	9.6 GHz	[Vio88]
Sheetrock (3/8 in) — 2 sheets	2	28.8 GHz	[Vio88]
Sheetrock (3/8 in) — 2 sheets	5	57.6 GHz	[Vio88]
Dry plywood (3/4 in) — 1 sheet	1	9.6 GHz	[Vio88]
Dry plywood (3/4 in) — 1 sheet	4	28.8 GHz	[Vio88]
Dry plywood (3/4 in) — 1 sheet	8	57.6 GHz	[Vio88]
Dry plywood (3/4 in) — 2 sheets	4	9.6 GHz	[Vio88]
Dry plywood (3/4 in) — 2 sheets	6	28.8 GHz	[Vio88]
Dry plywood (3/4 in) — 2 sheets	14	57.6 GHz	[Vio88]
Wet plywood (3/4 in) — 1 sheet	19	9.6 GHz	[Vio88]
Wet plywood (3/4 in) — 1 sheet	32	28.8 GHz	[Vio88]
Wet plywood (3/4 in) — 1 sheet	59	57.6 GHz	[Vio88]
Wet plywood (3/4 in) — 2 sheets	39	9.6 GHz	[Vio88]
Wet plywood (3/4 in) — 2 sheets	46	28.8 GHz	[Vio88]
Wet plywood (3/4 in) — 2 sheets	57	57.6 GHz	[Vio88]
Aluminium (1/8 in) — 1 sheet	47	9.6 GHz	[Vio88]
Aluminium (1/8 in) — 1 sheet	46	28.8 GHz	[Vio88]
Aluminium (1/8 in) — 1 sheet	53	57.6 GHz	[Vio88]

Average Floor Attenuations

point represents the average path loss over a 20λ measurement track [Sei92a].

Building	915 MHz FAF (dB)	σ (dB)	Number of locations	1900 MHz FAF (dB)	σ (dB)	Number of locations
Walnut Creek						
One Floor	33.6	3.2	25	31.3	4.6	110
Two Floors	44.0	4.8	39	38.5	4.0	29
SF PacBell						
One Floor	13.2	9.2	16	26.2	10.5	21
Two Floors	18.1	8.0	10	33.4	9.9	21
Three Floors	24.0	5.6	10	35.2	5.9	20
Four Floors	27.0	6.8	10	38.4	3.4	20
Five Floors	27.1	6.3	10	46.4	3.9	17
San Ramon						
One Floor	29.1	5.8	93	35.4	6.4	74
Two Floors	36.6	6.0	81	35.6	5.9	41
Three Floors	39.6	6.0	70	35.2	3.9	27

Average Floor Attenuations

Office Buildings [Sei92b].

Building	FAF (dB)	σ (dB)	Number of locations
Office Building 1:			
Through One Floor	12.9	7.0	52
Through Two Floors	18.7	2.8	9
Through Three Floors	24.4	1.7	9
Through Four Floors	27.0	1.5	9
Office Building 2:			
Through One Floor	16.2	2.9	21
Through Two Floors	27.5	5.4	21
Through Three Floors	31.6	7.2	21

Propagation Loss inside Buildings

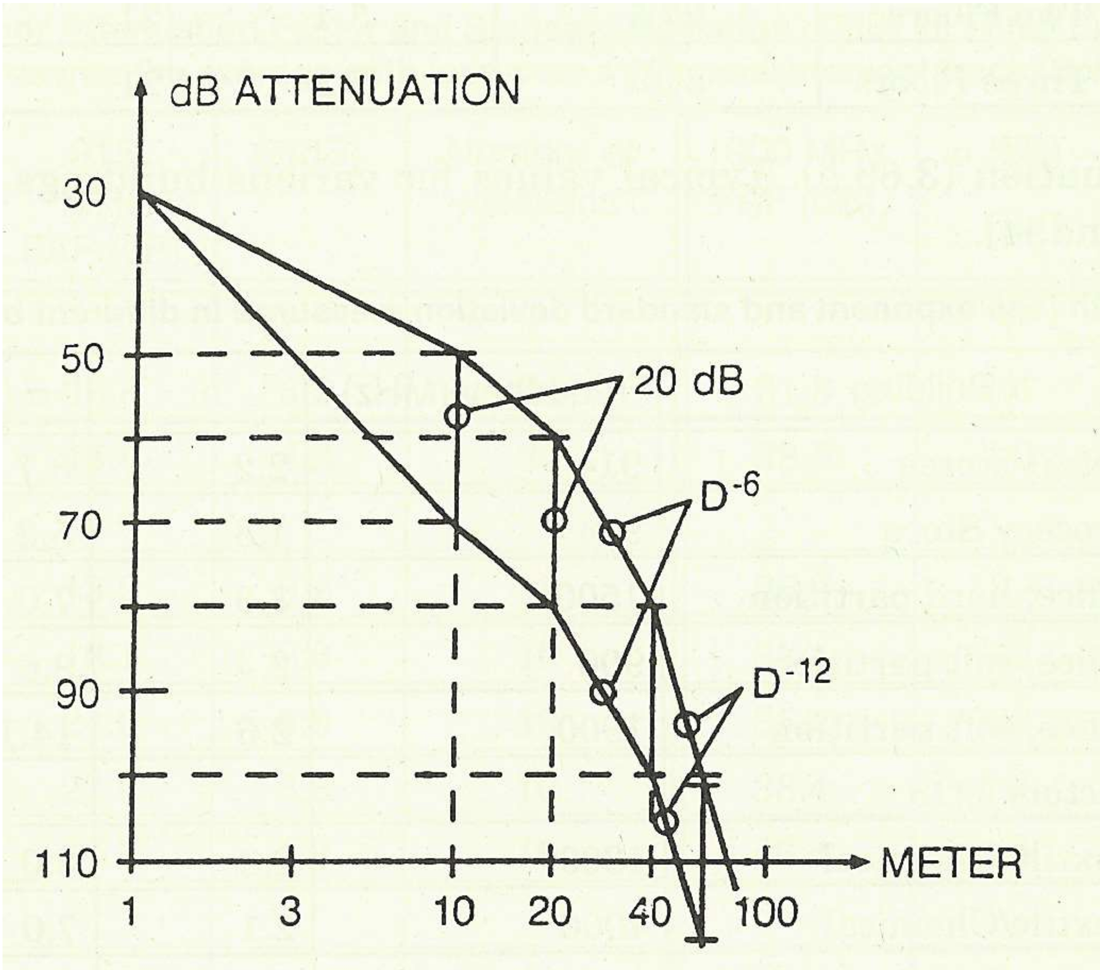
$$PL(dB) = PL(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma$$

$$X_\sigma(dB) \sim N(0,\sigma)$$

Path loss exponent and standard deviation measured in different buildings [A

Building	Frequency (MHz)	n	σ (dB)
Retail Stores	914	2.2	8.7
Grocery Store	914	1.8	5.2
Office, hard partition	1500	3.0	7.0
Office, soft partition	900	2.4	9.6
Office, soft partition	1900	2.6	14.1
Factory LOS			
Textile/Chemical	1300	2.0	3.0
Textile/Chemical	4000	2.1	7.0
Paper/Cereals	1300	1.8	6.0
Metalworking	1300	1.6	5.8
Suburban Home			
Indoor Street	900	3.0	7.0
Factory OBS			
Textile/Chemical	4000	2.1	9.7
Metalworking	1300	3.3	6.8

Ericsson Multiple Breakpoint Model



As MS moves further from the BS, the path loss change increases

Small Scale Fading and Multipath

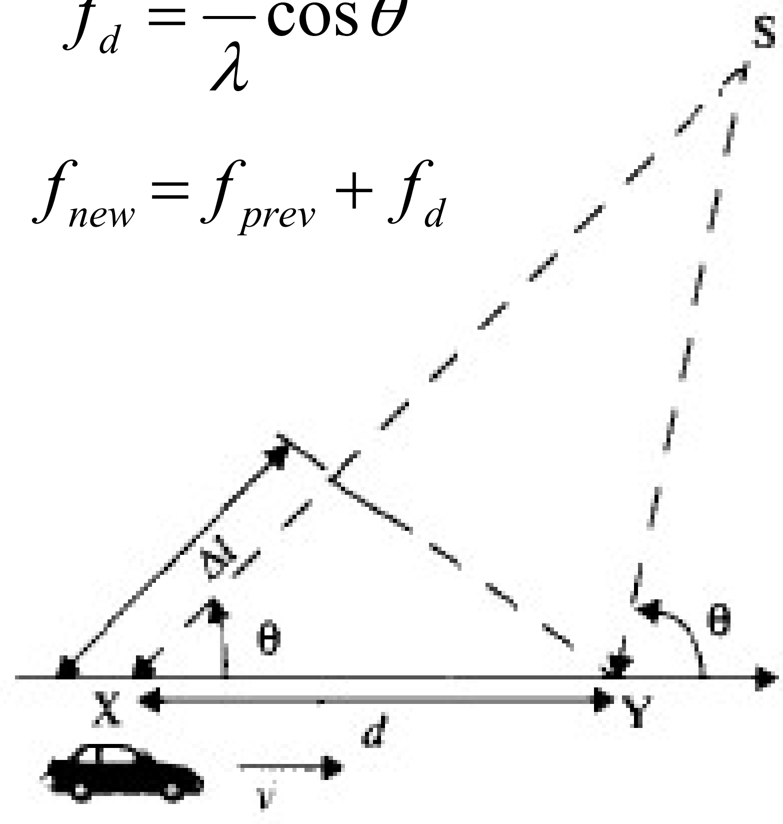
- Small scale fading (or simply fading) is used to describe the rapid fluctuation of the signal amplitude over a short period of time so that large-scale path loss effects may be ignored
- Fading is caused by interference between two or more version of the transmitted signal which arrive at the Rx at slightly different times. These waves are called multipath
- Multipath is combined at the Rx to produce the resultant signal that may vary widely in amplitude and phase, depending on the individual characteristics of every multipath components
- **Factors influencing fading:**
  - Multipath propagation
  - Speed of mobile (Doppler effect)
  - Speed of surrounding objects
  - The transmission bandwidth of the signal

Doppler Shift

❖ **Movement of MS relative to BS, leads to change in frequency**

$$f_d = \frac{v}{\lambda}\cos\theta$$

$$f_{new} = f_{prev} + f_d$$



Example:

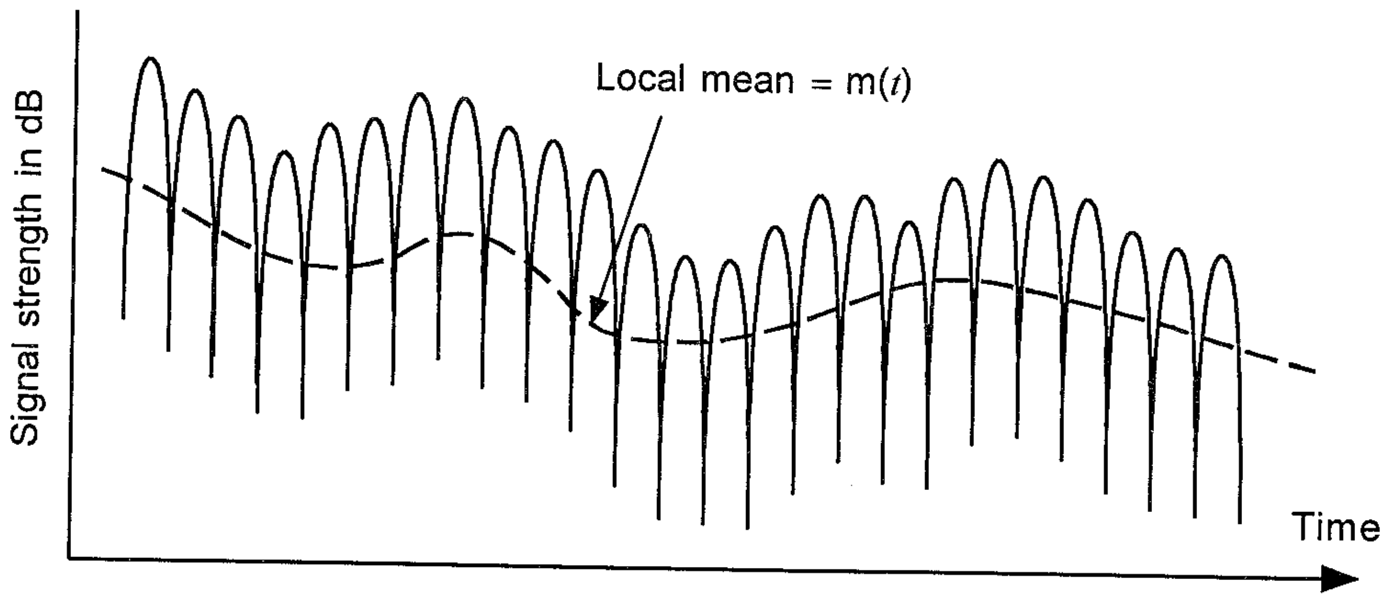
❖ **A Tx radiates a signal at 1850 MHz**

❖ **For a vehicle moving at 60mph:**

- **Directly towards Tx, then new frequency received by MS is 1850.00016 MHz**
- **Directly away from Tx, then new frequency received by MS is 1849.999834 MHz**
- **Perpendicular to Tx, then there in no change in received Frequency**

Multipath Propagation

- **Multiple components/ rays of the Tx signal arrive at the Rx end, with different amplitudes and phases**



- Time availability = The % of time, RSL is above the required level
- Outage = The % of time, RSL is below the required level = 1-Time availability

Signal Fading Statistics

- **In mobile environments**
  - **Rayleigh Fading distribution**

$$p(r) = \frac{r}{\sigma^2}\exp\left(-\frac{r^2}{2\sigma^2}\right), \quad r \ge 0$$

- **When there is a strong / non fading signal component (ex. LOS). This a typical case for Wireless Fixed Access Environments**
  - **Rician fading distribution**

$$p(r) = \frac{r}{\sigma^2}\exp\left(-\frac{(r^2 + A^2)}{2\sigma^2}\right) I_0\left(\frac{Ar}{\sigma^2}\right), \quad A, r \ge 0$$

Level Crossing and Fading Statistics

- **Level Crossing Rate (LCR) is the expected rate at which the Rayleigh fading signal, normalized to its mean value, falls below a pre-specified threshold "p"**
- **The number of level crossings per second is Nr**
- **Average Fade Duration, (τ) is the average period of time for which the received signal remains below a pre-specified level, relative to its mean value**
- **Both parameters depend on MS speed (i.e. a function of maximum Doppler Frequency "fm")**
- **"τ" helps estimating the average number of bits that may be lost during a fade**

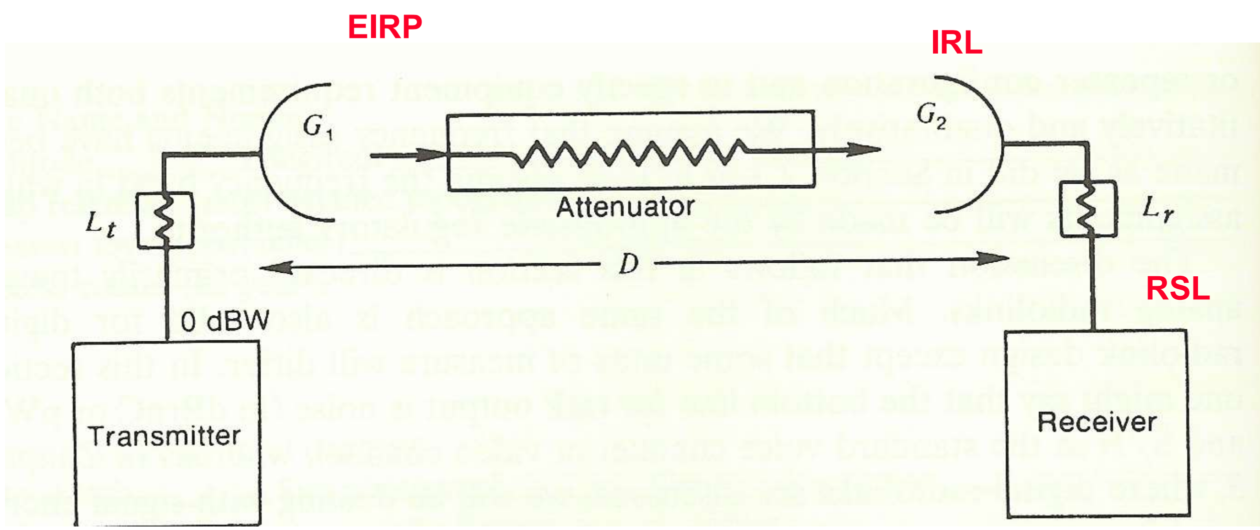
$$N_r = \sqrt{2\pi} f_m \rho e^{-\rho^2}$$

$$\tau = \frac{e^{\rho^2} - 1}{\rho f_m \sqrt{2\pi}}$$

Link Budget Analysis

Link Budget Analysis

- **It provides the Radio network designer with the necessary equipment parameters to**
  - **Prepare a block diagram of the terminal or repeater configuration**
  - **Determine equipment technical specifications**



Link Budget Analysis

- The Effective Isotropic Radiated Power

$$EIRP_{dBW} = P_0 + L_t + G_1$$

- The Isotropic Received Level

$$IRL_{dBW} = EIRP + FSL_{dB} + L_{air}$$

- The Received Signal level (at the Rx input)

$$RSL_{dbW} = IRL + G_2 + L_r$$

Example:

- Tx output power = 750mW
- Line losses = (-) 3.4dB
- Tx – Rx distance = 17 mi
- Operating Frequency = 7.1 GHz
- Antenna Gains = 30.5dB each
- Air Loss = 0.3 dB

$$RSL = -85.56\,dBW$$

$$1mW \Rightarrow 10\log(0{,}001W) = -30\,dBW$$

Digital Link Budget Analysis

- **In digital links, the received Eb/No (instead of RSL) is a key parameter**
  - **Eb: Received information energy per bit**
  - **No: Noise spectral density**
  - **No ~ f(Temperature)**

$$E_{b(dBW)} = RSL_{dBW} - 10\log(R_b)$$

$$N_0 = -204dBW + NF_{dB}$$

Thermal noise level of perfect Rx over 1Hz

Receiver QoS (BER) → **Eb/No** → **RSL** → **EIRP** → **Tx Specs**

Receiver QoS (BER) → **Eb/No** → **RSL** ← **EIRP** ← **Tx Specs**

RSL ↓ **FSL** → **System Coverage**

Link Budget Analysis In Fading

- **Link Availability denotes the time period during which a specified QoS (ex. BER) is met or exceeded**
- **Fade margin denotes the extra signal level required so that a specified link availability is attained**

Example:

- Assume, minimum (unfaded) C/N = 20dB
- Then, min C/N = 53dB for 99.95% availability, ie
- Outage is 0.05%
- C/N < 20 dB for 262.8 min/yr

TABLE 2.6 Fade Margins for Rayleigh Fading

Time Availability (%)	Fade Margin (dB)
90	8
99	18
99.9	28
99.99	38
99.999	48

Example of WCDMA Radio Link Budget

	Uplink		Downlink	
Transmitter power	125.00	a	1372.97	mW
	20.97	$b = 10 \cdot \log_{10}(a)$	31.38	dBm
Tx antenna gain	0.00	c	18.00	dBi
Cable/body loss	2.00	d	2.00	dB
Transmitter EIRP (incl. Losses)	18.97	$e = b + c - d$	47.38	dBm
Thermal noise density	−174.00	f	−174.00	dBm/Hz
Receiver noise figure	5.00	g	8.00	dB
Receiver noise density	−169.00	$h = f + g$	−166.00	dBm/Hz
Receiver noise power	−103.13	$i = 10 \cdot \log_{10}(W) + h$	−100.13	dBm
Interference margin	−3.01	j	−10.09	dB
Required E_c/I_0	−17.12	$k = 10 \cdot \log_{10}[E_b/N_0/(W/R)] - j$	−7.71	dB
Required Signal power [S]	−120.26	$l = i + k$	−107.85	dBm
Rx antenna gain	18.00	m	0.00	dBi
Cable/body loss	2.00	n	2.00	dB
Coverage probability outdoor (requirement)	95.00		95.00	%
Coverage probability indoor (requirement)	0.00		0.00	%
Outdoor location probability (calculated)	85.62		85.62	%
Indoor location probability (calculated)	32.33		32.33	%
Limiting environment	Outdoor		outdoor	
Slow fading constant, outdoor	7.00		7.00	dB
Slow fading constant, indoor	12.00		12.00	dB
Propagation model exponent	3.50		3.50	
Slow fading margin	−7.27	o	−7.27	dB
HO gain (incl. any macrodiversity combining gain at cell edge)	0.00	p	2.00	dB
Slow fading margin + HO gain	−7.27	$q = o + p$	−5.27	dB
Indoor loss	0.00	r	0.00	dB
TPC headroom (fast fade margin)	0.00	s	0.00	dB
Allowed propagation loss	147.96	$t = e - l + m - n + q + r - s$	147.96	dB

Η ανάλυση «Link Budget» αποτελεί θεμελιώδες βήμα στη σχεδίαση και ανάπτυξη ασύρματων δικτύων!

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