Module 4: Mobile Radio Propagation: Large Scale Path Loss

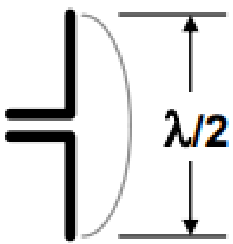
Prepared by

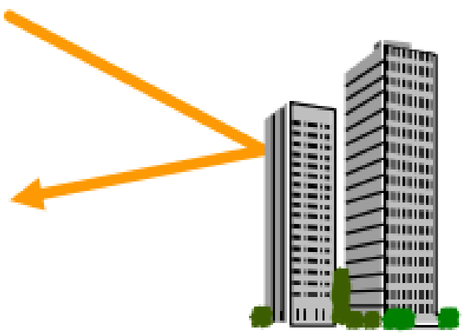
Dr. P. Vijayakumar

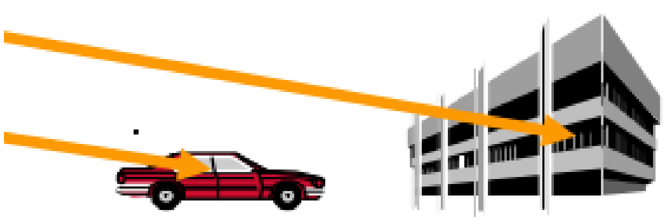
Associate Professor /SENSE

VIT Chennai

Wave Propagation Basics: Frequency and Wavelength



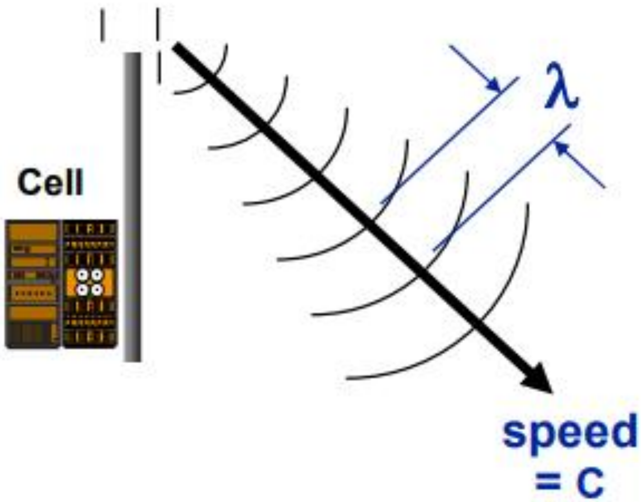




Wavelength is an important variable in RF propagation.

- **Wavelength determines the approximate required size of antenna elements.**
- **Objects bigger than roughly a wavelength can reflect or block RF energy.**
- **RF can penetrate into an enclosure if it has holes roughly a wavelength in size, or larger.**

Wave Propagation: Frequency and Wavelength



Examples:

AMPS cell site f = 870 MHz.

λ = 0.345 m = 13.6 inches

PCS-1900 site f = 1960 MHz.

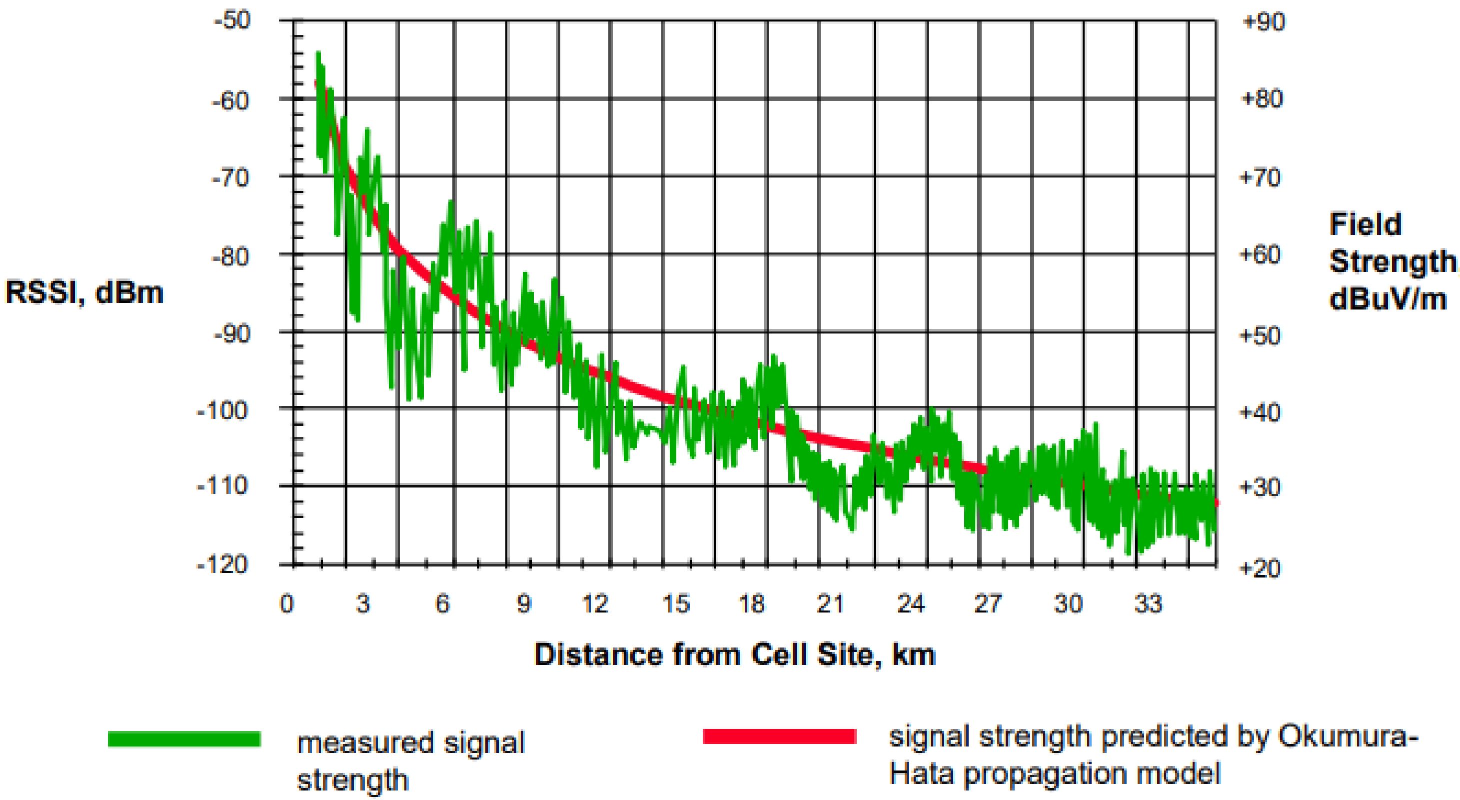
λ = 0.153 m = 6.0 inches

- **Radio signals travel through empty space at the** speed of light (C)
  - **C** = 186,000 miles/second (300,000,000 meters/second)
- Frequency (F) **is the number of waves per second (unit: Hertz)**
- Wavelength (λ) **(length of one wave) is calculated:**
  - (distance traveled in one second) /(waves in one second)

$$\boxed{\lambda = C / F}$$

Statistical Propagation Models

Prediction of Signal Strength as a function of distance without regard to obstructions or features of a specific propagation path



Radio Propagation

- **Mobile radio channel**
  - fundamental limitation on the performance of wireless communications.s
  - severely obstructed by building, mountain and foliage.
  - speed of motion
  - a statistical fashion
- **Radio wave propagation characteristics**
  - reflection, diffraction and scattering
  - no direct line -of-sight path in urban areas
  - multipath fading
- **Basic propagation types**
  - Propagation model: predict the average received signal strength
  - Large-scale fading: Shadowing fading
  - Small-scale fading: Multipath fading

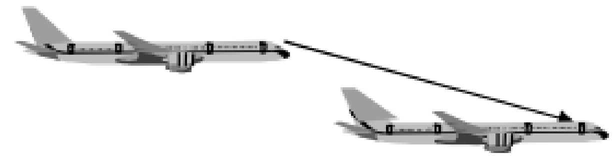
Propagation Model

- **To focus on predicting the average received signal strength at a given distance from the transmitter**
  - variability of the signal strength
  - is useful in estimating the radio coverage.
- **Large-scale propagation**
  - computed by averaging over $5\lambda \sim 40\lambda$, 1m ~ 10m, for1GHz ~ 2GHz.
- **Small-scale fading**
  - received signal strength fluctuate rapidly, as a mobile moves over very small distance.
  - Received signal is a sum of multi-path signals.
  - Rayleigh fading distribution
  - may vary by 30 ~ 40 dB
  - due to movement of propagation related elements in the vicinity of the receiver.

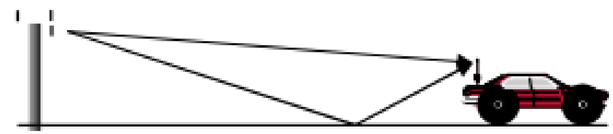
Deterministic Techniques
Basic Propagation Modes

- **There are several very commonly-occurring** modes of propagation, **depending on the environment through which the RF propagates. Three are shown at right:**
  - these are simplified, practically-calculable cases
  - real-world paths are often dominated by one or a few such modes
    - these may be a good starting point for analyzing a real path
    - you can add appropriate corrections for specific additional factors you identify
  - we're going to look at the math of each one of these

Free Space

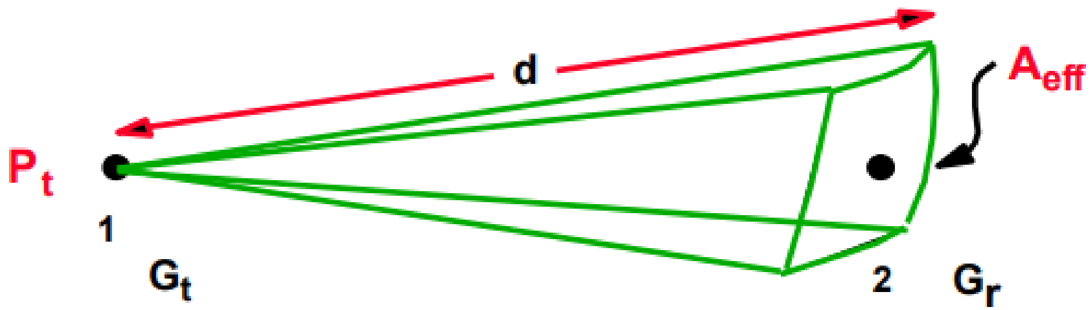


Reflection
with partial cancellation



Knife-edge Diffraction

Free-Space Propagation



$$|S| = \frac{P_t}{4\pi d^2} G_t$$: power density

$$P_r = |S| A_{eff}$$: Received power

$$A_{eff} = \frac{\lambda^2}{4\pi} \cdot G_r \Rightarrow G = \frac{4\pi A_{eff}}{\lambda^2}$$

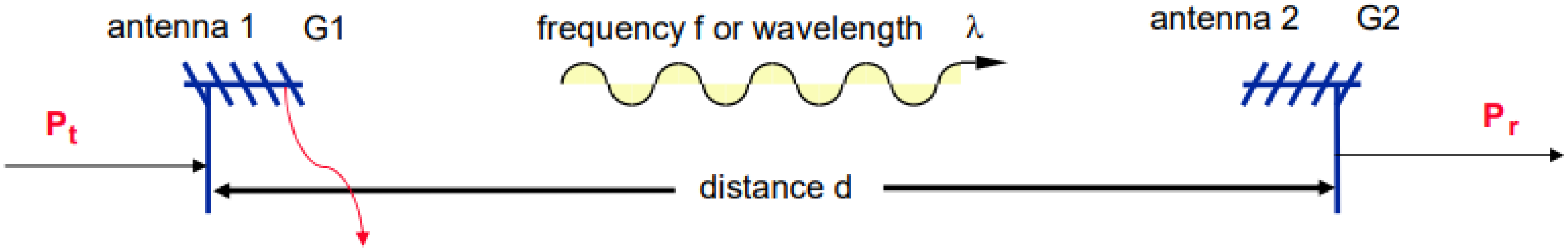
$$P_r = \frac{P_t}{4\pi d^2} \cdot G_t \cdot G_r \cdot \frac{\lambda^2}{4\pi}$$

EIRP = $P_t G_t$ (Effective isotropic radiated power)

- **Effective area (Aperture) $A_{eff} = \eta A$ ratio of power delivered to the antenna terminals to the incident power density**
  - η : Antenna efficiency
  - A : Physical area
- **Transmitter antenna gain = G_t**
- **Receiver antenna gain = G_r**
- **Propagation distance = d**
- **Wave length = λ**

Free-Space Propagation

- **A clear, unobstructed Line-of-sight path between them**
  - Satellite communication, Microwave Line-of-sight (Point-to-point)



EIRP= P_tG_t = effective isotropic radiated power (compared to an isotropic radiator) : dB_i
ERP = EIRP-2.15dB = effective radiated power (compared to an half-wave dipole antenna) : dB_d

Path Gain

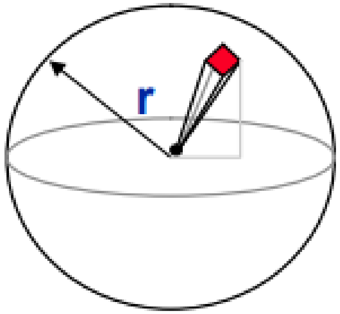
$$\text{gain} = \frac{P_r}{P_t} = G_1 G_2 \left(\frac{\lambda}{4\pi d}\right)^2 = G_1 G_2 \left(\frac{c}{4\pi d f}\right)^2 = G_1 G_2 \left(\frac{3\times 10^8}{4\pi d \cdot 1\times 10^3 \cdot f \cdot 1\times 10^6}\right)^2$$

for ***d*** in km, ***f*** in MHz

Path Loss = 1 / (P_r/P_t) when antenna gains are included

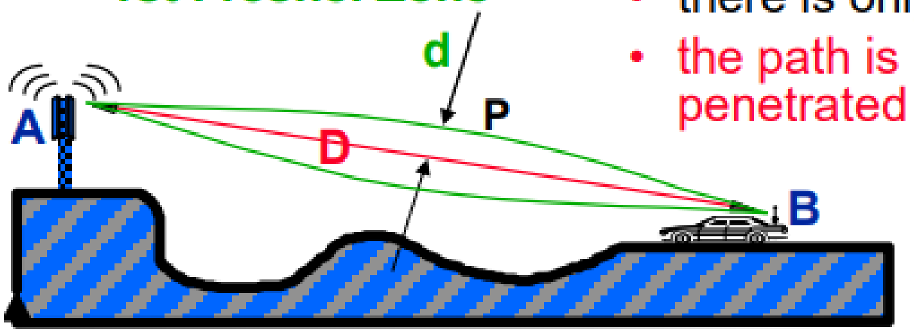
$$\text{loss(dB)} = 32.44 + 20\log d + 20\log f - G_1(dB) - G_2(dB)$$

Free-Space Propagation



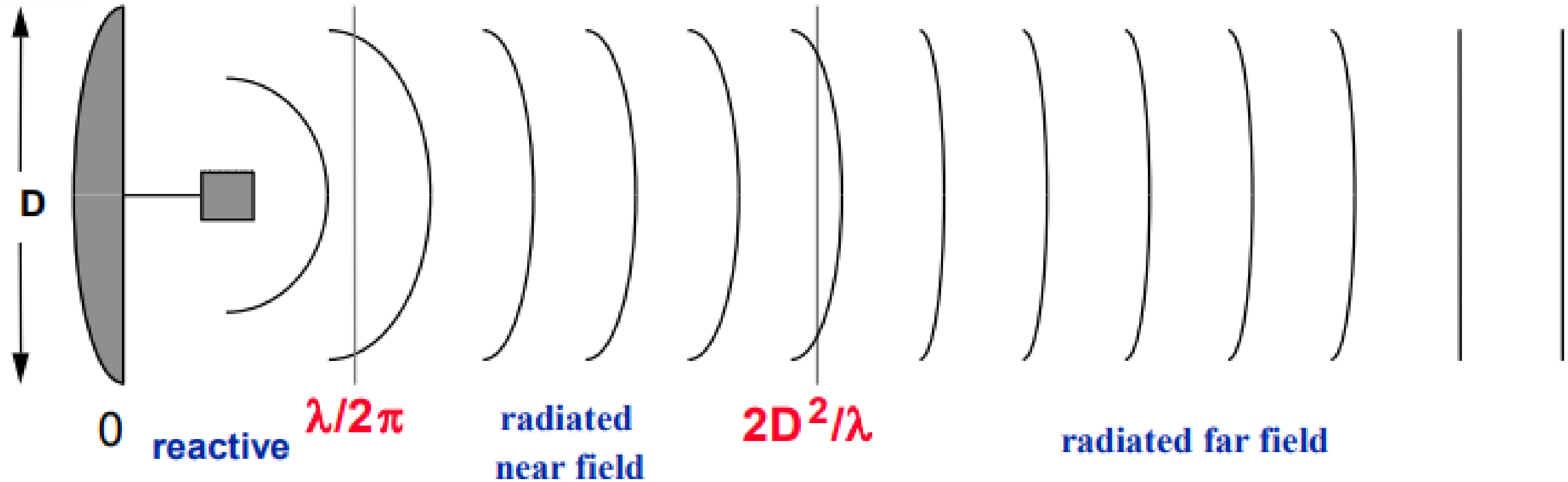
Free Space "Spreading" Loss energy intercepted by the red square is proportional to $\mathbf{1/r^2}$

- The simplest propagation mode
  - Imagine a transmitting antenna at the center of an empty sphere. Each little square of surface intercepts its share of the radiated energy
  - Path Loss, db (between two *isotropic antennas*)
    $= 36.58 + 20*\mathrm{Log}_{10}(F_{MHZ}) + 20\mathrm{Log}_{10}(Dist_{MILES})$
  - Path Loss, db (between two *dipole antennas*)
    $= 32.26 + 20*\mathrm{Log}_{10}(F_{MHZ}) + 20\mathrm{Log}_{10}(Dist_{MILES})$
  - Notice the rate of signal decay:
  - **6 db per octave** of distance change, which is **20 db per decade** of distance change
- When does free-space propagation apply?
  - there is only one signal path (no reflections)
  - the path is unobstructed (first Fresnel zone is not penetrated by obstacles)



First Fresnel Zone =
{Points P where AP + PB - AB $< \lambda/2$ }
Fresnel Zone radius $d = 1/2\ (\lambda D)^{(1/2)}$

Near and Far fields



- These distances are rough approximations!
- Reactive near field has substantial reactive components which die out
- Radiated near field angular dependence is a function of distance from the antenna (i.e., things are still changing rapidly)
- Radiated far field angular dependence is independent of distance
- Moral: Stay in the far field!

An Example

- **An antenna with maximum dimension (D) of 1m, operating frequency (f) = 900 MHz.**
  - **$\lambda = c/f = 3\times10^8/900\times10^6 = 0.33$**
  - **Far-field distance = $d_f = 2D^2/\lambda = 2\times(1)^2/0.33 = 6m$**

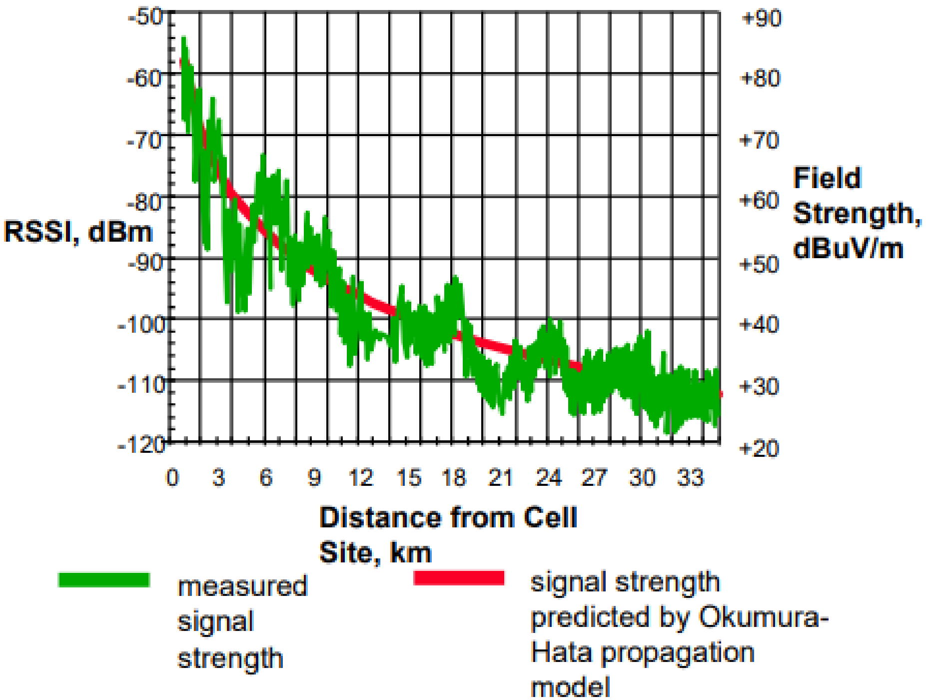
- **TX power, P_t = 50W, f_c = 900MHz, G_t = 1 = G_r**
  - **P_t (dBm) = 10log(50 $\times 10^3$ mW) = 47 dBm = 10lon(50) = 17 dBW**
  - G_t **= 1 =** G_r = 0dB
  - Loss (100m)= 32.44 +20log(d_{km})+20log(f_{MHz}) = 32.44 + 20log (0.1)+20log(900) =71.525 dB
    - P_r (100m)= 47 +0 –71.525 +0 = -24.5 dBm
  - Loss (10km)= 32.44 +20log(d_{km})+20log(f_{MHz}) = 32.44 + 20log (10)+20log(900) =71.525 dB + 40 = 111.525 dB
    - P_r (100m)= 47 +0 –111.525 +0 = -64.5 dBm

Propagation Model

- **General types**
  - Outdoor
  - Indoor : conditions are much more variable.
- **Most of these models are based on a systematic interpretation of measurement data obtained in the service area.**
- **Parameters used in propagation model**
  - Frequency
  - Antenna heights
  - Environments : Large city, medium city, suburban, Rural (Open) Area.
- **Common models**
  - Hata Model : 20km > Range >1km
  - Walfisch and Bertoni Model :Range < 5km
  - Indoor propagation models : include scattering, reflection, diffraction
    - conditions are much more variable

Statistical Propagation Models

- **Prediction of Signal Strength as a function of distance without regard to obstructions or features of a specific propagation path**



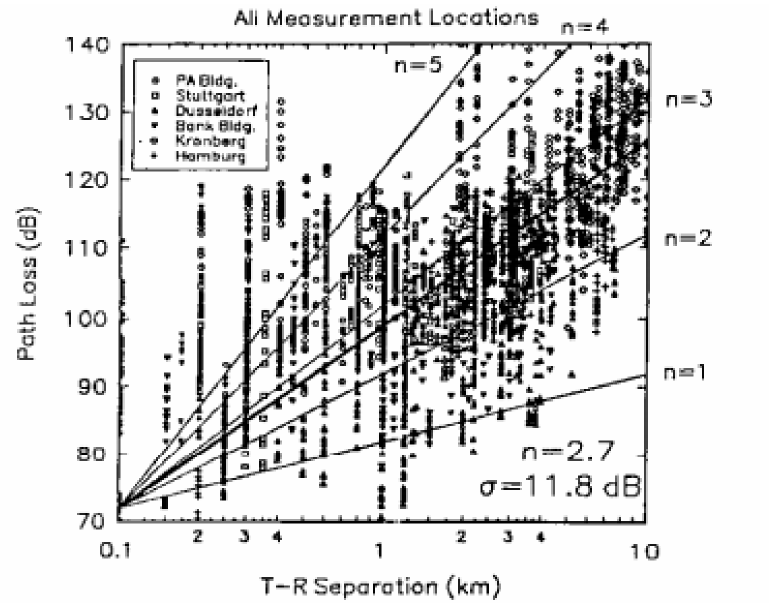


Figure 4.17 Scatter plot of measured data and corresponding MMSE path loss model for many cities in Germany. For this data, $n = 2.7$ and $\sigma = 11.8$ dB [from [Sei91] © IEEE].

Statistical Propagation Models:
Commonly-required Inputs

- Frequency
- Distance from transmitter to receiver
- Effective Base Station Height
- Average Terrain Elevation
- Arbitrary loss allowances based on rules-of-thumb for type of area (Urban, Suburban, Rural, etc.)
- Arbitrary loss allowance for penetration of buildings/vehicles
- Assumptions of statistical distribution of variation of field strength values

Okumura Model

$$L_{50}\,(dB) = L_F + A_{mu}\,(f,d) - G(h_t) - G(h_r) - G_{AREA}$$

- Widely used model for signal prediction in urban areas
- is based on measured data and does not provide any analytical explanation

Vhere:

L_{50} = The 50% (median) value of propagation path loss
L_F = The free space propagation loss
A_{mu} (f,d) = median attenuation relative to free space (see Fig. 3.23)
$G(h_t)$ = Base station antenna height gain factor (30m ~1000m)
$G(h_r)$ = mobile antenna height gain factor
G_{AREA} = Gain due to the type of environment (see Fig. 3. 24)

f : 150MHz ~ 1920MHz (up to 3000MHz), d: 1km ~ 100km

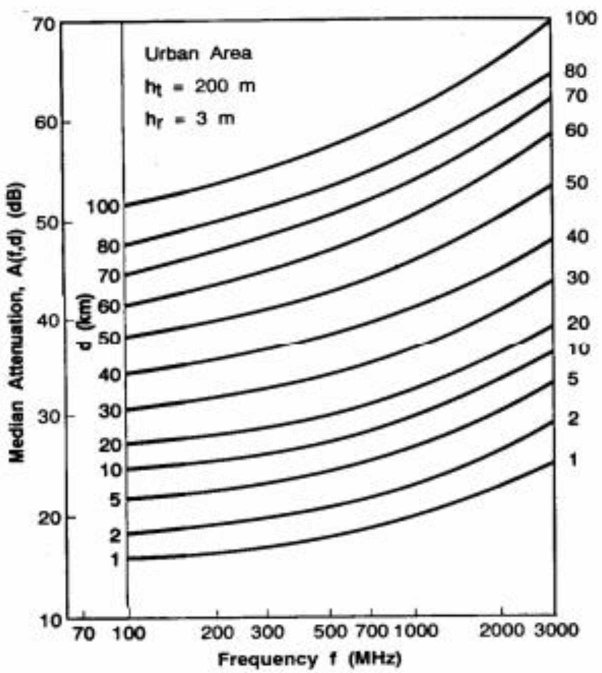
$G(h_t) = 20\log(h_t/200)$,

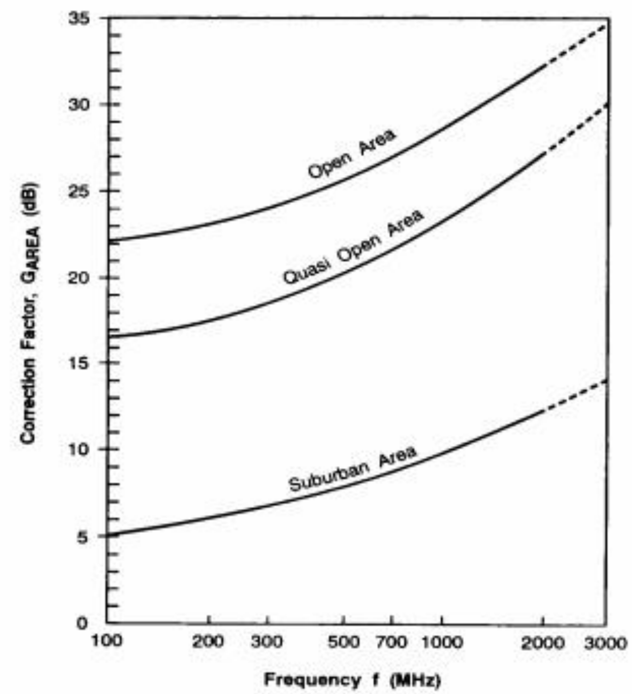
$G(h_r) = 10\log(h_r/3)$, $h_r \le 3m$
$G(h_r) = 20\log(h_r/3)$, $10m \ge h_r > 3m$

An Example
using Okumura Model

- D= 50 km, h_t = 100m, h_r = 10m, in an urban environment. EIRP = 1kW, f = 900 MHz, unit gain receiving antenna.

- L_F = 125.5dB
- A_{mu}(900MHz, 50 km)) = 43 dB
- G_{AREA} = 9dB
- $G(h_t)$ = -6dB
- $G(h_r)$ = 10.46 dB
- L_{50} = 155.04 dB
- $P_r(d)$ = 60-155.04 + 0 = -95.04 dBm





Hata Model

L_{50} *(Urban)* (dB) = 69.55 + 26.16 log (F) – 13.82 log(H_b) + (44. 9 – 6.55 log(H_b))*log (D) – a

Where:

A	=	Path loss
F	=	Frequency in mHz (**150M-1500 MHz**)
D	=	Distance between base station and terminal in km (1km ~20km)
H	=	Effective height of base station antenna in m (30m ~200m)
a	=	Environment correction factor for mobile antenna height (1m~10m)

a = **(1.1 log (F) - 0.7) H_m - (1.56 log (F)- 0.8) dB** **= Small~medium sized city** (urban)

8.29 (log (1.54 H_m))^2 - 1.1 dB for F ≤ 300 MHz **3.2 log (F) (log (11.75 H_m))^2 - 4.97 dB for F ≥ 300 MHz**	**= Large city** (Dense Urban)

- L_{50} *(Urban)* **- 2(log(F/28))^2 - 5.4** **=** Suburban
- L_{50} *(Urban)* **- 4.78(log(F))^2- 18.33 (log(F)) - 40.98** **=** Rural (open)

- **L_{90} = L_{50} + 10.32 dB : 90% QOS, L_{50} is the median value of propagation loss**

COST-231 Hata Model

A (dB) = 46.3 + 33.9log (F) – 13.82 log(H_b) + (44. 9 – 6.55 log(H_b))*log (D) – a + c

$$A\,(dB) = 46.3 + 33.9\log(F) - 13.82\log(H_b) + (44.9 - 6.55\log(H_b))\cdot\log(D) - a + c$$

Where:

A	=	Path loss
F	=	Frequency in MHz (**1500M-2000 MHz**)
D	=	Distance between base station and terminal in km (1km ~20km)
H	=	Effective height of base station antenna in m (30m ~200m)
a	=	Environment correction factor for mobile antenna height
c	=	Environment correction factor

C = **0 dB** **=** Small~medium sized city (urban), Suburban

3 dB **=** Dense Urban (metropolitan center)

A is defined in the Hata Model

Statistical Propagation Models
Okumura-Hata Model

A (dB) = 69.55 + 26.16 log (F) – 13.82 log(H) + (44. 9 – 6.55 log(H))*log (D) + C

Where:	A	=	Path loss
	F	=	Frequency in MHz (**800-900 MHz**)
	D	=	Distance between base station and terminal in km
	H	=	Effective height of base station antenna in m
	C	=	Environment correction factor

C =			
	0 dB	=	Dense Urban
	- 5 dB	=	Urban
	- 10 dB	=	Suburban
	- 17 dB	=	Rural

Statistical Propagation Models
COST-231 HATA Model

$$A\ (dB) = 46.3 + 33.9 * \log F - 13.82 * \log H + (44.9 - 6.55 * \log H) * \log D + C$$

Where:

A	=	Path loss
F	=	Frequency in mHz (**between 1700 and 2000 mHz**)
D	=	Distance between base station and terminal in km
H	=	Effective height of base station antenna in m
C	=	Environment correction factor

C =

- 2 dB	=	for dense urban environment: high buildings, medium and wide streets
- 5 dB	=	for medium urban environment: modern cities with small parks
- 8 dB	=	for dense suburban environment, high residential buildings. wide streets
- 10 dB	=	for medium suburban environment. industrial area and small homes
- 26 dB	=	for rural with dense forests and quasi no hills

Log Distance Path Loss Model

Both theoretical and measurement-based propagation models indicate that average received signal power decreases logarithmically with distance, whether in outdoor or indoor radio channels. Such models have been used extensively in the literature. The average large-scale path loss for an arbitrary T-R separation is expressed as a function of distance by using a path loss exponent, n.

$$\overline{PL}(d) \propto \left(\frac{d}{d_0}\right)^n \tag{3.67}$$

or

$$\overline{PL}(\mathrm{dB}) = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) \tag{3.68}$$

where n is the path loss exponent which indicates the rate at which the path loss increases with distance, d_0 is the close-in reference distance which is determined from measurements close to the transmitter, and d is the T-R separation

Log Distance Path Loss Model

distance. The bars in equations (3.67) and (3.68) denote the ensemble average of all possible path loss values for a given value of d. When plotted on a log-log scale, the modeled path loss is a straight line with a slope equal to $10n$ dB per decade. The value of n depends on the specific propagation environment. For example, in free space, n is equal to 2, and when obstructions are present, n will have a larger value.

It is important to select a free space reference distance that is appropriate for the propagation environment. In large coverage cellular systems, 1 km reference distances are commonly used [Lee85], whereas in microcellular systems, much smaller distances (such as 100 m or 1 m) are used. The reference distance should always be in the far field of the antenna so that near-field effects do not alter the reference path loss. The reference path loss is calculated using the free space path loss formula given by equation (3.5) or through field measurements at distance d_0. Table 3.2 lists typical path loss exponents obtained in various mobile radio environments.

Table 3.2 Path Loss Exponents for Different Environments

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

Log Normal Shadowing

The model in equation (3.68) does not consider the fact that the surrounding environmental clutter may be vastly different at two different locations having the same T-R separation. This leads to measured signals which are vastly different than the *average* value predicted by equation (3.68). Measurements have shown that at any value of d, the path loss $PL(d)$ at a particular location is random and distributed log-normally (normal in dB) about the mean distance-dependent value [Cox84], [Ber87]. That is

$$PL(d)[dB] = \overline{PL}(d) + X_\sigma = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma \qquad (3.69.a)$$

and

$$P_r(d)[dBm] = P_t[dBm] - PL(d)[dB] \text{ (antenna gains included in } PL(d)\text{)} \qquad (3.69.b)$$

where X_σ is a zero-mean Gaussian distributed random variable (in dB) with standard deviation σ (also in dB).

Link budget design using path loss model

Practical Link Budget Design using Path Loss model

- So far the models have been oversimplified.
- Radio Propagation Model can be derived by
  - ***Using Empirical Method:*** Collect measurement , fit curves.
  - ***Using Analytical Methods :*** Model the propagation mechanism mathematically and derive equation for path loss

Log-distance Path Loss Model

- Average Received signal power decreases logarithmically with distance, whether in outdoor or indoor radio channels.

$\bar{P}_L(d)$ = Path loss

η = path loss exponent

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

$d = Tx - Rx$

$P_R(d) = P_t - P_L$

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

$\bar{PL}(d_0) = -10\log\left(P_t/P_r\right)$

$= -10\log\left[\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}\right]$

Ref path loss

Path Loss Exponents for Different Environments

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Free space	2
Urban area cellular radio	2.7 to 3.5
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Log-Normal Shadowing Path Loss Model

- The log distance model does not consider the fact that surrounding environment may be vastly different at two locations having the same Tx-Rx.

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

Random variable with normal distribution about distant dependent mean.

X_σ = Gaussian Random Variable with zero mean

- This distribution describes the random shadowing effects, which happens when a large nos. of measurement locations which have the same Tx- Rx
- This variable is used only when there is a shadowing effect. If there is no shadowing effect, then this variable is zero.

Log-Normal Shadowing Path Loss Model

- This describes the random shadowing effects which occur over a large number of measurement locations which have the same T-R separation, but having different levels of clutter on the propagation path.
- This is referred as **LOG NORMAL Shadowing** (As X_σ is a normal random variable)
- It simply implies that measured signal levels at a specific T-R separation have a Gaussian Distributions about the distant dependent mean

$$P_r(d) = P_t(d) - PL(d) \Rightarrow \text{LOG NORMAL SHADOWING.}$$

- The probability that the received signal will exceed a certain value γ can be expressed using Q- function (at a certain distance)

$$P_r\left(P_r(d) > \gamma\right) = Q\left(\frac{\gamma - \overline{P_r(d)}}{\sigma}\right)$$

or if $\gamma > P_r$

$$P_r\left(P_r(d) < \gamma\right) = Q\left(\frac{\overline{P_r(d)} - \gamma}{\sigma}\right)$$

OUTAGE PROBABILITY

Mean Square Error

- In practice values of η and σ are computed from measured data using "Linear Regression".
- The difference between measured data and estimated path losses are minimized in a Mean Square Error.

$$MSE = \sqrt{\sum_{i=0}^{K} (P_i - P_r)^2}$$

$P_i \Rightarrow$ Measured value (R_n)

$P_r \Rightarrow$ Estimated value.

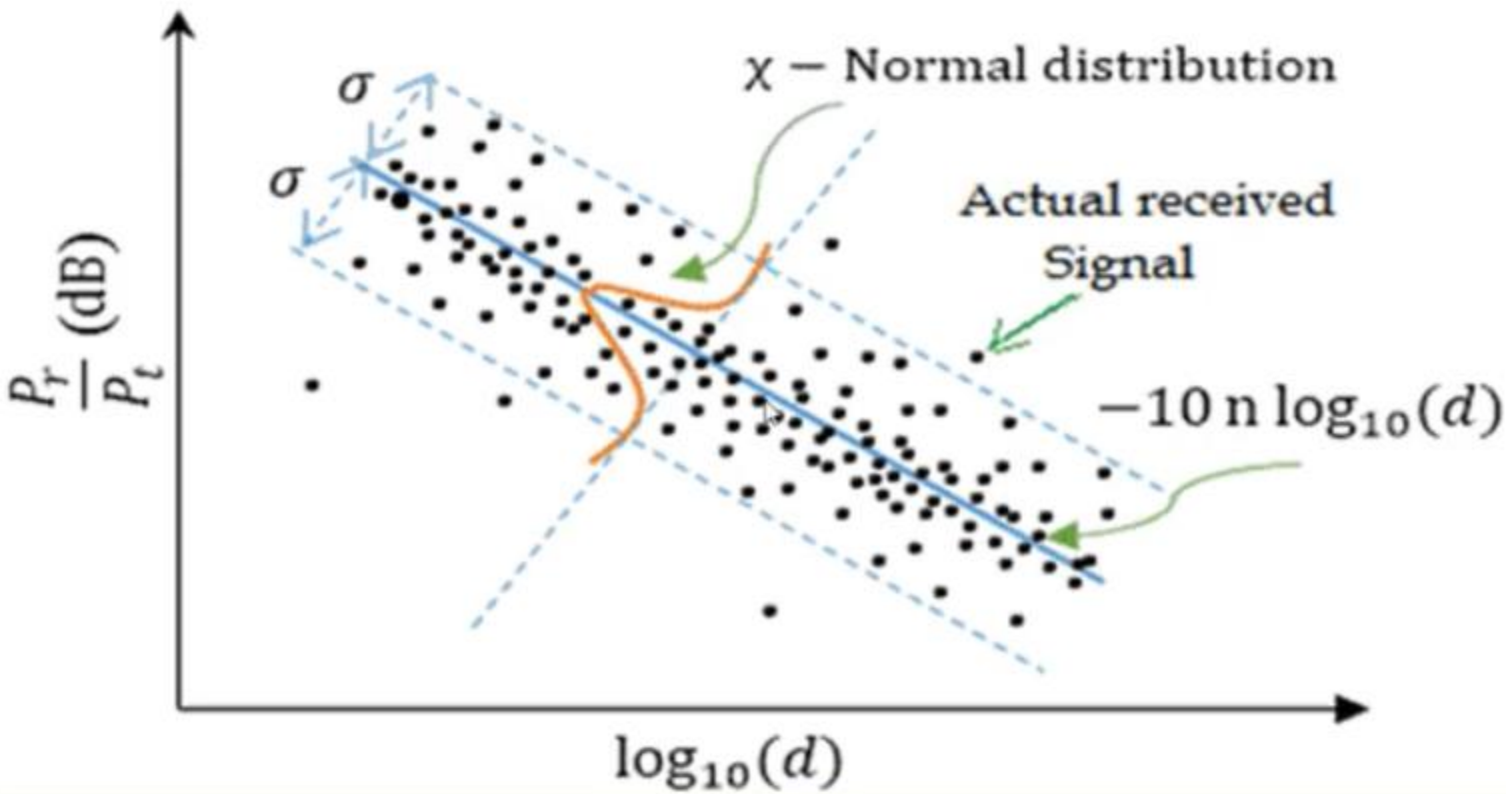
At that value of 'n'' where MSE is min. (Min MSE)

$$\boxed{\sigma^2 = MSE/K = \text{standard deviation}}$$

$K \Rightarrow$ No of samples.

$n' \Rightarrow n$ for getting min MSE.

Log-Normal Shadowing Path Loss Model



Calculate the **received power** at a distance of **3km** from the transmitter if the **path loss exponent is 4**. Assume the transmitting power of 4W at 800 MHz, a shadow effect of **10.5 dBm** and the power at reference distance (d0 = 100 m) of -32 dBm. What is the allowable path loss?

Calculate the **received power** at a distance of **3km** from the transmitter if the **path loss exponent is 4**. Assume the transmitting power of 4W at 800 MHz, a shadow effect of **10.5 dBm** and the power at reference distance (d0 = 100 m) of -32 dBm. What is the allowable path loss?

3 Km = 3000

$$PL(d) = \underbrace{PL(d_0)}_{-32\,dBm} + 10\,\underbrace{n}_{4} \log\left(\frac{d}{\underbrace{d_0}_{100m}}\right) + \underbrace{X_\sigma}_{10.5} = 37.5\,dBm$$

$$P_R = P_t - P_L = \underbrace{36}_{10\log(4\times10^3)} - 37.5 = -1.5\,dBm$$

Four measured power measurements were taken at distances of 100mt, 200mt, 1km and 2km from the transmitter. The measurement values at these distances are 0 dBm, -25 dBm , -35 dBm and -38 dBm. Assuming a Log Normal Shadowing model is followed and d = 100 m, calculate the (i) Find the value of η for which Minimum MSE would be attained.(ii) comment on η (iii) calculate the standard deviation about the mean value. (iv) Estimate the receive power at d = 2 km using the results obtained.

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d	$\hat{P_i}$
100	0 dBm
200	-25 dBm
1000	-35 dBm
2000	-38 dBm

$$J(n) = MSE = \sum_{i=1}^{4} [P_i - \hat{P_R}]^2 = [0 - 0]^2$$

$$+ \left[-25 - \left(0 - 10n \log\left(\frac{d_1}{100}\right)\right)\right]^2$$

$$+ \left[-35 - \left(0 - 10n \log\left(\frac{d_2}{100}\right)\right)\right]^2$$

$$+ \left[-38 - \left(0 - 10n \log\left(\frac{d_3}{100}\right)\right)\right]^2$$

$$\frac{d}{dn}(J(n)) = 556n - 1838 = 0$$

$$J(n) = 278n^2 - 1838n + 3294 \rightarrow MSE$$

$$\sigma = \frac{\sqrt{MSE}}{\sqrt{K}} = 8 \text{ dB}$$

Outdoor Propagation Models

- Outdoor Radio transmission takes place over **irregular terrain**.
- The **terrain profile** must be taken into consideration for estimation path loss.
- **Trees, buildings, hills, desert, water bodies** etc. must be taken into consideration
- Outdoor Propagation Model Include:
    - **Longley Rice Model**
    - **Okumura Model**
    - **Hata Model**

Longley Rice Model

- Also known as Irregular Terrain Model (ITM), calculates large scale median ***propagation loss*** relative to free space propagation loss over ***irregular terrain***.
- It is applicable to **point to point communication.**
- It covers **40 MHz to 100 GHz**
- It accounts for a **wide range of terrains**
- Path geometry of the terrain and the refractivity of the troposphere is used for calculations.
- **Geometrical optics** is used along with two ray ground reflection model.

Longley Rice Model

- The Longley Rice Model is normally available as a **computer Program** that takes as input:
  - Transmission Frequency
  - Path Length
  - Polarization
  - Antenna Height
  - Surface Reflectivity
  - Ground Conductivity and Dielectric Constant
  - Climatic Factors
- Does **not** take into account building or foliage

- **Does not consider** the effect of multipath, buildings, foliages and other environmental factor.

Okumura Model

- In early days, the models were based on **empirical** studies.
- Okumura did comprehensive measurements in **1968** and came up with a model.
- Discovered that a good model for path loss was a **simple power law** where the **exponent η** is a function of frequency, antenna heights, etc.

- One of he most widely used models for signal prediction in the **Urban Areas.**

- **Applicable to :** Frequency Range → ***150 MHz to 1920 MHz***
  Can be extrapolated up to **3 GHz**
  Distance : **1Km to 100 Km**

Okumura Model

Okumura developed a set of curves giving the median attenuation relative to free space in an urban area over quasi smooth terrain

$$L_{50}(dB) = L_F + A_{mu}(f,d) - G(h_{te}) - G(h_{re}) - G_{AREA}$$

50th Percentile (median) value of the Path loss

Free Space Propagation Loss

Median attenuation relative to free space

Base station antenna height gain factor

Mobile station antenna height gain factor

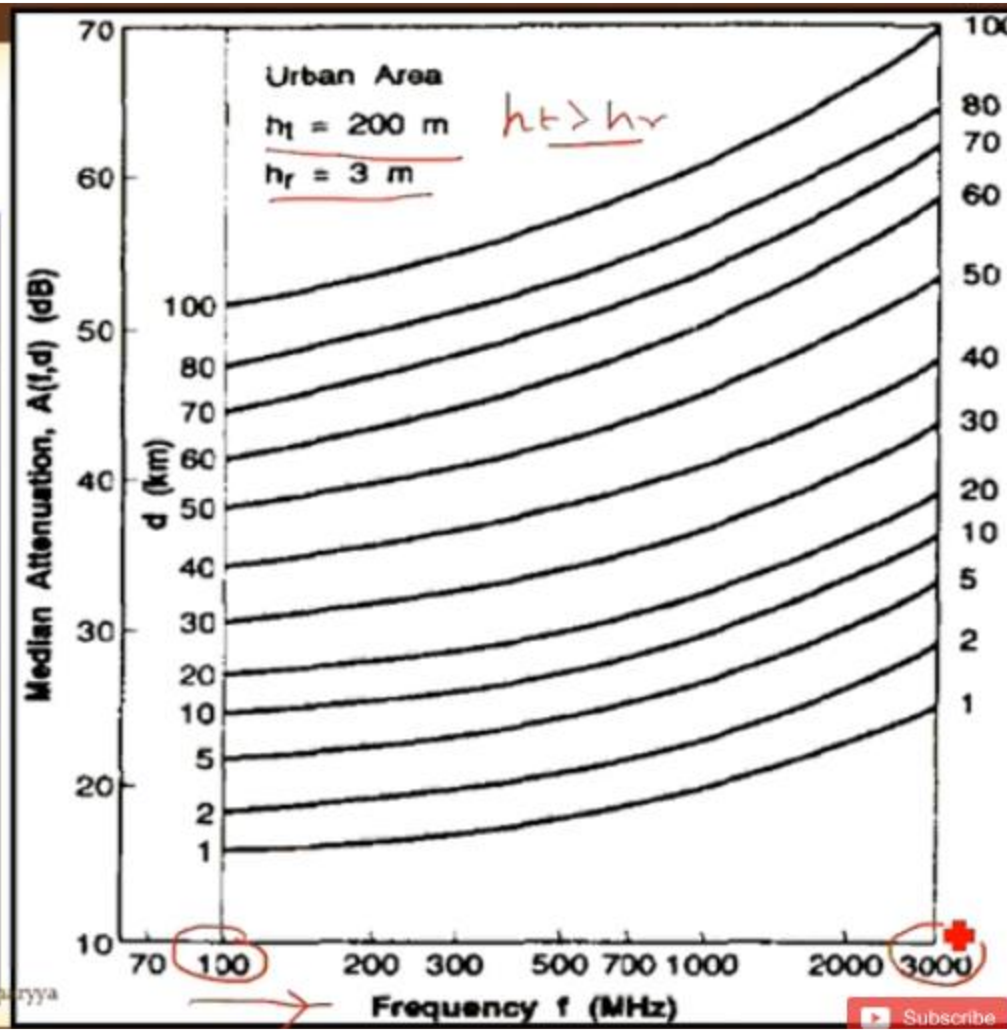
Gain due to the type of environment

Relationship between Gain and height

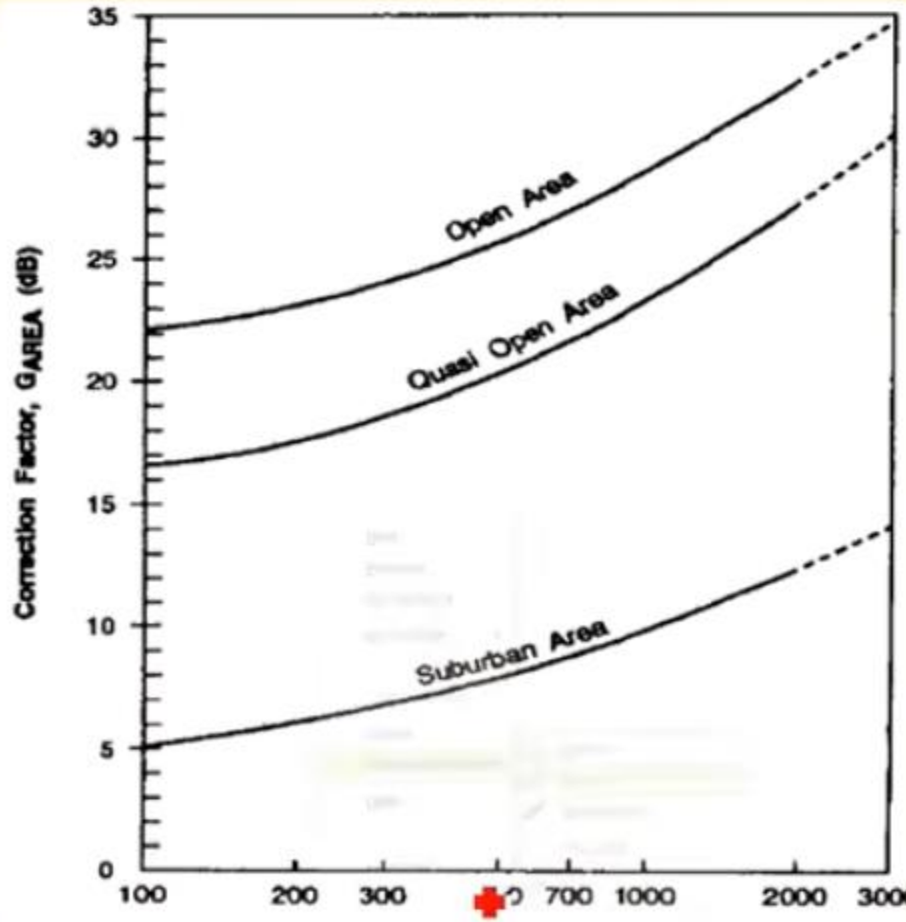
$$G(h_{te}) = 20\log\left(\frac{h_{te}}{200}\right) \qquad 1000\text{ m} > h_{te} > 30\text{ m}$$

$$G(h_{re}) = 10\log\left(\frac{h_{re}}{3}\right) \qquad h_{re} \leq 3\text{ m}$$

$$G(h_{re}) = 20\log\left(\frac{h_{re}}{3}\right) \qquad 10\text{ m} > h_{re} > 3\text{ m}$$



Okumura Model



Okumura Model

- Okumura's model is wholly based on **measured data.**
- There is **no analytical explanation.**
- In certain cases the curves can be extrapolated
- Okumura model is one of the simplest and most accurate path loss prediction model.

Hata and Extended Hata Model

- The Hata Model is the emperical formulation of the graphical path loss data provided by Okumura and is valid from 150 MHz to 1.5 GHz.

L_{50} (dB) = 69.55 + 26.16 $\log f_c$ (MHz) – 13.82 $\log h_{te}$ - $a(h_{re})$ + (44.9 – 6.55 $\log h_{te}$)log d

h_{te} = BS antenna height (30m to 200m)

h_{re} = Mobile antenna height (1m to 10m)

$a(h_{re})$ = is a **correction factor** for effective mobile antenna height which is a function of coverage area.

Hata Model

$$a(h_{re}) = (1.1\log f_c - 0.7)h_{re} - (1.56\log f_c - 0.8)\ \text{dB}$$

Medium Sized City

$$a(h_{re}) = 8.29(\log 1.54h_{re})^2 - 1.1\ \text{dB} \quad \text{for } f_c \le 300\ \text{MHz}$$

$$a(h_{re}) = 3.2(\log 11.75h_{re})^2 - 4.97\ \text{dB} \quad \text{for } f_c \ge 300\ \text{MHz}$$

Large Sized City

$$L_{50}(\text{dB}) = L_{50}(urban) - 2[\log(f_c/28)]^2 - 5.4$$

Path Loss in Suburban area

$$L_{50}(\text{dB}) = L_{50}(urban) - 4.78(\log f_c)^2 - 18.33\log f_c - 40.98$$

Open rural area

Extended Hata Model (COST - 231)

- The Extended Hata Model is the emperical formulation of the graphical path loss data provided by Okumura and is valid from 150 MHz to 2 GHz.

$$L_{50}\,(dB) = 46.3 + 33.9 \log f_c - 13.82 \log h_{te} - a(h_{re}) + (44.9 - 6.55 \log h_{te}) \log d + C_M$$

h_{te} = BS antenna height (30m to 200m)
h_{re} = Mobile antenna height (1m to 10m)
d = 1km to 20 km
C_m= 0 dB to 3 dB with respect to medium city and suburban areas and metopolitan centers
$a(h_{re})$ = is a **correction factor** for effective mobile antenna height which is a function of coverage area.

Employing the Okumura Model compute the median loss at a distance of 10 km when the carrier frequency (Fc) is 2.1 GHz. Assume hte = 40 m, hre = 2 m, for a large city. If EIRP is given by 1kW at the carrier frequency , find the Received power for the same scenario.

Also use the same conditions to apply over a Hata Model and comment on the same.

Carrier freq = 2·1 GHz $\Rightarrow 2 \times 10^9$ Hz

$$\lambda = c/f \simeq ?\ 3 \times 10^8 / 2 \times 10^9 = 0.143\,\underline{m}$$

$$LF = -10 \log\left(\frac{\lambda^2}{(4\pi)^2 d^2}\right) \simeq 10 \log\left(\frac{d^2 (4\pi)^2}{\lambda^2}\right)$$

$$= 10 \log\left(\frac{(10 \times 10^3)^2 (4\pi)^2}{(0.143)^2}\right)$$

$$\simeq 118\ \underline{\underline{dB}}$$

$h_{te} = 40m.$ $\quad G(h_{te}) = 20 \log\left(\frac{h_{te}}{200}\right) \simeq -14\,dB$

$h_{re} = 2m$ $\quad G(h_{re}) = 10 \log\left(\frac{h_{re}}{3}\right) \simeq -1.\underline{\underline{76}}\,dB$

$A_{mu}(2.1, 10\,km) = \underline{\underline{34}}\ dB$

$G_{Area} = ? = 0$

$L_{50} = L_F + A_{mu} - G(h_{te}) - G(h_{re}) - G_{Area}$

$= 118 + 34 - (-14) - (-1.78) - 0$

$= \underline{\underline{167\ dB}}$

Hata Model:

$$L_{50} = 69.55 + 26.16 \log(\underset{\text{MHz}}{f_c}) - a(h_{re}) + (44.9 - 6.55 \log(h_{te})) \log(d)$$

***

$$a(h_{re}) = ? = 3.2 \left(\log(11.75 \times h_{re})\right)^2 - 4.97$$

Example 1 Let us use Okumura model to determine the received signal level 2.3 miles from the site operating at 870MHz. The following numerical data is given:

Radiation centerline of the BTS transmitter: $h_{bts} = 40\,\text{m}$

Height of the mobile receive antenna: $h_m = 3\,\text{m}$

Terrain elevation at the location of the BTS: $E_{bts} = 340\,\text{m}$

Average height of the terrain in the area: $E_{terrain} = 312\,\text{m}$

Power delivered to the BTS antenna: $P_{BTS} = 19.5\text{W}$

BTS antenna gain: $10\log(G_t) = 10\,\text{dB}$

MS antenna gain: $10\log(G_m) = 0\,\text{dB}$

The free space loss between the TX and RX can be calculated as:

$$L_{FS} = 32.45 + 20\log(2.3\times 1.609) + 20\log(870) - 10 = 92.61\,\text{dB}$$

The basic median attenuation is determined from Figure 1 as:

$$A_{mu} = 24\,\text{dB}$$

The effective height of the BTS transmitter is given as:

$$h_{te} = 40 + 340 - 312 = 68\,\text{m}$$

Correction for the base station height gain can be determined from Figure 2 as:

$$H_{tu} \approx -9\,\text{dB}$$

The total path loss between the transmitter and receiver (including the antenna gains) is given as:

$$L_{50} = 92.61 + 24 + 9 = 129.61\,\text{dB}$$

The received signal level is obtained as:

$$RSL = 10\log(19.5\times 1000) - 125.61 = -82.7\,\text{dBm}$$