WIRELESS ACCESS COMMUNICATION.

Kajian 2 b.Large Scale Fading

Faculty of Electrical Engineering
Bandung – 2020

Subject

a. Path Loss Model.

b. Model Okumura-Hatta, COST 231.

c. Model Walfish Ikegami.

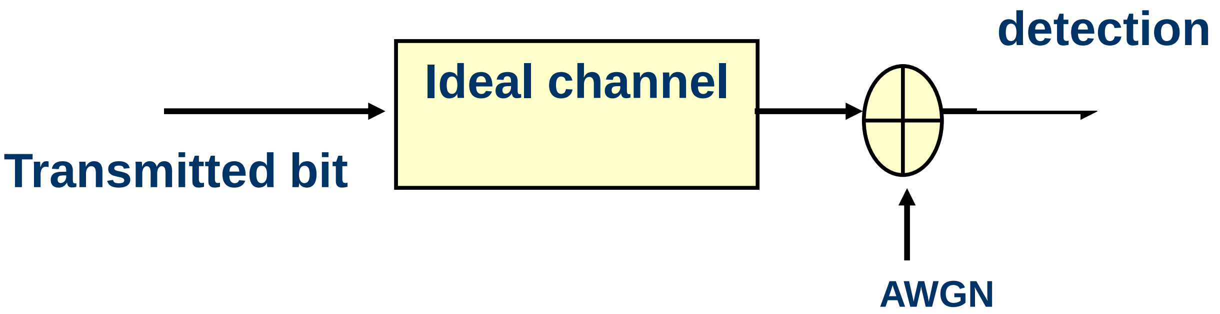
1. Pendahuluan

Kenapa penting untuk mengerti karakteristik-karakteristik dari kanal wireles ?

- Untuk menentukan desain sinyal yang paling tepat (source dan channel coding, serta modulasi)
- Untuk mengembangkan teknologi-teknologi baru dalam pentransmisian dan penerimaan sinyal
- Dalam komunikasi multiuser, skema akses kanal harus dilakukan dengan seefisien mungkin.
- Pada sistem seluler, cakupan sinyal diinginkan dihitung dengan seakurat mungkin → karena daya berlebih akan menghasilkan interferensi yang juga berlebihan.
- Di dalam sistem seluler juga, level terendah yang diijinkan harus ditentukan untuk menjaga koneksi komunikasi dari sel ke sel.

1. Pendahuluan

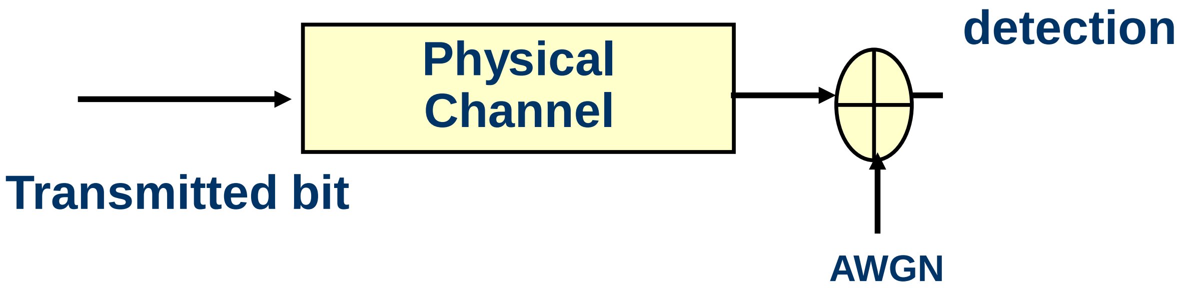
- **Ideal Channel**



- Kanal Ideal meloloskan semua spektrum sinyal **tanpa distorsi** (dikatakan BW kanal takberhingga, respon frekuensi ‘flat’ untuk semua frekuensi)
- Pelemahan dan error hanya disebabkan oleh AWGN (*Additive White Gaussian Noise*).
- Sinyal terima adalah besaran deterministik dengan menggunakan statistik-statistik dari AWGN (terdistribusi Gaussian)

1. Pendahuluan

- **Kanal Real (Physical Channel) :**



- Kanal fisik selalu memiliki **bandwidth yang terbatas**
- Hanya komponen yang signifikan dari spektrum sinyal yang diloloskan melewati kanal → terjadi **Distorsi**
- Bandwidth sinyal harus lebih kecil atau sama dengan bandwidth kanal agar relatif tidak terjadi distorsi → **Pertanyaannya sekarang :** Bagaimana membuat BW sinyal lebih kecil dari BW kanal ??

1. Pendahuluan

Pada umumnya, sinyal yang diterima pada titik penerima adalah jumlah dari sinyal langsung dan sejumlah sinyal terpantul dari berbagai obyek. Pada komunikasi mobile, refleksi akan disebabkan oleh :

- Permukaan tanah
- Bangunan-bangunan
- Obyek bergerak berupa kendaraan

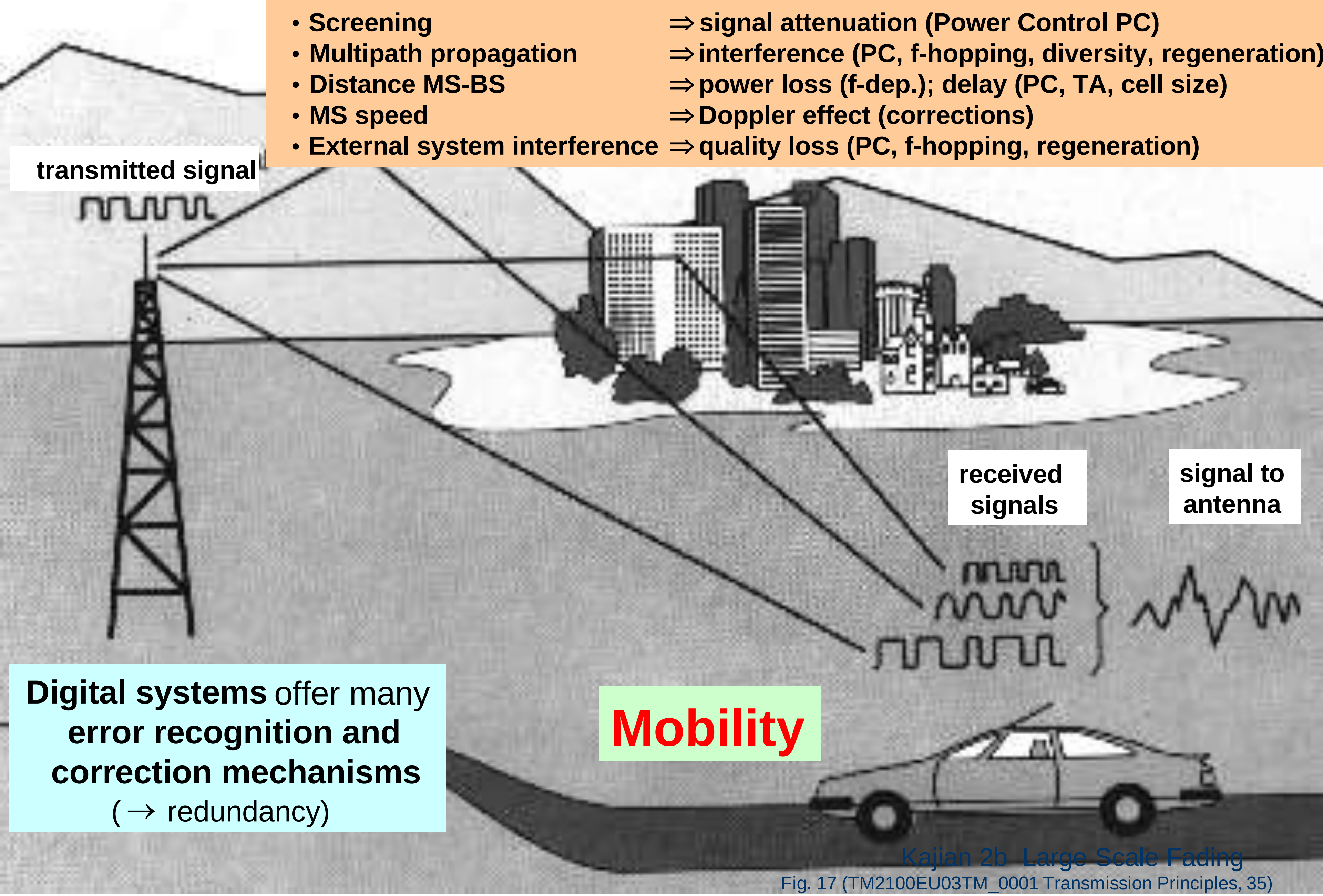
Gelombang pantul akan berubah magnitude dan fasanya, tergantung dari koefisien refleksi, lintasannya, dan juga tergantung pada sudut datangnya. Jadi, antara sinyal langsung dan sinyal pantulan kan berbeda dalam hal :

- **Amplitudo**, tergantung dari magnitude koefisien refleksi
- **Phasa**, yang tergantung pada perubahan fasa refleksi serta pada perbedaan jarak tempuh antara gelombang langsung dan gelombang pantul

Kondisi terburuk terjadi saat gelombang langsung dan gelombang pantul memiliki magnituda yang sama serta berbeda fasa 180o. Pada kondisi yang demikian, terjadi saling menghilangkan antara gelombang langsung dan pantulnya (***complete cancellation***)

Radio Transmission: Physical Disturbances

- Screening ⇒ signal attenuation (Power Control PC)
- Multipath propagation ⇒ interference (PC, f-hopping, diversity, regeneration)
- Distance MS-BS ⇒ power loss (f-dep.); delay (PC, TA, cell size)
- MS speed ⇒ Doppler effect (corrections)
- External system interference ⇒ quality loss (PC, f-hopping, regeneration)



Digital systems offer many **error recognition and correction mechanisms** (→ redundancy)

Mobility

Kajian 2b Large Scale Fading

Fig. 17 (TM2100EU03TM_0001 Transmission Principles, 35)

Introduction

Free Space Loss

Diasumsikan terdapat satu sinyal langsung (line of sight path) → sangat mudah memprediksi dengan free space formula

Reflection

Terdapat sinyal tak langsung datang ke receiver setelah mengalami pantulan terhadap object. Mungkin terdapat banyak pantulan yang berkontribusi terhadap besarnya delay.

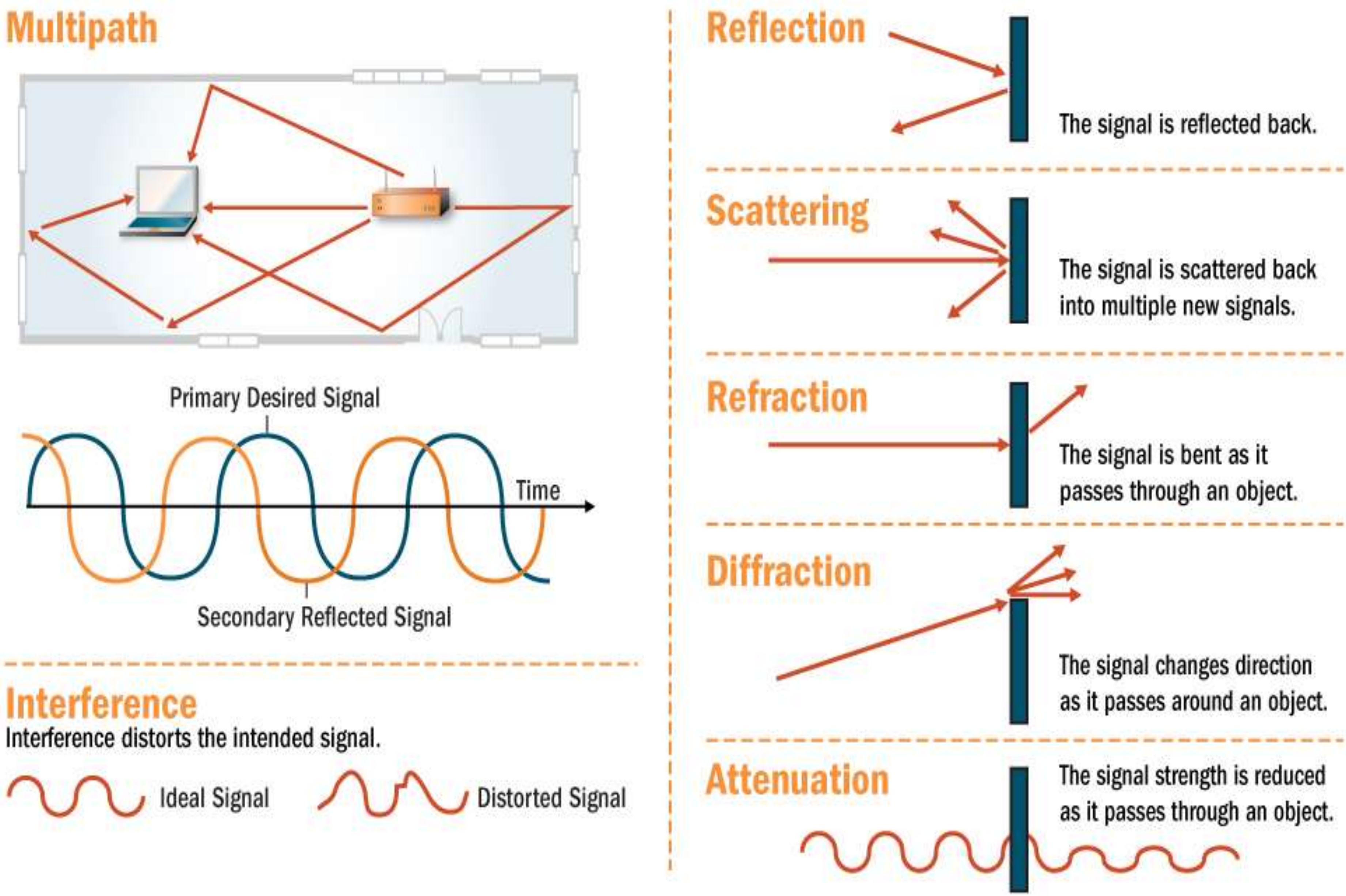
Diffraction

Propagasi melewati object yang cukup besar → seolah-olah menghasilkan sumber sekunder, seperti puncak bukit dsb.

Scattering

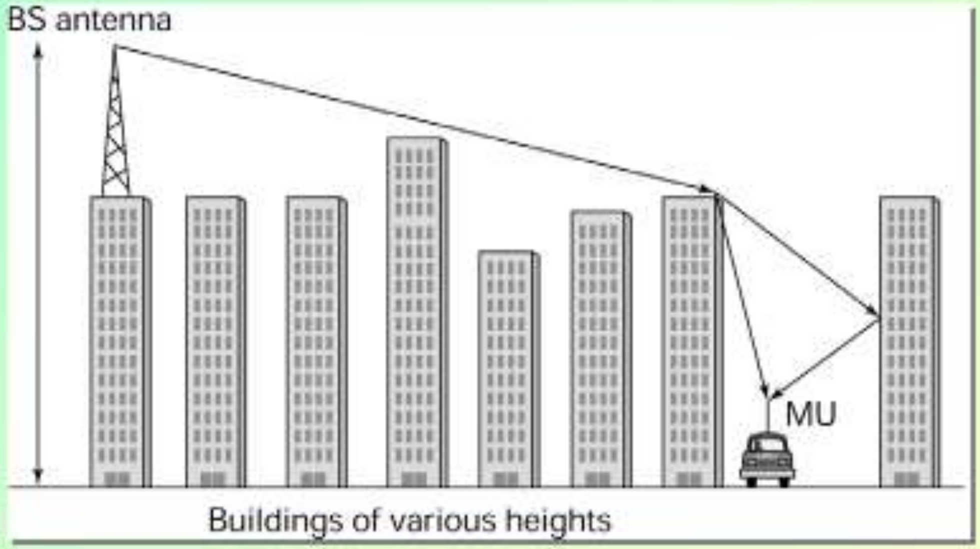
Propagasi melewati object yang kecil dan/atau kasar yang menyebabkan banyak pantulan untuk arah-arah yang berbeda.

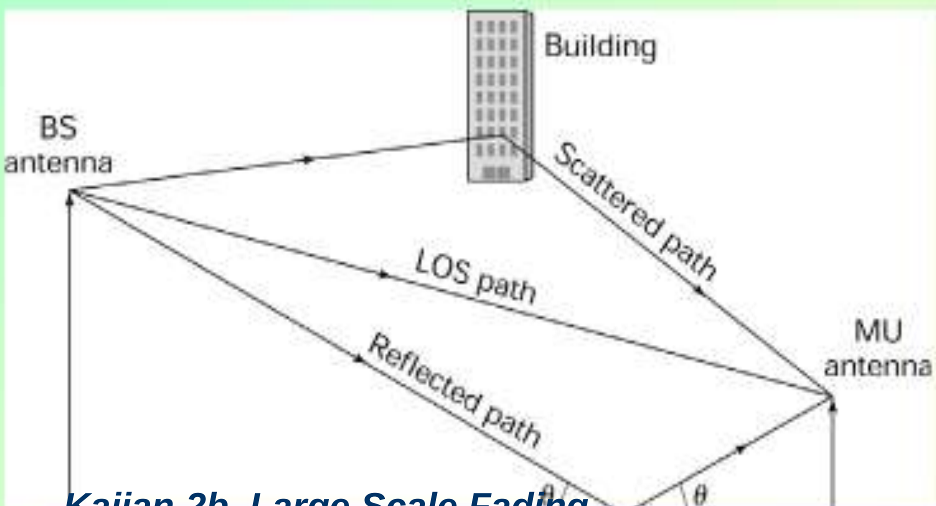
Multipath at Wireless

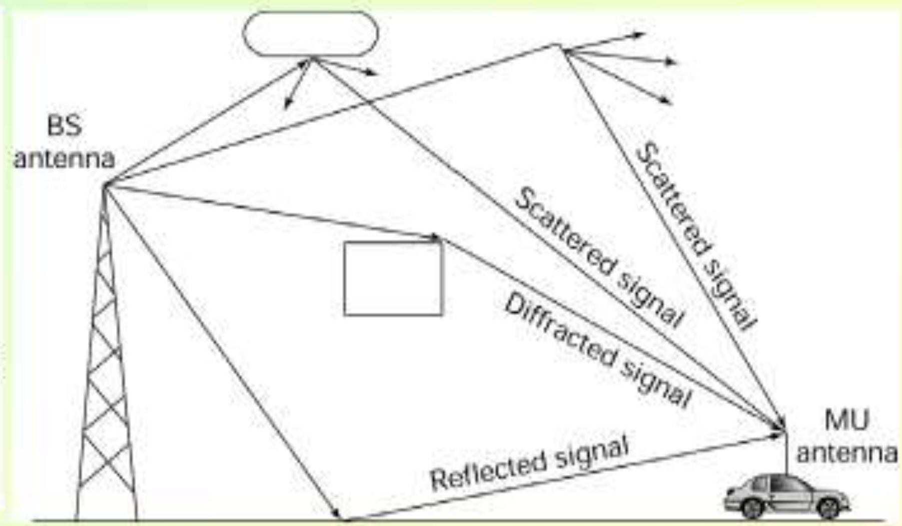


Propagation Model - Mechanisms

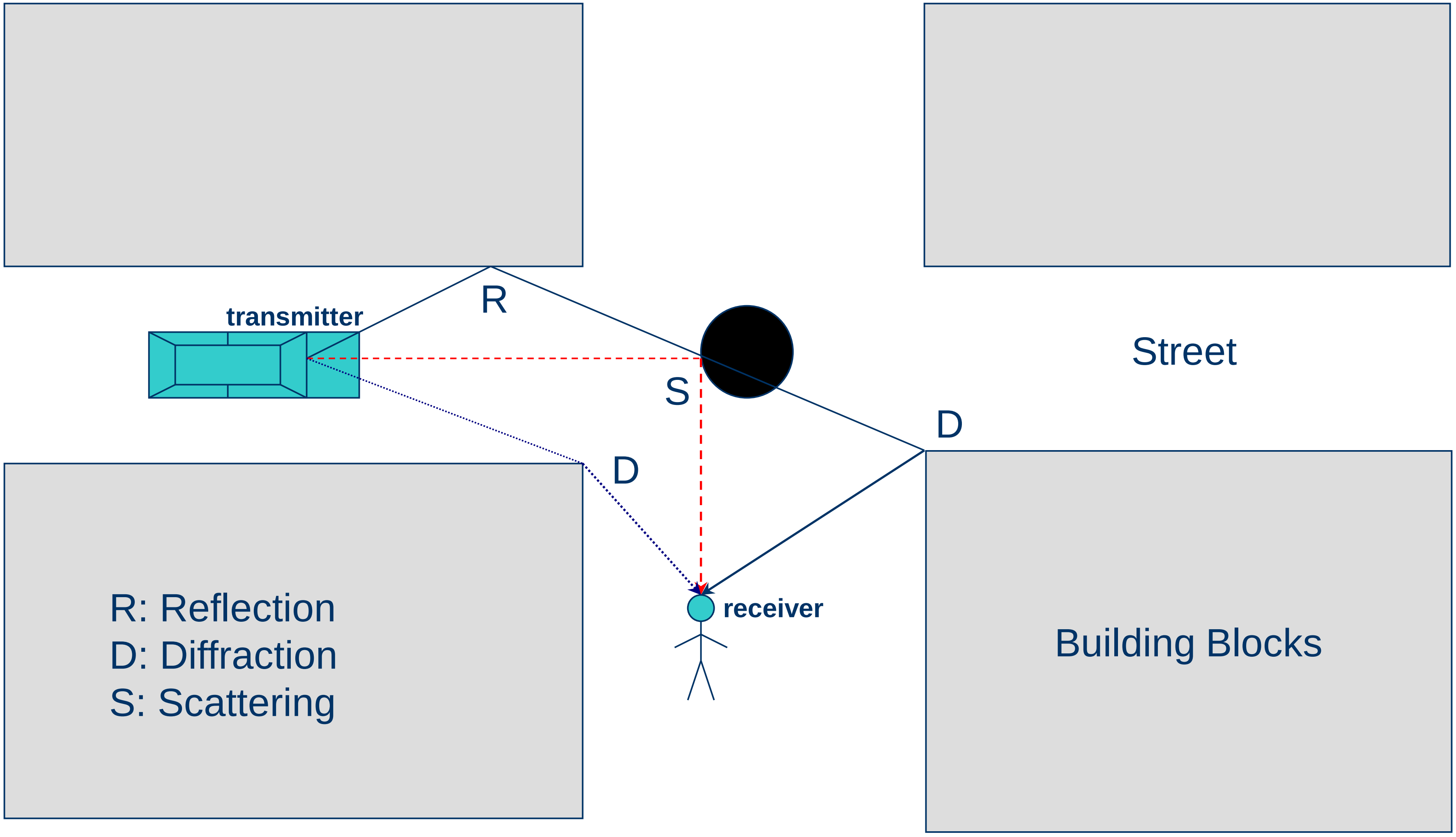
- Reflection
- Diffraction
- Scattering





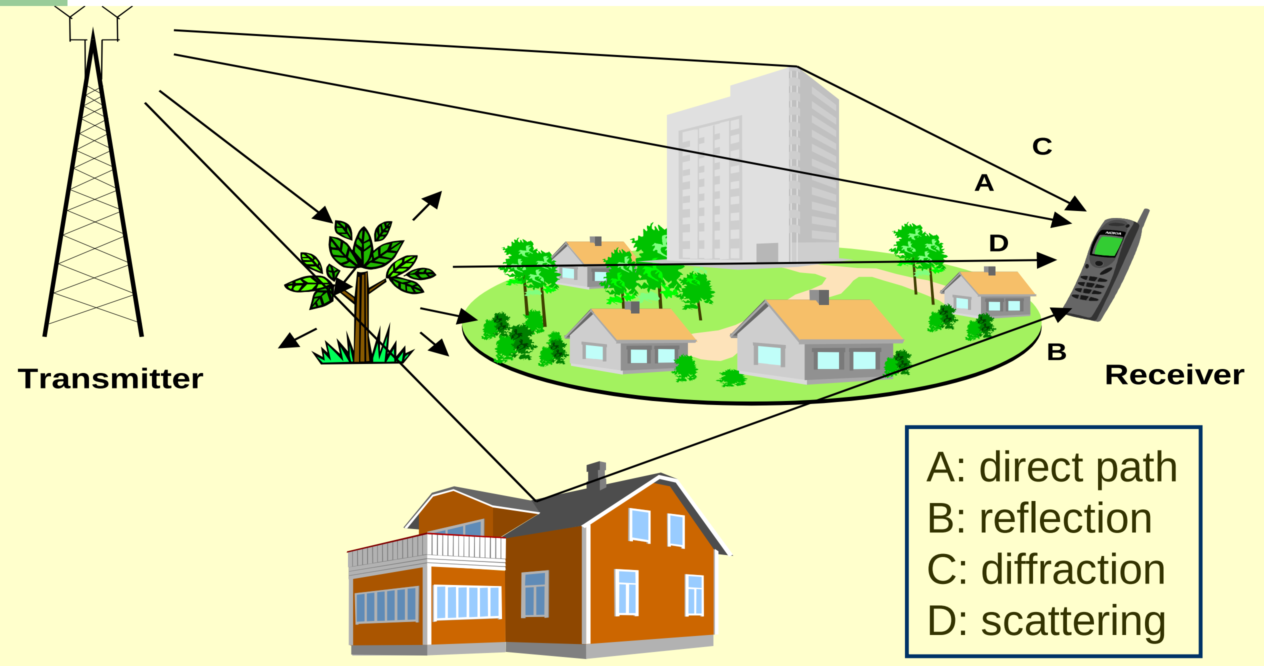


Radio Propagation Mechanisms

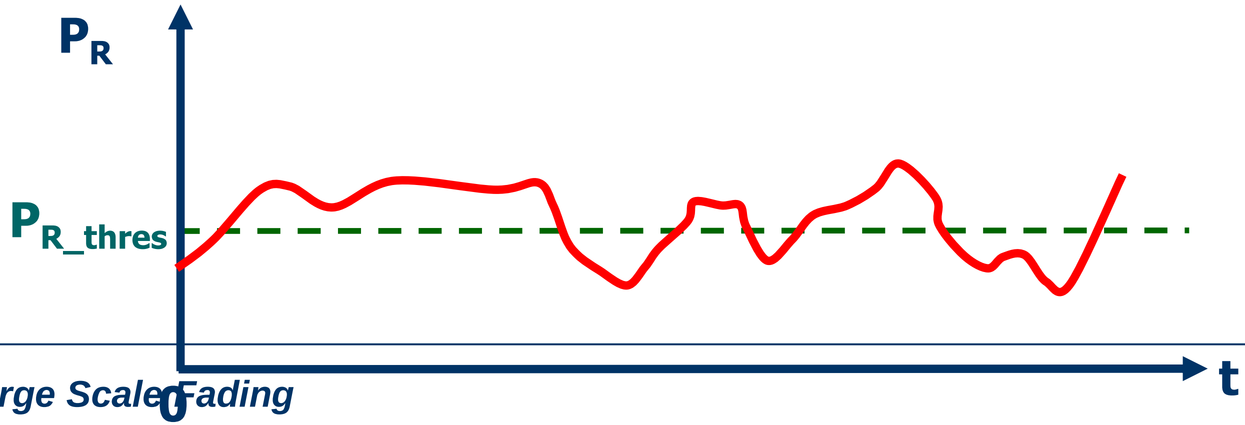


KANAL MULTIPATH FADING

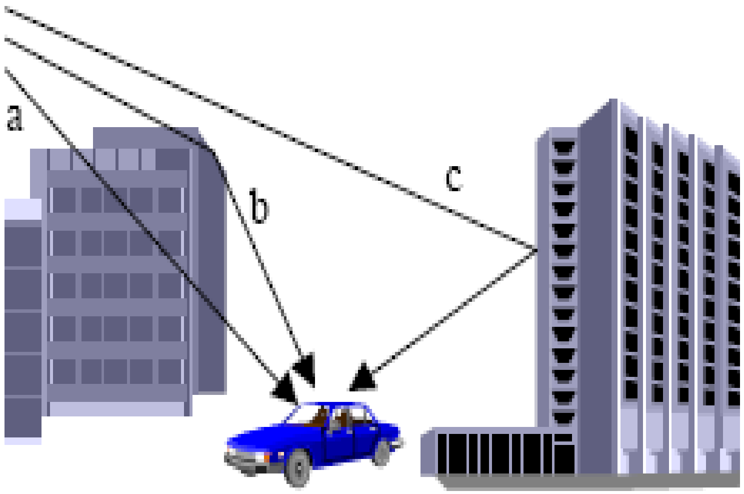
FADING : ***Fenomena fluktuasi daya sinyal terima akibat adanya proses propagasi dari gelombang radio.***

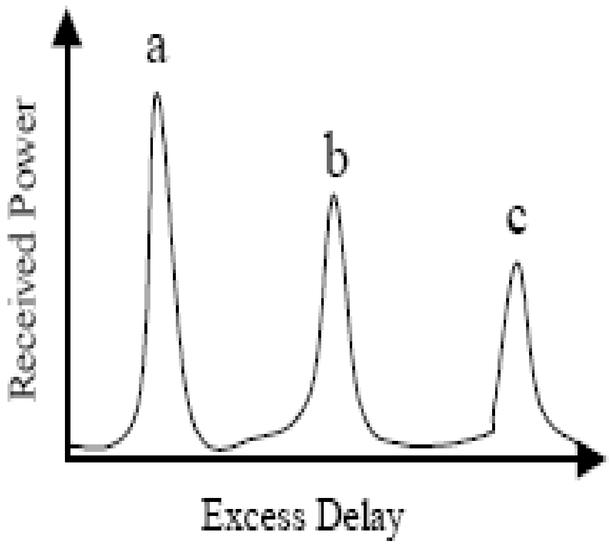


Pengaruh fading terhadap level sinyal terima adalah dapat menguatkan ataupun melemahkan tergantung phasa dari sinyal resultan masing-masing path.



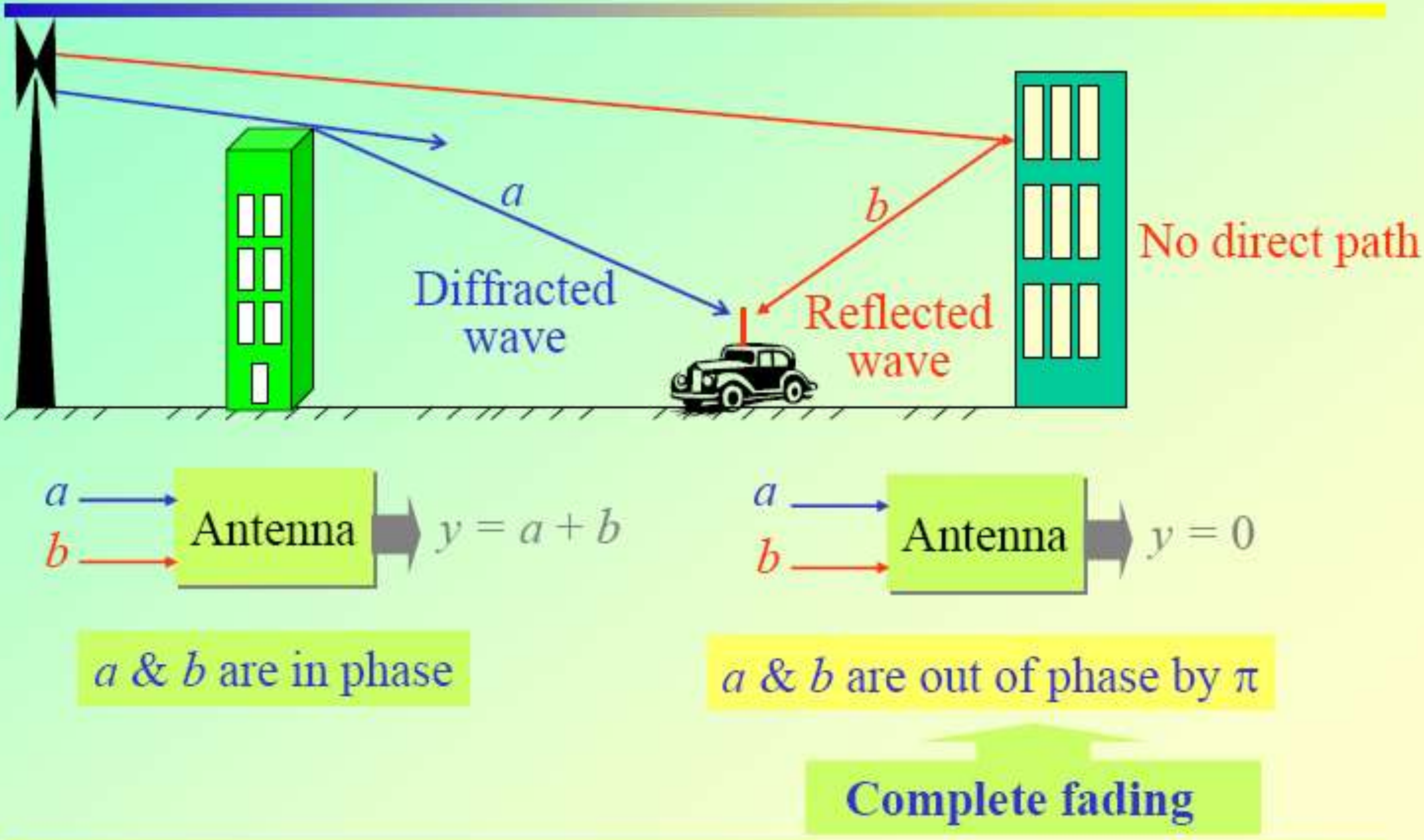
The Multipath Environment





- The received signal is made up of a sum of attenuated, phase-shifted and time delayed versions of the transmitted signal.
- Propagation modes include diffraction, transmission and reflection.

Multipath Propagation - Fading



Multipath Fading , atau *Short Term Fading*

Lingkungan kanal radio mobile (*indoor / outdoor*) seringkali tidak terdapat lintasan gelombang langsung antara Tx dan Rx, sedemikian daya terima adalah superposisi dari banyak komponen gelombang pantul masing-masing memiliki amplitudo dan fasa saling independen

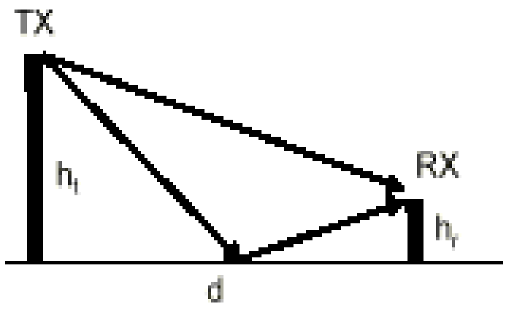
Multipath dalam kanal radio menyebabkan :

- **Perubahan yang cepat** dari amplituda kuat sinyal
- **Modulasi frekuensi random** berkaitan dengan efek Doppler pada sinyal multipath yang berbeda-beda
- **Dispersi waktu (echo)** yang disebabkan oleh delay propagasi multipath

Introduction

Plain Earth Propagation Model…. (Egli's Model)

- As the basic theory of wave trajectory analysis in mobile communication
- Key words: there are multiple paths (multipath): 1 direct wave and a wave reflection.
- Analysis of the signal path in mobile communications is much different from the LOS microwave communications because signals have diffraction, much obstructed, and a lot of reflection.



Empirical Model….

- Derived from measurements and intensive research in an area
- Attenuation curves are plotted and the results made formulations
- Popular attenuation formula : **Okumura-Hata, dan Walfish Ikegami**
- Another path attenuation models developed by: **Lee, Egli, Carey, Longley-Rice, Ibrahim-Parson,** etc

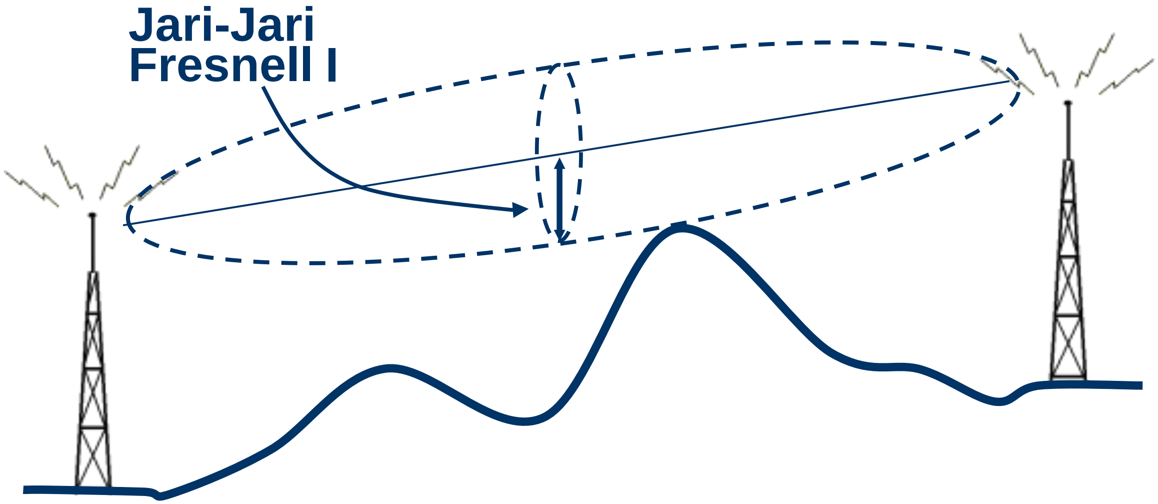
1. Pendahuluan

Komunikasi Gelombang Mikro dan Satelit….

- Rumus **Transmisi Friis,**

$$L_P = 32{,}45 + 20\log f_{(MHz)} + 20\log D_{(Km)}$$

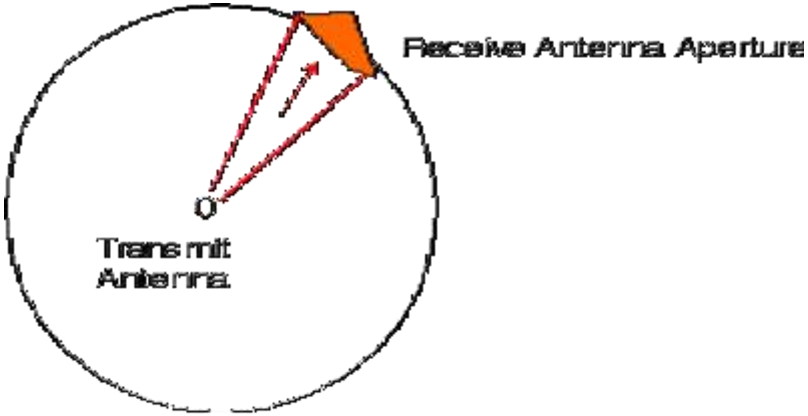
- **Asumsi :** hanya ada 1 gelombang langsung dari pengirim ke penerima
- Perencanaan link dibuat dengan menjaga agar daerah Fresnell I (R_1) bebas dari penghalang dengan cara meninggikan menara pemancar dan penerima



$$R_1 = \frac{4h_1h_2}{\lambda}$$

Free Space Prop. Model

- *Isotropic antenna*: power is distributed homogeneously over surface area of a sphere.



Received power is power through effective antenna surface over total surface area of a sphere of radius *d*

(Free Space Prop. Model), continued

The power density w at distance d is

$$w = \frac{P_T}{4\pi d^2}$$

where P_T is the transmit power.

The received power is

$$P_R = \frac{A}{4\pi d^2} P_T$$

with A the `antenna aperture' or the effective receiving surface area.

(Free Space Prop. Model), continued

The antenna gain G_R is related to the aperture A according to

$$G_R = \frac{4\pi A}{\lambda^2}$$

$$P_R = P_T G_R \bullet \frac{\lambda^2}{4\pi} \bullet \frac{1}{4\pi d^2}$$

Thus the received signal power is

$$P_R = P_T G_T G_R \bullet \left(\frac{\lambda}{4\pi d} \right)^2$$

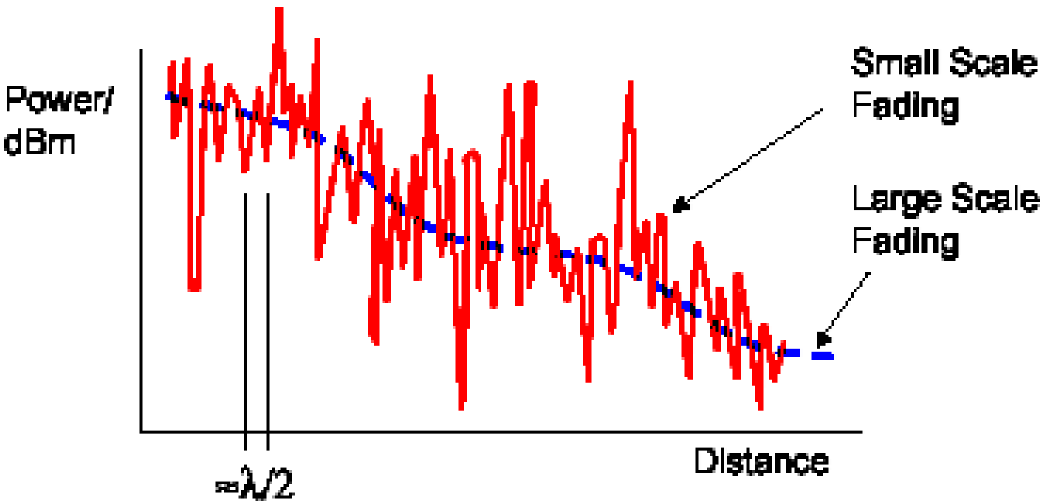
Received power decreases with distance, $P_R :: d^{-2}$
Received power decreases with frequency, $P_R :: f^{-2}$

Cellular radio planning: Path Loss in dB:

L_{fs} = 32.44 + 20 log (f / 1 MHz) + 20 log (d / 1 km)

- **Efek propagasi multipath pada kanal wireless mobile adalah:**
  - Large scale fading → ***Large scale path loss***
  - ***Small scale propagation***
- **<u>Large scale path loss</u>**
  - Large attenuation dalam rata-rata
  - Daya sinyal terima menurun berbanding terbalik dengan pangkat-γ terhadap jarak , dimana umumnya $2 < \gamma < 5$ (untuk komunikasi bergerak). → γ disebut ***Mean Pathloss Exponent***
  - Sebagai dasar untuk metoda prediksi pathloss
- **<u>Small scale</u>**
  - **Flukstuasi sinyal yang cepat disekitar nilai rata-rata (large scale) - nya**
  - Doppler spread berhubungan dengan kecepatan fading (***fading rate***)
  - Penyebaran waktu berhubungan dengan perbedaan delay waktu kedatangan masing-masing sinyal multipath.

Definisi Fading



- Fading didefinisikan sebagai fluktuasi daya di penerima
- Karena perilaku sinyal pada kanal multipath adalah acak, maka analisis fading menggunakan analisis probabilitas stokastik
- Fading terjadi karena interferensi atau superposisi gelombang multipath yang memiliki amplitudo dan fasa yang berbeda-beda

Fading

Large Scale Fading

- Terdistribusi Lognormal

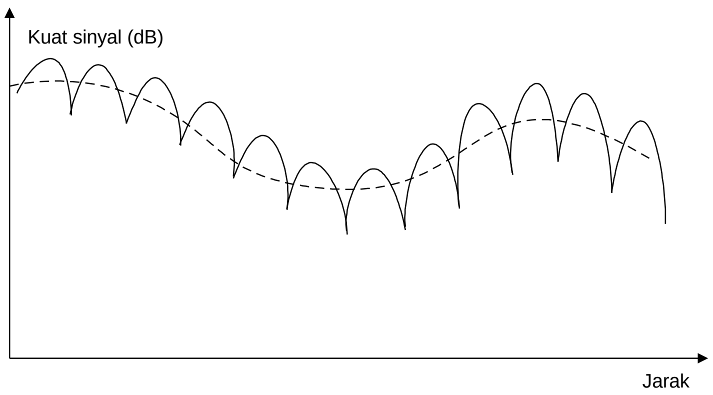
Small Scale Fading

- Terdistribusi Rayleigh / Rician

Large Scale Fading

Large Scale Fading disebabkan karena akibat keberadaan obyek-obyek pemantul serta penghalang pada kanal propagasi serta pengaruh kontur bumi, menghasilkan perubahan sinyal dalam hal energi, fasa, serta delay waktu yang bersifat random.

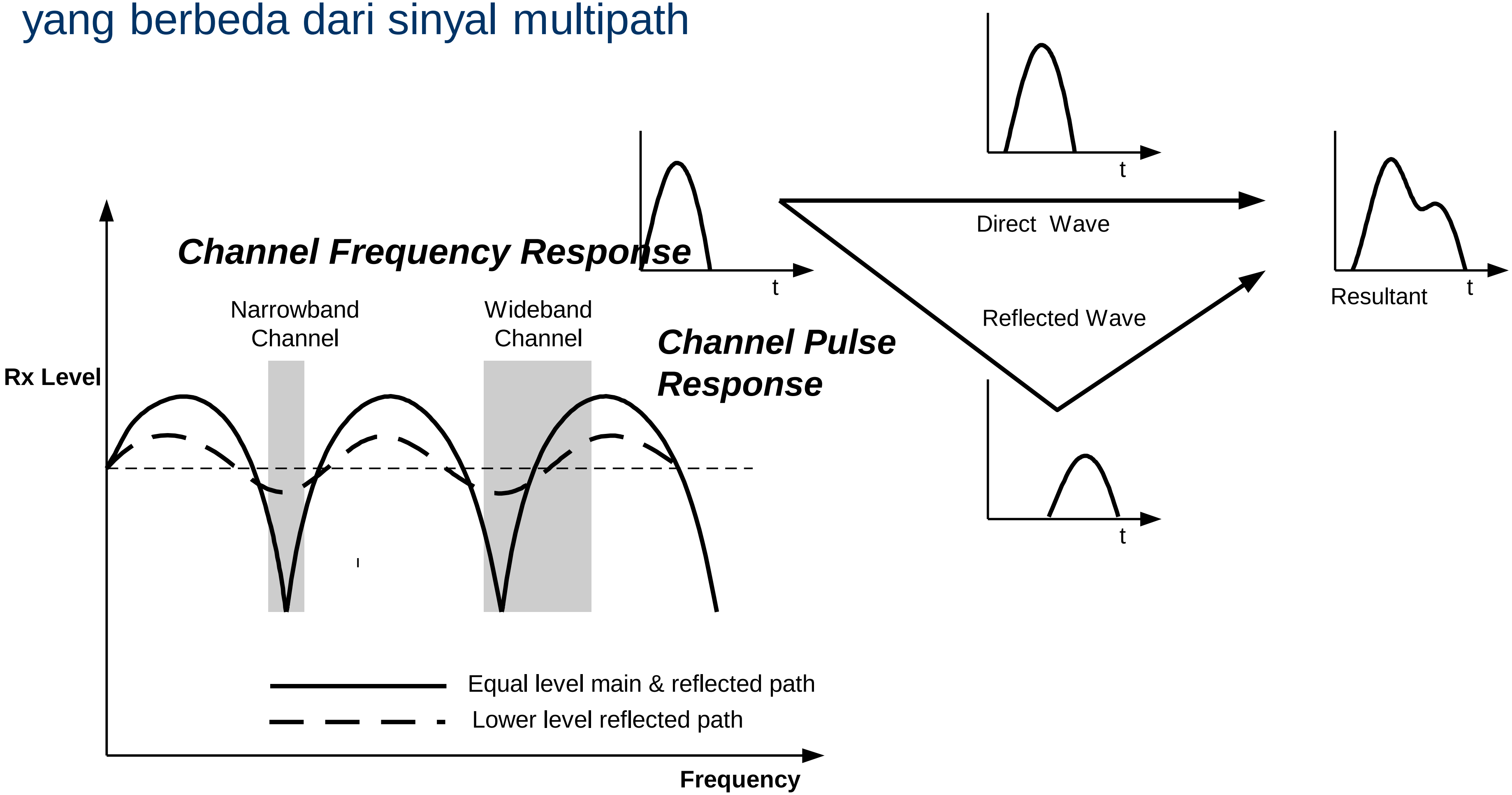
- Sesuai namanya, *large scale fading* memberikan representasi rata-rata daya sinyal terima dalam suatu daerah yang luas.
- Statistik dari *large scale fading* memberikan cara perhitungan untuk estimasi pathloss sebagai fungsi jarak.



Definisi :
local mean (*time averaged*) dari variasi sinyal

Large Scale Fading

Sinyal multipath juga akan menyebabkan distorsi sinyal / cacat sinyal. Problem ini secara khusus berkaitan dengan bandwidth sinyal yang digunakan dalam komunikasi mobile, dan juga karena respon pulsa yang berbeda dari sinyal multipath



Large Scale Fading

Probability Distribution Function (PDF) of a lognormal distributed random variable is represented as follows :

$$p(m) = \frac{1}{\sigma_m \sqrt{2\pi}} e^{-\left[\frac{(m-\overline{m})^2}{2\sigma_m^2}\right]}$$

where

m = normal random variable signal strength(dBm)

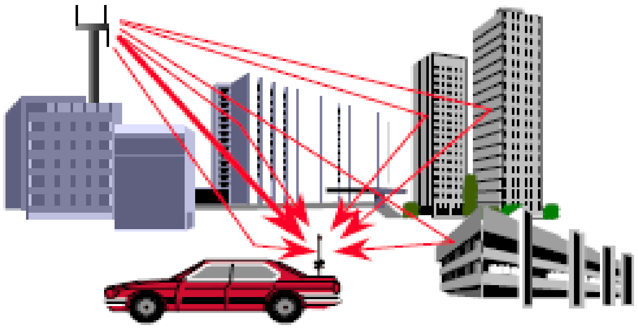
$\overline{m}$ = Average (mean) signal strength (dBm)

σ_m = standard deviation

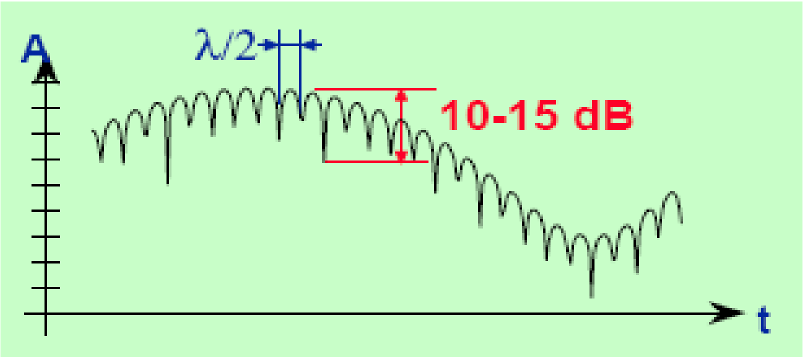
Wireless Propagation Radio

Local Variability: Multipath Effects

Multi-path Propagation

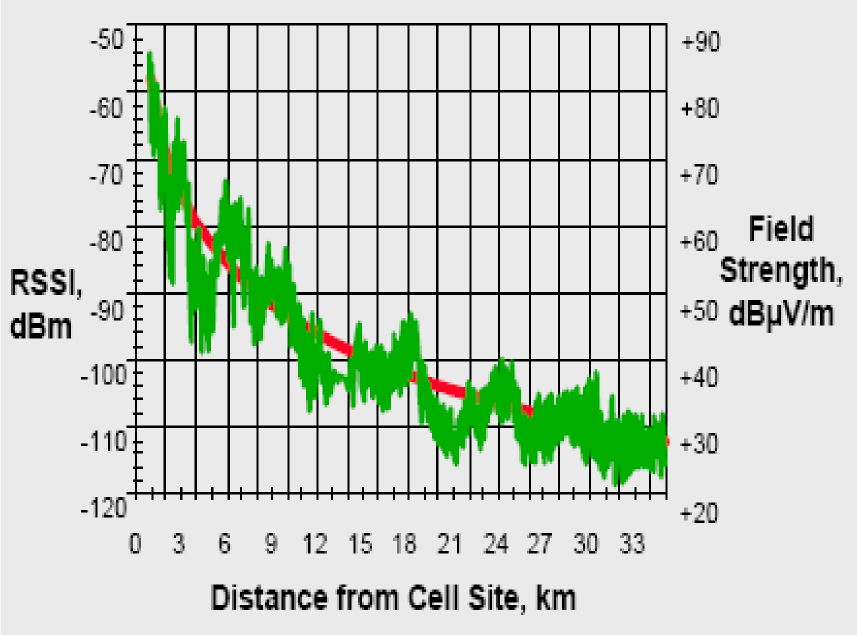


Rayleigh Fading



- The free-space, reflection, and diffraction mechanisms described earlier explain signal level variations on a large scale, but other mechanisms introduce small-scale local fading
- Slow Fading occurs as the user moves over hundreds of wavelengths due to shadowing by local obstructions
- Rapid Fading occurs as signals received from many paths drift into and out of phase
  - the fades are roughly **$\lambda/2$** apart in space:
    - 7 inches apart at 800 MHz., 3 inches apart at 1900 MHz
  - fades also appear in the frequency domain and time domain
  - fades are typically 10-15 db deep, occasionally deeper
  - **Rayleigh distribution** is a good model for these fades
- these fades are often called “Rayleigh fades”

General Principles Of Area Models



- **Green Trace** shows actual measured signal strengths on a drive test radial, as determined by real-world physics.
- **Red Trace** shows the Okumura-Hata prediction for the same radial. The smooth curve is a good "fit" for real data. However, the signal strength at a specific location on the radial may be much higher or much lower than the simple prediction.

- Area models mimic an *average path* in a defined area
- They're based on measured data alone, with no consideration of individual path features or physical mechanisms
- Typical inputs used by model:
  - Frequency
  - Distance from transmitter to receiver
  - Actual or effective base station & mobile heights
  - Average terrain elevation
  - Morphology correction loss (Urban, Suburban, Rural, etc.)
- Results may be quite different than observed on individual paths in the area

Types Of Propagation Models And Their Uses

Examples of various model types

- **Simple Analytical**
  - Free space (Friis formula)
  - Reflection cancellation
  - Knife-edge diffraction
- **Area**
  - Okumura-Hata
  - Euro/Cost-231
  - Walfisch-Betroni/Ikegami
- **Point-to-Point**
  - Ray Tracing
    - Lee's Method, others
  - Tech-Note 101
  - Longley-Rice, Biby-C
- **Local Variability**
  - Rayleigh Distribution
  - Normal Distribution
  - Joint Probability Techniques

- Simple ***Analytical*** models
  - Used for understanding and predicting individual paths and specific obstruction cases
- General ***Area*** models
  - Primary drivers: statistical
  - Used for early system dimensioning (cell counts, etc.)
- ***Point-to-Point*** models
  - Primary drivers: analytical
  - Used for detailed coverage analysis and cell planning
- ***Local Variability*** models
  - Primary drivers: statistical
  - Characterizes microscopic level fluctuations in a given locale, confidence-of-service probability

Semiempirical Model

Practical models are based on combination of measurement and theory. Correction factors are introduced to account for:

- Terrain profile
- Antenna heights
- Building profiles
- Road shape/orientation
- Lakes, etc.

- **Okumura model**
- **Hata model**

Outdoor

- **Saleh model**
- **SIRCIM model**

Indoor

GENERAL AREA MODEL

Karakteristik propagasi pada jaringan bergerak (seluler) berbeda dibandingkan dengan karakteristik propagasi pada jaringan tetap. Pada jaringan bergerak fading yang terjadi lebih hebat dan fluktuatif dibandingkan dengan jaringan tetap.

Untuk menghitung path loss pada propagasi jaringan seluler telah banyak dilaakukan percobaan dan penelitian. Beberapa diantaranya yang sering dipakai adalah

- ***Model Hata***
- ***Model Walfisch-Ikegami (COST-231)***
- ***Model Okumura***
- ***dll***

PROPAGATION MODEL

Macrocells

- In early days, the models were based on emprical studies
- Okumura did comprehesive 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 n is a function of the frequency, antenna heights, etc.
  - Valid for frequencies in: 150 MHz – 1920 MHz
    for distances: 1km – 100km

Okumura Model

- Widely used emprical model (no analytical basis!)
- Predicts average (median) path loss
- "Accurate" within 10-14 dB in urban and suburban areas
- Frequency range: 150 - 1920 MHz
- Distance 1-100 km
- BS antenna height: 30 - 1000 meter
- MU antenna height up to 3m.
- Correction factors are then added.

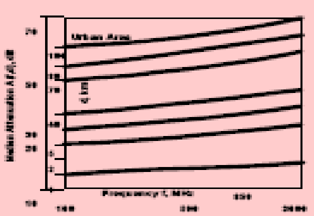
The Okumura Model: General Concept

- The Okumura model is based on detailed analysis of exhaustive drive-test measurements made in Tokyo and its suburbs during the late 1960's and early 1970's. The collected date included measurements on numerous VHF, UHF, and microwave signal sources, both horizontally and vertically polarized, at a wide range of heights.
- The measurements were statistically processed and analyzed with respect to almost every imaginable variable. This analysis was distilled into the curves above, showing a median attenuation relative to free space loss **Amu (f,d)** and correlation factor **Garea (f,area), for** BS antenna height **ht = 200 m** and MS antenna height **hr = 3 m.**
- **Okumura has served as the basis for high-level design of many existing wireless systems, and has spawned a number of newer models adapted from its basic concepts and numerical parameters.**

Path Loss [dB] = $L_{FS} + A_{mu}(f,d) - G(H_b) - G(H_m) - G_{area}$

Free-Space Path Loss

$A_{mu}(f,d)$ Additional Median Loss from Okumura's Curves

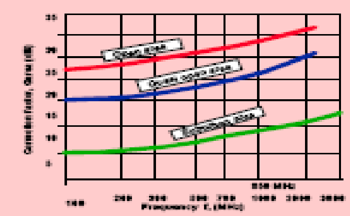


Base Station Height Gain = 20 x Log (H_b/200)

Mobile Station Height Gain = 10 x Log (H_m/3)

Morphology Gain

0 dense urban
5 urban
10 suburban
17 rural



Okumura Model

- $L_{50}(d)(dB) = L_F(d) + A_{mu}(f,d) – G(h_{te}) – G(h_{re}) – G_{AREA}$
  - **L_{50}: 50th percentile (i.e., median) of path loss**
  - **$L_F(d)$: free space propagation pathloss.**
  - **$A_{mu}(f,d)$: median attenuation relative to free space**
    - **Can be obtained from Okumura's emprical plots shown in the book (Rappaport), page 151.**
  - **$G(h_{te})$: base station antenna heigh gain factor**
  - **$G(h_{re})$: mobile antenna height gain factor**
  - **G_{AREA}: gain due to type of environment**

    - **$G(h_{te}) = 20\log(h_{te}/200)$ 1000m > h_{te} > 30m**
    - **$G(h_{re}) = 10\log(h_{re}/3)$ h_{re} <= 3m**
    - **$G(h_{re}) = 20\log(h_{re}/3)$ 10m > h_{re} > 3m**
      - **h_{te}: transmitter antenna height**
      - **h_{re}: receiver antenna height**

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

Path Loss in dB:

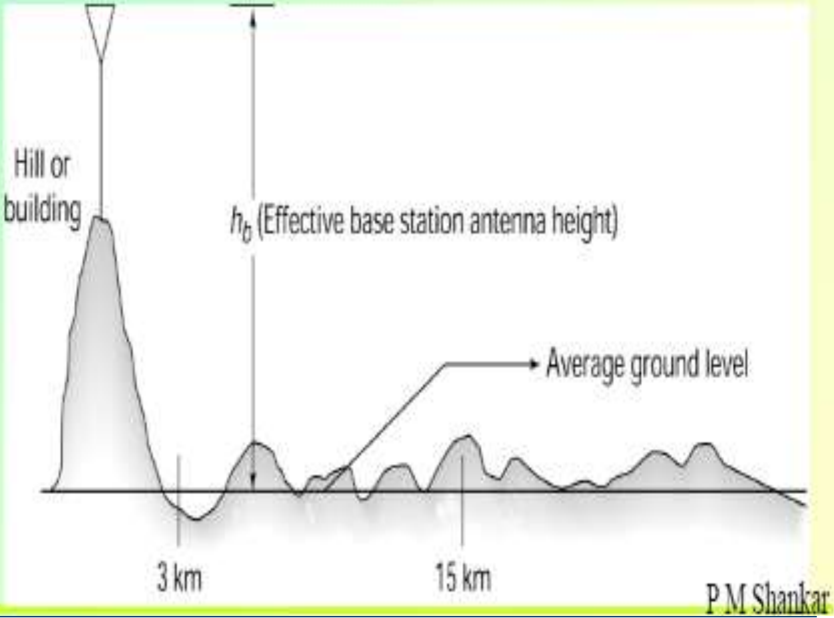
Lfs = 32.44 + 20 log *f* (MHz) + 20 log *d* (km)

Hata Model

- Consolidate Okumura's model in standard formulas for **macrocells** in urban, suburban and open rural areas.
- Empirically derived correction factors are incorporated into the standard formula to account for:
  - Terrain profile
  - Antenna heights
  - Building profiles
  - Street shape/orientation
  - Lakes
  - Etc.

Hata Model – *contd.*

- The loss is given in terms of effective heights.
- The starting point is an urban area. The BS antennae is mounted on tall buildings. The effective height is then estimated at 3 - 15 km from the base of the antennae.



The Hata Model: General Concept

- The *Hata* model is an empirical formula for propagation loss derived from *Okumura's* model, to facilitate automatic calculation.
- The propagation loss in an urban area is presented in a simple general format **A + B x log R**, where **A** and **B** are functions of frequency and antenna height, **R** is distance between BS and MS antennas
- The model is applicable to frequencies **150 MHz-1500 MHz**, distances **1-20 km**, BS antenna heights **30-200 m**, MS antenna heights **1-10 m**
- The model is simplified due to following limitations:
  - Isotropic antennas
  - Quasi-smooth (not irregular) terrain
  - Urban area propagation loss is presented as the **standard** formula
  - Correction equations are used for other areas
- Although Hata model does not imply *path-specific corrections*, it has significant practical value and provide predictions which are very closely comparable with Okumura's model

Hatta Model

- Valid from 150MHz to 1500MHz
- A standard formula
- For urban areas the formula is:

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

  where

  f_c is the ferquency in MHz

  h_{te} is effective transmitter antenna height in meters (30-200m)

  h_{re} is effective receiver antenna height in meters (1-10m)

  d is T-R separation in km

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

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

  for a small to medium sized city

Hata Model General Concept and Formulas

(1) L_{HATA} *(urban)* [*dB*] $= 69.55 + 26.16 \times \log(f) + [44.9 - 6.55 \times \log(h_b)] \times \log(d) - 13.82 \times \log(h_b) - A(h_m)$

(2) L_{HATA} *(suburban)* [*dB*] $= L_{HATA}(urban) - 2 \times [\log(f/28)]^2 - 5.4$

(3) L_{HATA} *(rural)* [*dB*] $= L_{HATA}(urban) - 4.78 \times [\log(f)]^2 + 18.33 \times \log(f) - 40.94$

(4) $A(h_m)$ [*dB*] $= [1,1 \times \log(f) - 0.7] \times h_m - [1.56 \times \log(f) - 0.8]$

(5) $A(h_m)$ [*dB*] $= 8.29 \times [\log(1.54 \times h_m)]^2 - 1.1$ (for f<= 300 MHz.)

(6) $A(h_m)$ [*dB*] $= 3.2 \times [\log(11,75 \times h_m)]^2 - 4.97$ (for f > 300 MHz.)

f - carrier frequency, MHz

h_b and h_m - BS and MS antenna heights, m

d - distance between BS and MS antennas, km

Formulas for median path loss are:

- (1) - Standard formula for urban areas
- (2) - For suburban areas
- (3) - For rural areas

Formulas for MS antenna ht. gain correction factor A(hm)

- (4) - For a small to medium sizes cities
- (5) and (6) - For large cities

Environmental Factor C	
0	dense urban
-5	urban
-10	suburban
-17	rural

Prediction Model COST-231 (PCS Extension Hata Model)

Merupakan formula pengembangan rumus Okumura Hata untuk frekuensi PCS (2GHz)

$$L_u = 46{,}3 + 33{,}9\log f_c - 13{,}82\log h_T - a(h_R) + (44{,}9 - 6{,}55\log h_T)\log d + C_M$$

dimana , $1500\ \text{MHz} \le f_C \le 2000\ \text{MHz}$

$30\ \text{m} \le h_T \le 200\ \text{m}$,

$1\ \text{m} \le hR \le 10\ \text{m}$

$1 \le d \le 20\ \text{km}$

$a(h_R)$ adalah faktor koreksi antena mobile yang nilainya sebagai berikut :

- **Untuk kota kecil dan menengah,**

  $a(h_R) = (1{,}1 \log f_C - 0{,}7)h_R - (1{,}56 \log f_C - 0{,}8)$ dB

  dimana, $1 \le h_R \le 10$ m

- **Untuk kota besar,**

  $a(h_R) = 8{,}29 (\log 1{,}54h_R)^2 - 1{,}1$ dB $f_C \le 300$ MHz

  $a(h_R) = 3{,}2 (\log 11{,}75h_R)^2 - 4{,}97$ dB $f_C \ge 300$ MHz

dan,

$$CM = \begin{cases} 0\ \text{dB} & \text{untuk kota menengah dan kota suburban} \\ 3\ \text{dB} & \text{untuk pusat kota metropolitan} \end{cases}$$

The EURO COST-231 Model

$$L_{COST}\ (urban)\ [dB] = 46.3 + 33.9 \times \log(f) + [44.9 - 6.55 \times \log(h_b)] \times \log(d) + C_m - 13.82 \times \log(h_b) - A(h_m)$$

The COST-231 model was developed by European **CO**operative for **S**cientific and **T**echnical Research committee. It extends the HATA model to the 1.8-2 GHz. band in anticipation of PCS use.

- COST-231 is applicable for frequencies **1500-2000 MHz**, distances **1-20 km**, BS antenna heights **30-200 m**, MS antenna heights **1-10 m**
- Parameters and variables:
  - **f** is carrier frequency , in MHz
  - **hb** and **hm** are BS and MS antenna heights (m)
  - **d** is BS and MS separation, in km
  - **A(hm)** is MS antenna height correction factor (same as in Hata model)
  - **Cm** is city size correction factor: **Cm=0 dB** for suburbs and **Cm=3 dB** for metropolitan centers

Environmental Factor C	
1900	
-2	dense urban
-5	urban
-10	suburban
-26	rural

Typical Model Results Including Environmental Correction

COST-231/Hata

f =1900 MHz.

	Tower Height, m	EIRP (watts)	C, dB	Range, km
Dense Urban	30	200	0	2.52
Urban	30	200	-5	3.50
Suburban	30	200	-10	4.8
Rural	50	200	-17	10.3

Okumura/Hata

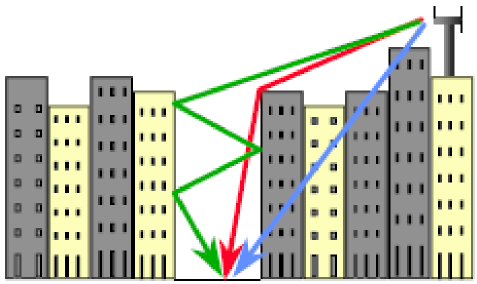
f = 870 MHz.

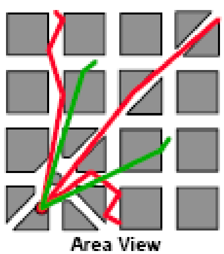
	Tower Height, m	EIRP (watts)	C, dB	Range, km
Dense Urban	30	200	-2	4.0
Urban	30	200	-5	4.9
Suburban	30	200	-10	6.7
Rural	50	200	-26	26.8

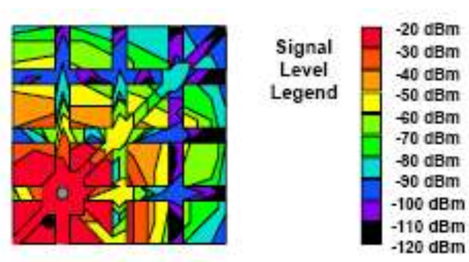
Propagation at 1900 MHz. vs. 800 MHz.

- Propagation at 1900 MHz. is similar to 800 MHz., but all effects are more pronounced.
  - Reflections are more effective
  - Shadows from obstructions are deeper
  - Foliage absorption is more attenuative
  - Penetration into buildings through openings is more effective, but absorbing materials within buildings and their walls attenuate the signal more severely than at 800 MHz.
- The net result of all these effects is to increase the “contrast” of hot and cold signal areas throughout a 1900 MHz. system, compared to what would have been obtained at 800 MHz.
- Overall, coverage radius of a 1900 MHz. BTS is approximately two-thirds the distance which would be obtained with the same ERP, same antenna height, at 800 MHz.

Walfisch-Betroni/Walfisch-Ikegami Models







- Ordinary Okumura-type models do work in this environment, but the Walfisch models attempt to improve accuracy by exploiting the actual propagation mechanisms involved

$$\text{Path Loss} = L_{FS} + L_{RT} + L_{MS}$$

L_{FS} = free space path loss (Friis formula)

L_{RT} = rooftop diffraction loss

L_{MS} = multiscreen reflection loss

- Propagation in built-up portions of cities is dominated by ray *diffraction* over the tops of buildings and by ray *"channeling"* through multiple *reflections* down the street canyons

COST231 Walfish Ikegami Model

Cost231 Walfish Ikegami Model digunakan untuk estimasi pathloss untuk **lingkungan urban** untuk range frekuensi seluler 800 hingga 2000 MHz.

Wallfisch/Ikegami model terdiri dari 3 komponen :

- Free Space Loss (L_f)
- Roof to street diffraction and scatter loss (L_{RTS})
- Multiscreen loss (L_{ms})

$$L_C = \begin{cases} L_f + L_{RTS} + L_{ms} & \\ L_f & ; \text{ untuk } L_{RTS} + L_{ms} \leq 0 \end{cases}$$

- $L_f = 32.4 + 20 \log_{10} R + 20 \log_{10} f_c$ dimana R (km); f_c (MHz)

- $L_{RTS} = -16.9 + 10 \log_{10} W + 20 \log_{10} fc + 20 \log_{10} \Delta hm + L_\Phi$

di mana

$$L_\Phi = \begin{cases} -10 + 0.354\phi & ; \quad 0 \leq \phi \leq 35 \\ 2.5 + 0.075(\phi - 35) & ; 35 \leq \phi \leq 55 \\ 4.0 - 0.114(\phi - 55) & ; 55 \leq \phi \leq 90 \end{cases}$$

COST231 Walfish Ikegami Model

- $L_{ms} = L_{bsh} + k_a + k_d \log_{10} R + k_f \log_{10} f_c - 9 \log_{10} b$

dimana $L_{bsh} = \begin{cases} -18 + \log_{10}(1 + \Delta h_b) & ; h_b < h_r \\ \phi & ; h_b > h_r \end{cases}$

$k_a = \begin{cases} 54 & ; h_b > h_r \\ 54 + 0.8 h_b & ; d \geq 500 \text{ m } h_b < h_r \\ 54 + 0.8\, \Delta h_b \,.\, R & ; 55 \leq \phi \leq 90 \end{cases}$

Catatan : L_{sh} dan k_a meningkatkan path loss untuk h_b yang lebih rendah.

$k_d = \begin{cases} 18 & ; h_b > h_r \\ 18 - 15\,(\Delta h_b / \Delta h_r) & ; h_b \leq h_r \end{cases}$

$k_f = \begin{cases} -4 + 0.7\,(f_c/925 - 1) & \text{; Untuk kota ukuran sedang dan suburban dengan kerapatan pohon cukup moderat} \\ -4 + 1.5\,(f_c/925 - 1) & \text{; Pusat kota metropolitan} \end{cases}$

3. WALFISCH-IKAGEMI (MODEL COST 231)

- Model ini valid ; d ≤ 5km, hb ≤ 50m, micro cell, data base gedung dan jalan yang lengkap

- Pada prinsipnya model ini terdiri dari 3 elemen yaitu :
  - Free Space Loss,
  - Rooftop to Street Diffraction Scatter Loss,
  - Multi Screen Loss, seperti rumus berikut :

$$L_{50} = L_f + L_{rts} + L_{ms}$$

$$L_{50} = L_f \,, \quad \text{jika} \quad L_{rts} + L_{ms} \leq 0$$

L_f = free space loss, Lrts = rooftop to street diffraction & scatter dan L_{ms} = multi screen loss

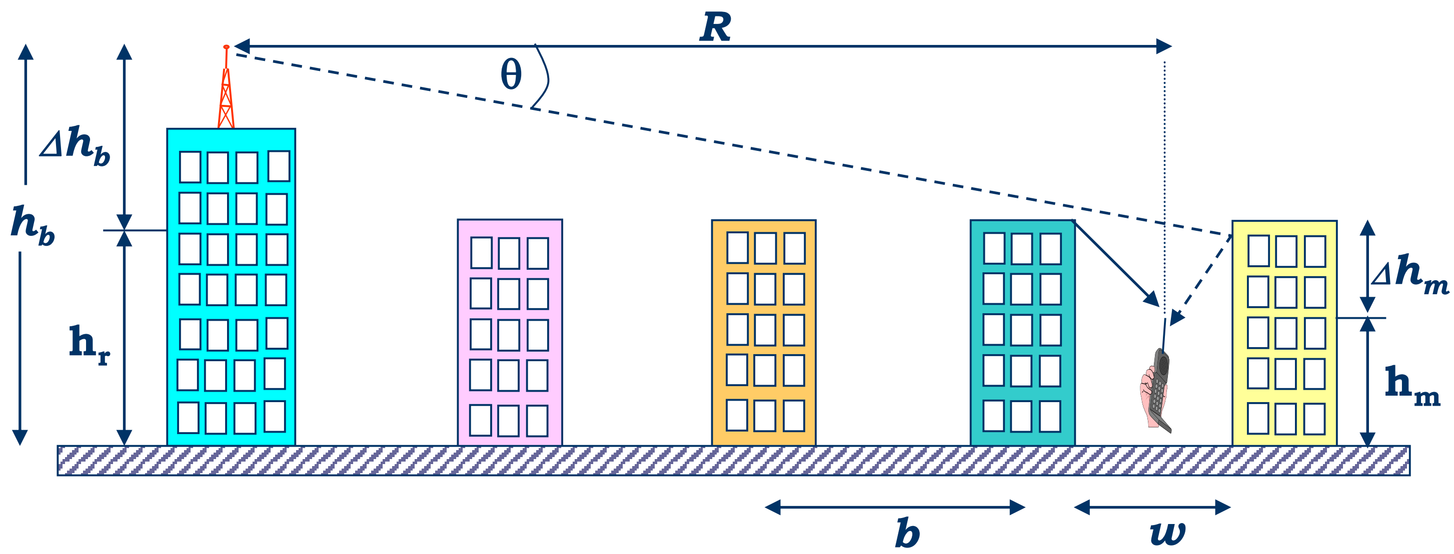
- Seperti disinggung di depan Lf dapat dihitung dengan rumus

$$L_f = 32{,}4 + 20\log r + 20 \log fc \text{ (dB)}$$

❖ L_{rts} dapat dihitung dengan rumus

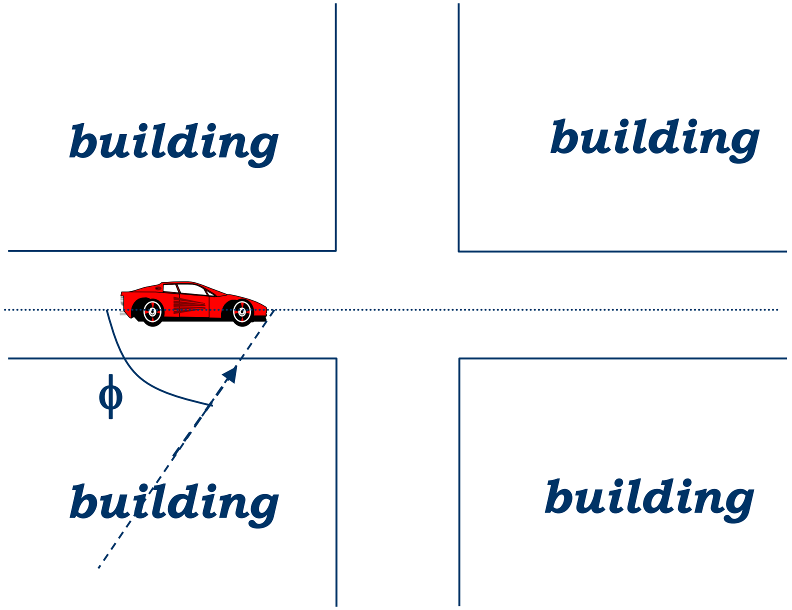
$$L_{rts} = -16{,}9 + 10\log W + 20\log f_c + 20\log \Delta h_m + L_0 \quad \text{(dB)}$$

❖ Variable yang mendukung rumus di atas ditunjukan seperti gambar berikut



W lebar jalan (m) dan $\Delta h_m = h_r - h_m$ (m)

$L_{rst} = 0 \qquad$ jika $\Delta hm \leq 0$



L_0 = -10 +0,354 ϕ dB untuk $0^0 \leq \phi < 35^0$

L_0 = 2,5 + 0,075(ϕ-35) dB untuk $35^0 \leq \phi < 55^0$

L_0 = 4 - 0,114(ϕ-55) dB untuk $55^0 \leq \phi \leq 90^0$

❖ L_{ms} dapat dihitung dengan rumus

$$L_{ms} = L_{bsh} + k_a + k_d \log r + k_f \log f_c - 9\log b \quad (dB)$$

$L_{bsh} = -18\log(1+\Delta h_b)$ **Untuk** $h_b > h_r$

$= \phi$ ***Untuk*** $h_b < h_r$

$K_a = 54$ ***Untuk*** $h_b > h_r$

$K_a = 54 - 0{,}8\ \Delta h_b$ ***Untuk*** $d \geq 500$ m $h_b < h_r$

$K_a = 54 - 1{,}6\ \Delta h_b\ r$ ***Untuk*** $55 \leq \phi \leq 90$

$K_d = 18$ ***Untuk*** $h_b > h_r$

$K_d = 18 - 15\left(\frac{\Delta h_b}{h_r}\right)$ ***Untuk*** $h_b \leq h_r$

$K_f = 4 + 0{,}7\left(\frac{f}{925} - 1\right)$ ***Untuk urban dan suburban***

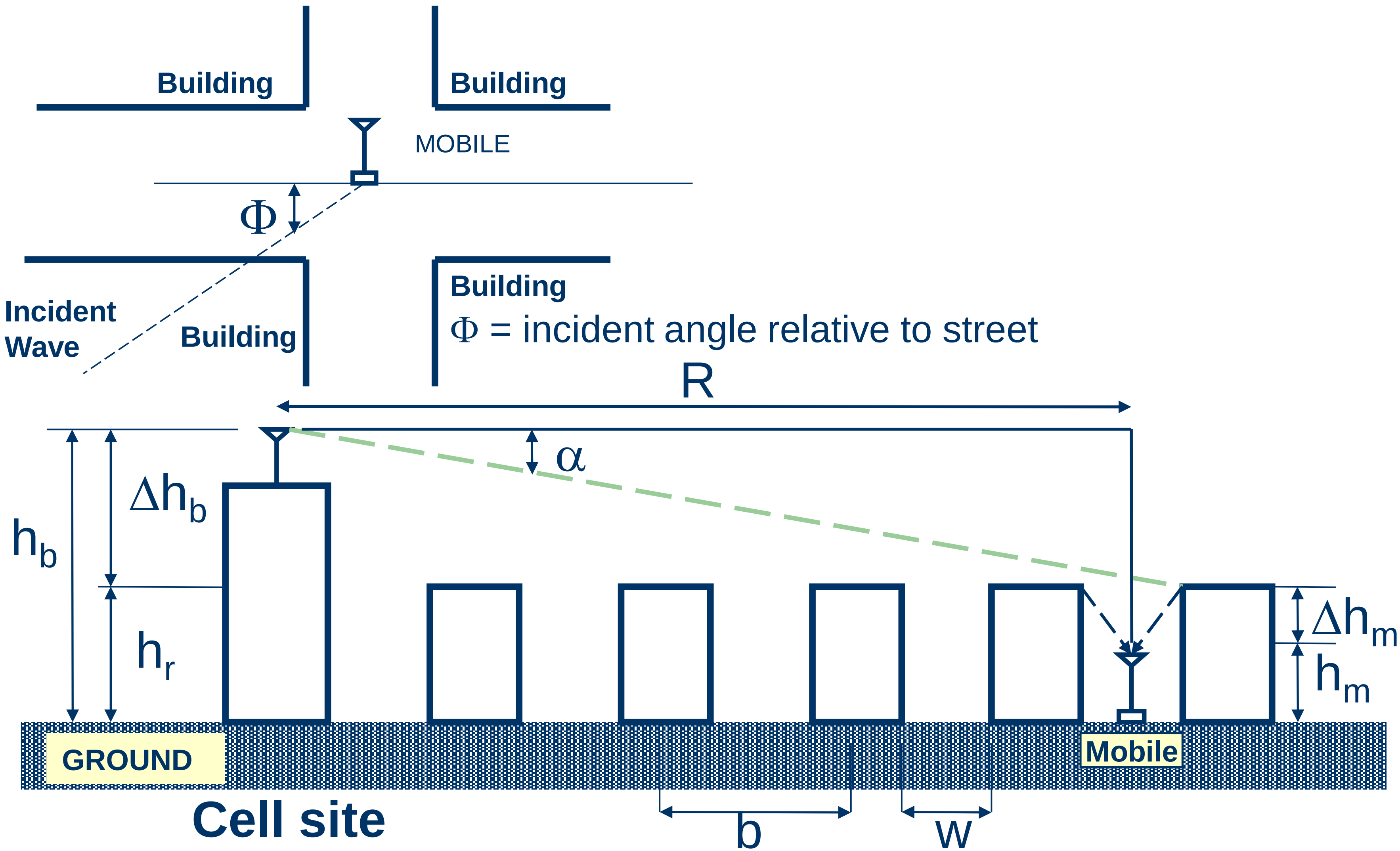
$K_f = 4 + 1{,}5\left(\frac{f}{925} - 1\right)$ ***Untuk dense urban***

Contoh

Tentukan loss propagasi dengan menggunakan model Hata ,COST 231 dan Walfish Ikegami antara BTS dan MS pada daerah dense urban
jika diketahui data-data sbb :

f = 1887 MHz, hm = 1,5 m , hb = 35 m, r = 3km , hr = 15 m
$\phi = 35^0$, b = 30 m, W = 15 m

Diagram Parameter



Cell site

Log Distance Path Loss Model

- **$L\,[dB] = L(d_0) + 10\gamma \log(d/d_0)$**
- **γ from table 3.2 (Rappa, pp 104)**

Environment	Pathloss Exponent
Free Space	2
Urban	2.7 - 3.5
Shadowed Urban	3.0 - 5.0
in building LOS	1.6 - 1.8
in building Obstructed	4.0 - 6.0
in factories Obstructed	2.0 - 3.0

Log-normal Shadowing

- **$L\,[dB] = L\,(d_0) + 10\gamma \log\,(d/d_0) + X_\sigma$**
- Shadowing effect
- + fading margin
- + availability

- **(Rappa, pp 104)**

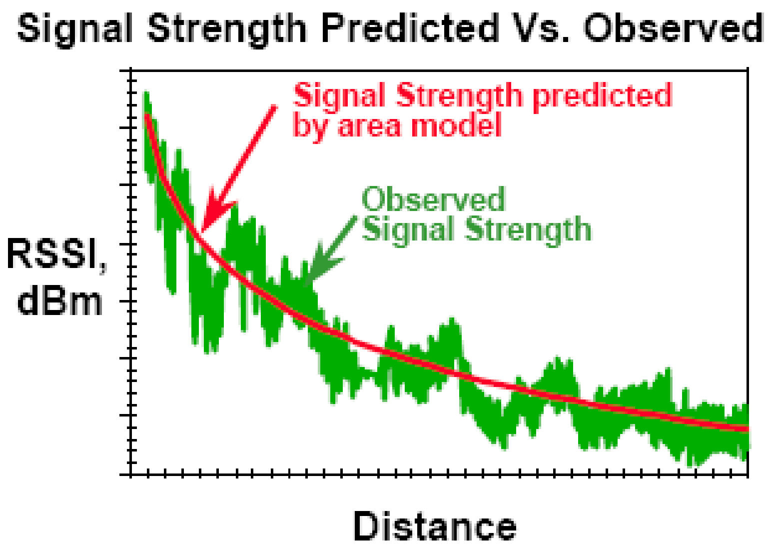
Types Of Propagation Models And Their Uses

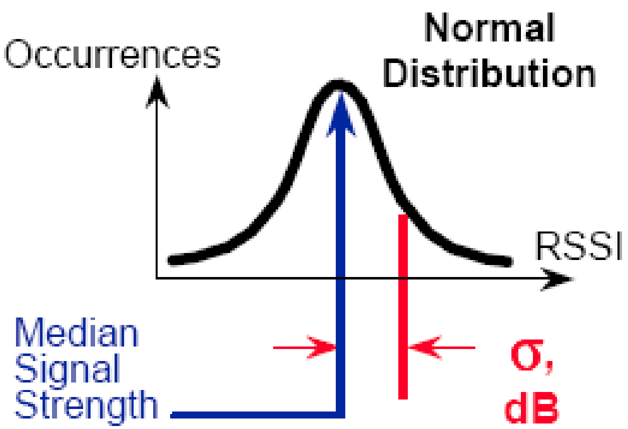
Examples of various model types

- **Simple Analytical**
  - Free space (Friis formula)
  - Reflection cancellation
  - Knife-edge diffraction
- **Area**
  - Okumura-Hata
  - Euro/Cost-231
  - Walfisch-Betroni/Ikegami
- **Point-to-Point**
  - Ray Tracing
    - Lee's Method, others
  - Tech-Note 101
  - Longley-Rice, Biby-C
- **Local Variability**
  - Rayleigh Distribution
  - Normal Distribution
  - Joint Probability Techniques

- Simple ***Analytical*** models
  - Used for understanding and predicting individual paths and specific obstruction cases
- General ***Area*** models
  - Primary drivers: statistical
  - Used for early system dimensioning (cell counts, etc.)
- ***Point-to-Point*** models
  - Primary drivers: analytical
  - Used for detailed coverage analysis and cell planning
- ***Local Variability*** models
  - Primary drivers: statistical
  - Characterizes microscopic level fluctuations in a given locale, confidence-of-service probability

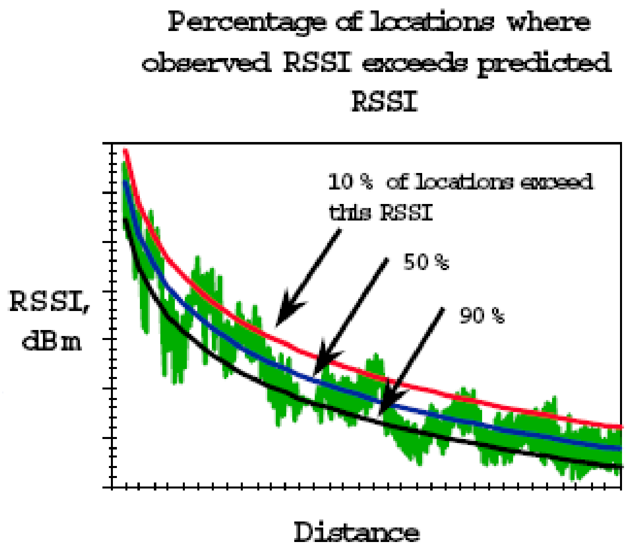
Statistical Techniques
Distribution Statistics Concept

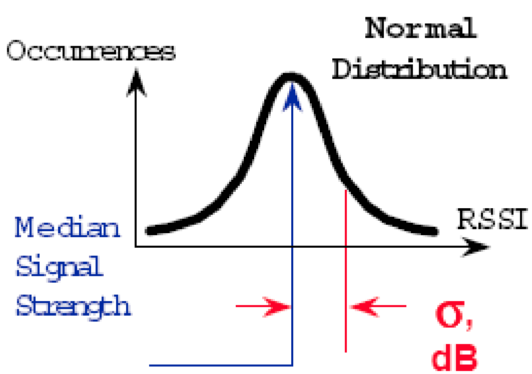




- An area model predicts signal strength Vs. distance over an area
  - This is the *"median"* or most probable signal strength at every distance from the cell
  - The actual signal strength at any real location is determined by local physical effects, and will be higher or lower
  - It is feasible to measure the observed median signal strength **M** and standard deviation **σ**
  - **M** and **σ** can be applied to find probability of receiving an arbitrary signal level at a given distance

Statistical Techniques
Practical Application Of Distribution Statistics





- General Approach:
  - Use a model to predict RSSI
  - Compare measurements with model
    - obtain median signal strength **M**
    - obtain standard deviation **σ**
    - now apply correction factor to obtain field strength required for desired probability of service
- Applications: Given
  - A desired outdoor signal level (dbm)
  - The observed standard deviation **σ** from signal strength measurements
  - A desired percentage of locations which must receive that signal level
  - Compute a “cushion” in dB which will give us that % coverage confidence

Cell Edge
Area Availability And Probability Of Service

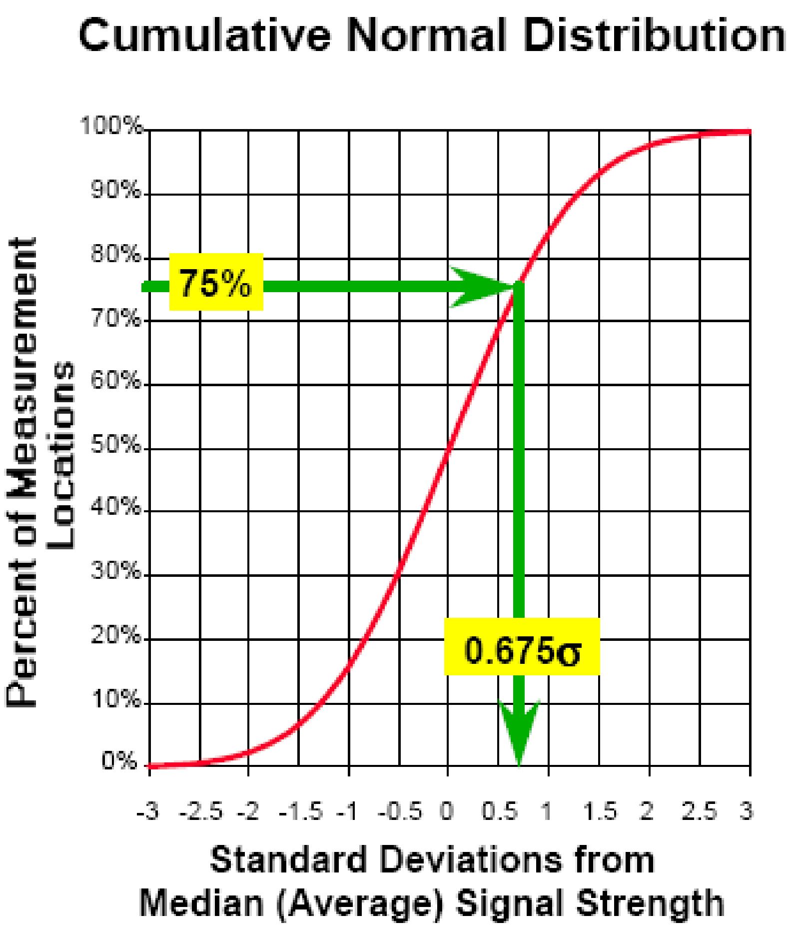
Statistical View of Cell Coverage

Area Availability:
90% overall within area
75%at edge of area

- Overall probability of service is best close to the BTS, and decreases with increasing distance away from BTS
- For overall 90% location probability within cell coverage area, probability will be 75% at cell edge
  - Result derived theoretically, confirmed in modeling with propagation tools, and observed from measurements
  - True if path loss variations are log-normally distributed around predicted median values, as in mobile environment
  - **90%/75%** is a commonly-used wireless numerical *coverage objective*
  - Recent publications by Nortel's Dr. Pete Bernardin describe the relationship between area and edge reliability, and the field measurement techniques necessary to demonstrate an arbitrary degree of coverage reliability

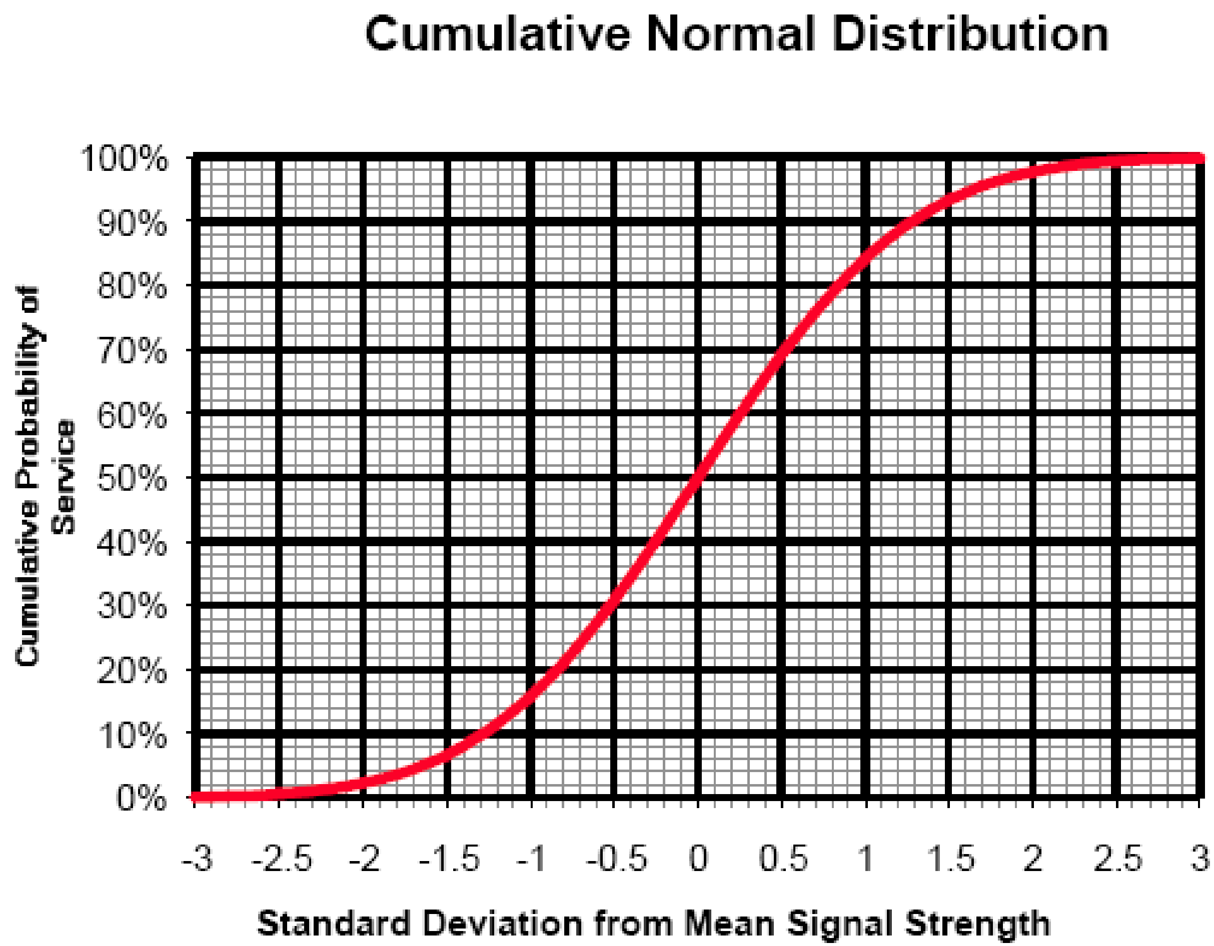
Application Of Distribution Statistics: Example

- Let's design a cell to deliver at least **-95 dBm** to at least **75%** of the locations at the cell edge (*This will provide coverage to 90% of total locations within the cell*)
- Assume that measurements you have made show a **10 dB** standard deviation **σ**
- On the chart:
  - To serve **75%** of locations at the cell edge , we must deliver a median signal strength which is **.675** times **σ** stronger than **-95 dBm**
  - Calculate:
    - 95 dBm + (.675 x 10 dB)
    = - 88 dBm
  - So, design for a median signal strength of **-88 dBm!**



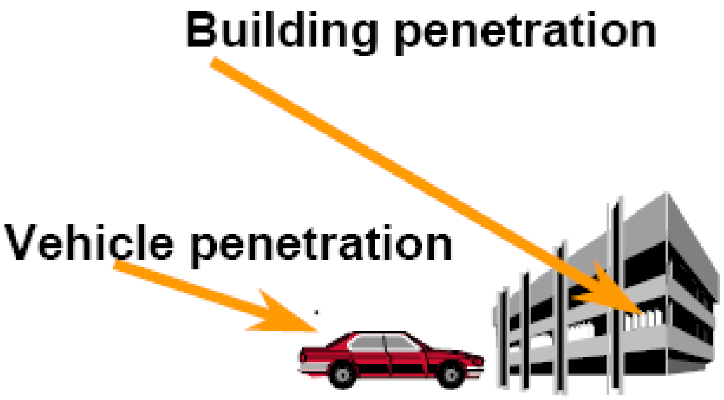
Statistical Techniques:
Normal Distribution Graph & Table For Convenient Reference

Standard Deviation	Cumulative Probability
-3.09	0.1%
-2.32	1%
-1.65	5%
-1.28	10%
-0.84	20%
-0.52	30%
0	50%
0.52	70%
0.675	75%
0.84	80%
1.28	90%
1.65	95%
2.35	99%
3.09	99.9%
3.72	99.99%
4.27	99.999%



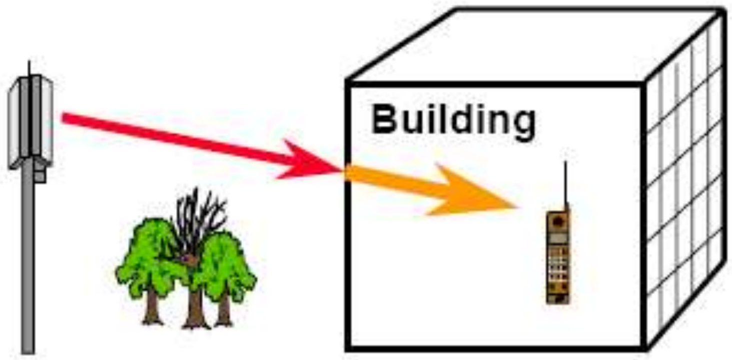
Building Penetration
Statistical Characterization

- Statistical techniques are effective against situations that are difficult to characterize analytically
  - Many analytical parameters, all highly variable and complex
- Building coverage is modeled using existing outdoor *path loss* plus an additional *"building penetration loss"*
  - *Median* value estimated/sampled
  - Statistical *distribution* determined
  - *Standard deviation* estimated or measured
  - Additional *margin* allowed in link budget to offset assumed loss
- Typical values are shown at left



Typical Penetration Losses, dB compared to outdoor street level		
Environment Type ("morphology")	Median Loss, dB	Std. Dev. σ, dB
Dense Urban Bldg.	20	8
Urban Bldg.	15	8
Suburban Bldg.	10	8
Rural Bldg.	10	8
Typical Vehicle	8	4

Composite Probability Of Service
Adding Multiple Attenuating Mechanisms



Outdoor Loss + Penetration Loss

$$\sigma_{COMPOSITE} = ((\sigma_{OUTDOOR})^2+(\sigma_{PENETRATION})^2)^{1/2}$$

$$LOSS_{COMPOSITE} = LOSS_{OUTDOOR}+LOSS_{PENETRATION}$$

- For an in-building user, the actual signal level includes regular outdoor path attenuation plus building penetration loss
- Both outdoor and penetration losses have their own variabilities with their own standard deviations
- The user's overall composite probability of service must include composite median and standard deviation factors

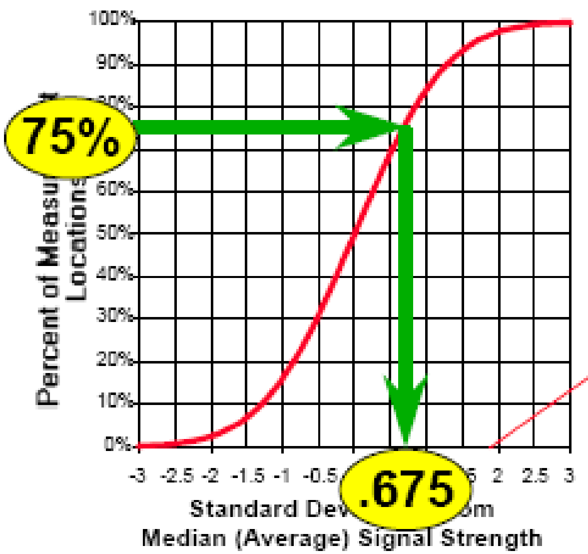
Composite Probability of Service
Calculating Fade Margin For Link Budget

$\sigma_{COMPOSITE} = ((\sigma_{OUTDOOR})^2+(\sigma_{PENETRATION})^2)^{1/2}$

$= ((\mathbf{8})^2+(\mathbf{8})^2)^{1/2} = (\mathbf{64}+64)^{1/2} = (128)^{1/2} = \mathbf{11.31\ dB}$

On cumulative normal distribution curve, 75% probability is 0.675 σ above median.
Fade Margin required =
(11.31) • (0.675) = 7.63 dB.

Cumulative Normal Distribution

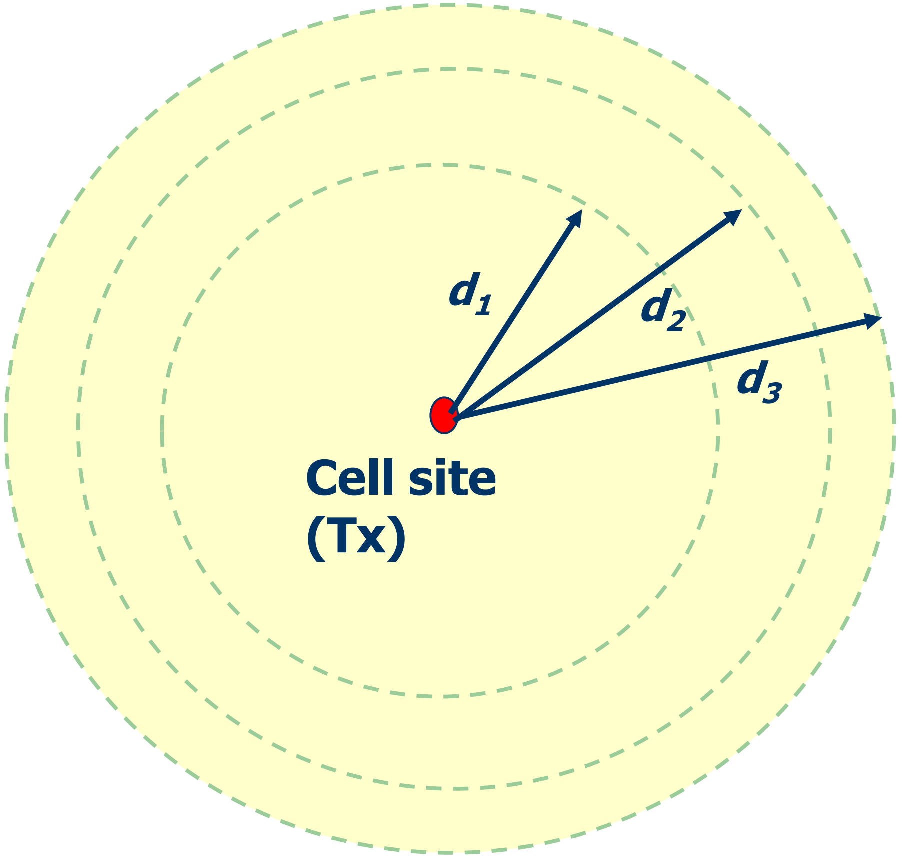


Composite Probability of Service Calculating Required Fade Margin					
Environment Type ("morphology")	Building Penetration		Out-Door	Composite Total	
	Median Loss, dB	Std. Dev. σ, dB	Std. Dev. σ, dB	Area Availability Target, %	Fade Margin dB
Dense Urban Bldg.	20	8	8	90%/75% @edge	7.6
Urban Bldg.	15	8	8	90%/75% @edge	7.6
Suburban Bldg.	10	8	8	90%/75% @edge	7.6
Rural Bldg.	10	8	8	90%/75% @edge	7.6
Typical Vehicle	8	4	8	90%/75% @edge	6.0

- *Example Case*: Outdoor attenuation σ is **8 dB**., and penetration loss σ is **8 dB**. Desired probability of service is **75%** at the cell edge
- What is the composite σ? How much fade margin is required?

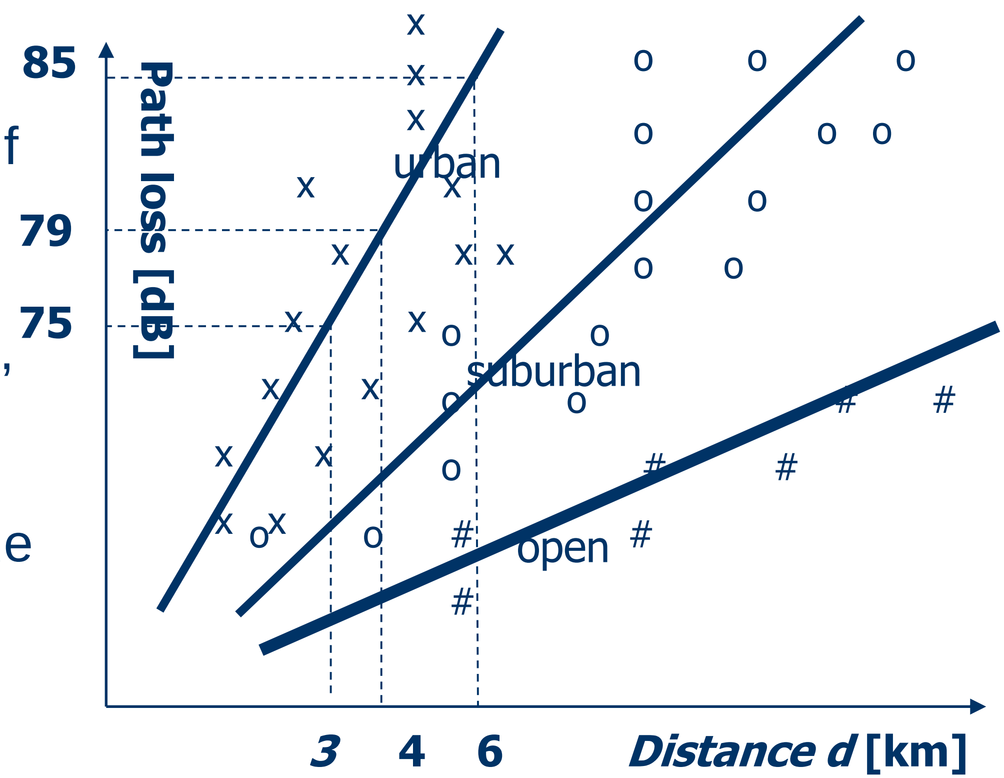
The measurement method with Regression Methods

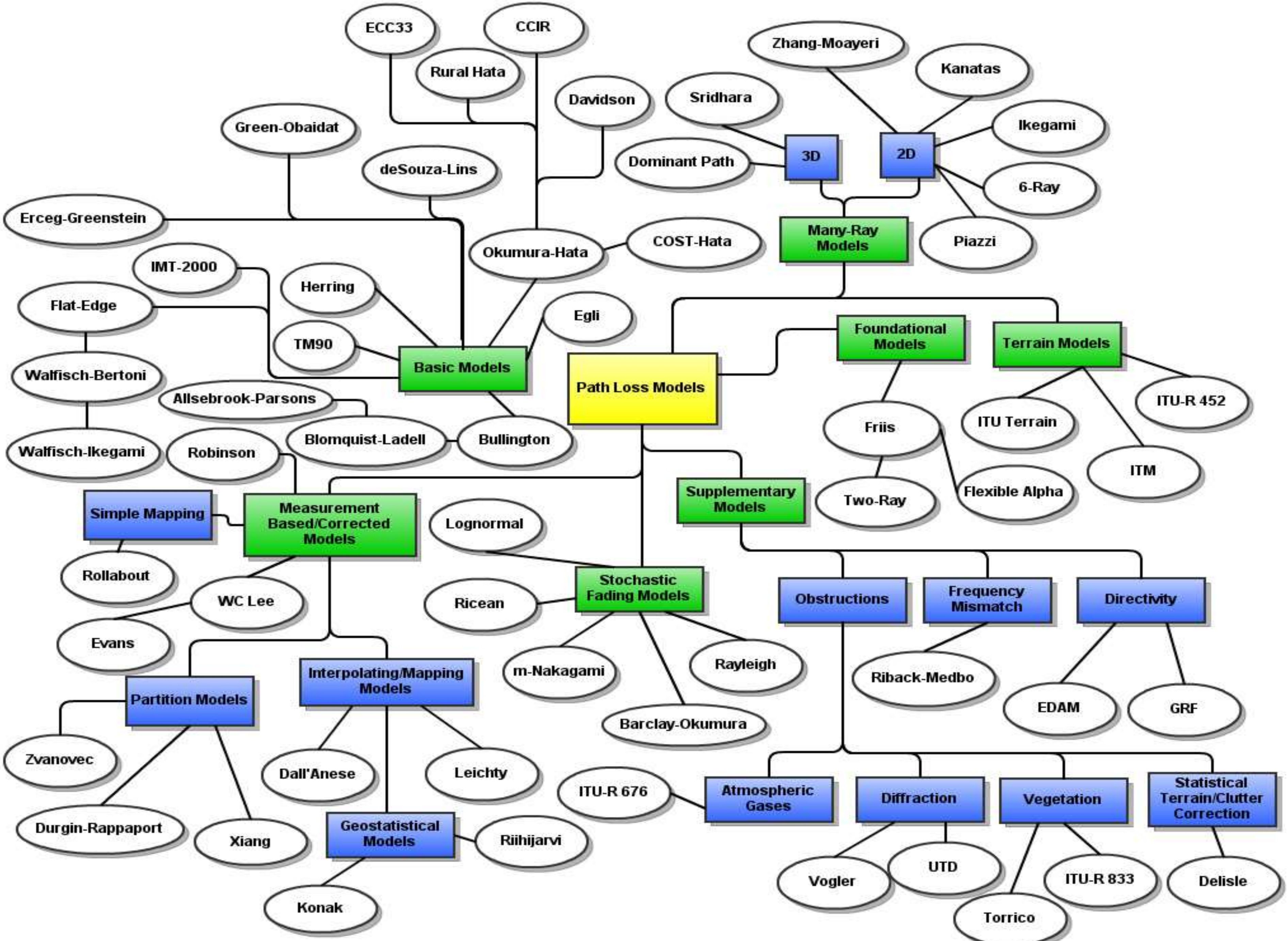
- Select multiple locations at distances d_1 and take the measurement of path loss
- Repeat for the distance d_2 and d_3, etc.
- Plot of the mean pathloss as a function of distance



Getting Mean and Standard Deviation

- Measurement is usually done for some types of areas: Urban, suburban, and open areas
- Measurements at constant radius from the BTS to produce different pathloss
- With the linear regression method, we can obtain the mean pathloss trend and standard deviation around the average value
- Example for urban: path loss
  - → Slope = 33.2 dB / decade and
  - → Std dev. = 7 dB





Path Loss Models
Many-Ray Models
3D
2D
Sridhara
Dominant Path
Zhang-Moayeri
Kanatas
Ikegami
6-Ray
Piazzi
Foundational Models
Friis
Two-Ray
Flexible Alpha
Terrain Models
ITU Terrain
ITM
ITU-R 452
Basic Models
ECC33
CCIR
Rural Hata
Davidson
Green-Obaidat
deSouza-Lins
Erceg-Greenstein
Okumura-Hata
COST-Hata
IMT-2000
Herring
Egli
Flat-Edge
TM90
Walfisch-Bertoni
Walfisch-Ikegami
Allsebrook-Parsons
Blomquist-Ladell
Bullington
Robinson
Measurement Based/Corrected Models
Simple Mapping
Rollabout
WC Lee
Evans
Partition Models
Zvanovec
Durgin-Rappaport
Xiang
Interpolating/Mapping Models
Dall'Anese
Leichty
Geostatistical Models
Riihijarvi
Konak
Stochastic Fading Models
Lognormal
Ricean
m-Nakagami
Rayleigh
Barclay-Okumura
Supplementary Models
Obstructions
Frequency Mismatch
Riback-Medbo
Directivity
EDAM
GRF
Atmospheric Gases
ITU-R 676
Diffraction
Vogler
UTD
Vegetation
Torrico
ITU-R 833
Statistical Terrain/Clutter Correction
Delisle

TABLE I

A priori MODELS STUDIED ALONG WITH THEIR CATEGORIZATION, REQUIRED INPUT, COVERAGE REMARKS, RELEVANT CITATIONS, AND YEAR OF (INITIAL) PUBLICATION.

Name	Short Name	Category	Coverage Notes	Citations	Year
Friis' Freespace	friis	Foundational	$d > 2a^2/\lambda$	[32]	1946
Egli	egli	Basic	$30MHz < f < 3GHz$	[27], [79]	1957
Hata-Okumura	hata	Basic	$1km < d < 10km; 150 <= f <= 1500MHz$ $30 <= h_1 <= 200m; 1 <= h_1 <= 20$	[67]	1968
Edwards-Durkin	edwards	Basic/Terrain		[26], [21]	1969
Allsebrook-Parsons	allsebrook	Basic/Terrain	$f \in 85, 167, 441MHz$; Urban	[3], [21]	1977
Blomquist-Ladell	blomquist	Basic/Terrain		[8], [21]	1977
Longley-Rice Irregular Terrain Model (ITM)	itm	Terrain	$1km < d < 2000km$ $20MHz < f < 20GHz$	[42], [43]	1982
Walfisch-Bertoni	bertoni	Basic		[90]	1988
Flat-Edge	flatedge	Basic		[77]	1991
TM90	tm90	Basic	$d <= 10miles; h_1 <= 300feet$	[17]	1991
COST-231	cost231	Basic	$1km < d < 20km;$	[12]	1993
Walfisch-Ikegami	walfish	Basic	$200m < d < 5km; 800MHz < f < 2GHz;$ $4m < h_b < 50m; 1m < h_m < 3m$	[12], [65], [7]	1993
Two-Ray (Ground Reflection)	two.ray	Foundational		[71], [79], [68]	1994
Hata-Davidson	davidson	Basic	$1km < d < 300km; 150MHz < f < 1.5GHz;$ $30m < h_b < 1500m; 1m < h_m < 20m$	[9], [65]	1997
Oda	oda	Basic		[66]	1997
Erceg-Greenstein	erceg	Basic	$f \approx 1.9GHz$; Suburban	[28]	1998
Directional Gain Reduction Factor (GRF)	grf	Supplementary	Dir. Recv. Ant., $f \approx 1.9GHz$	[36]	1999
Rural Hata	rural.hata	Basic	$f \in 160, 450, 900MHz$; Rural (Lithuania)	[62]	2000
ITU Terrain	itu	Terrain		[79], [48]	2001
Stanford University Interium (SUI)	sui	Basic	$2.5 < f < 2.7GHz$	[29], [2]	2001
Green-Obaidat	green	Basic		[35]	2002
ITU-R	itur	Basic	$1km < d < 10km; 1.5GHz < f < 2GHz;$ $30m < h_b < 200m; 1m < h_m < 10m$	[48], [65]	2002
ECC-33	ecc33	Basic	$1km < d < 10km; 700 <= f <= 3000MHz$ $20 <= h_1 <= 200m; 5 <= h_1 <= 10$	[24], [2]	2003
Riback-Medbo	fc	Supplementary	$460MHz < f < 5.1GHz$	[73]	2006
ITU-R 452	itur452	Terrain		[50]	2007
IMT-2000	imt2000	Basic	Urban	[33]	2007
deSouza	desouza	Basic	$f \approx 2.4GHz; d < 120\,m$	[20]	2008
Effective Directivity Antenna Model (EDAM)	edam	Supplementary	Directional Antennas; $f \approx 2.4GHz$	[5]	2009
Herring Air-to-Ground	herring.atg	Basic	$f \approx 2.4GHz$	[39]	2010
Herring Ground-to-Ground	herring.gtg	Basic	$f \approx 2.4GHz$	[39]	2010