Wireless Communication System

Modul 4
Small Scale Fading : Doppler Effect

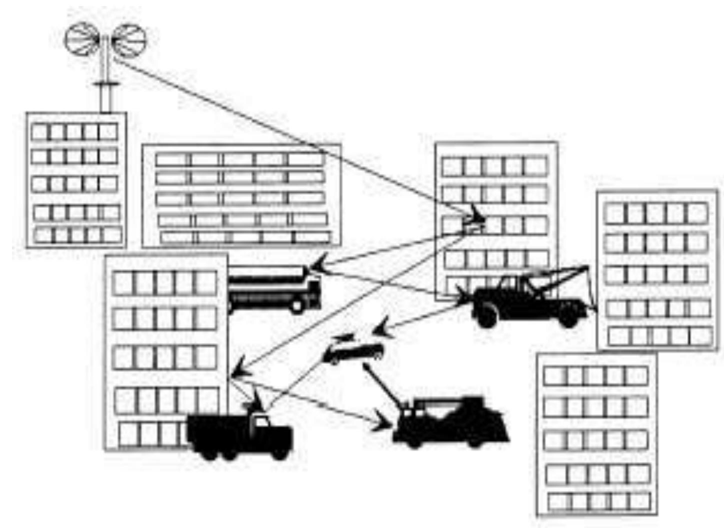
Faculty of Electrical Communication
Bandung - 2020

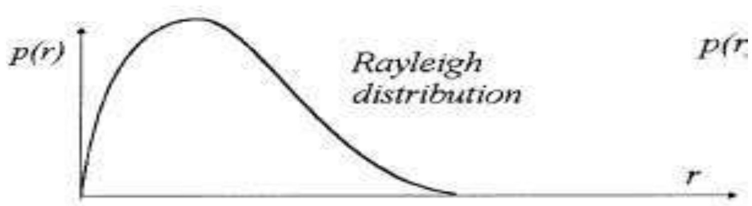
Subject

a. Doppler Effect

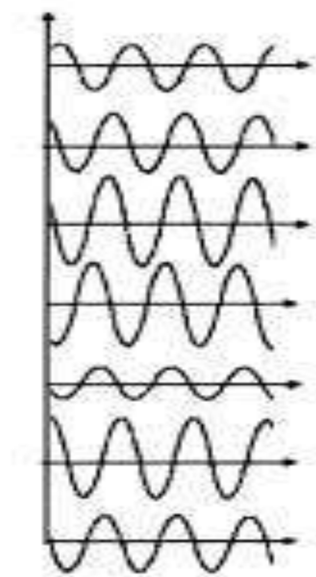
Basic Theory...Small Scale Fading ...
multipath signal analysis

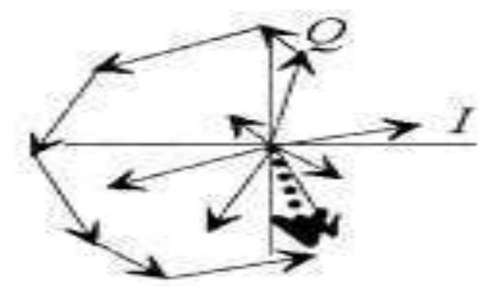
- **Mobile Radio Propagation**
  - The received signal is a sum of real signals that have experience attenuation, reflection, refraction and diffraction according to its path.
  - Mobile station movement
  - Rayleigh Distribution





$$p(r)=\begin{cases}\dfrac{r}{\sigma^2}\exp\left(-\dfrac{r^2}{2\sigma^2}\right) & (0\le r\le\infty)\\ 0 & (r<0)\end{cases}$$

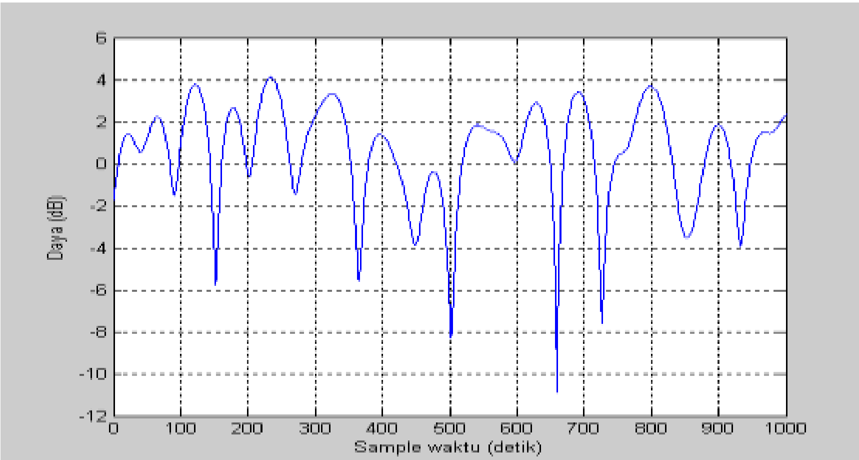




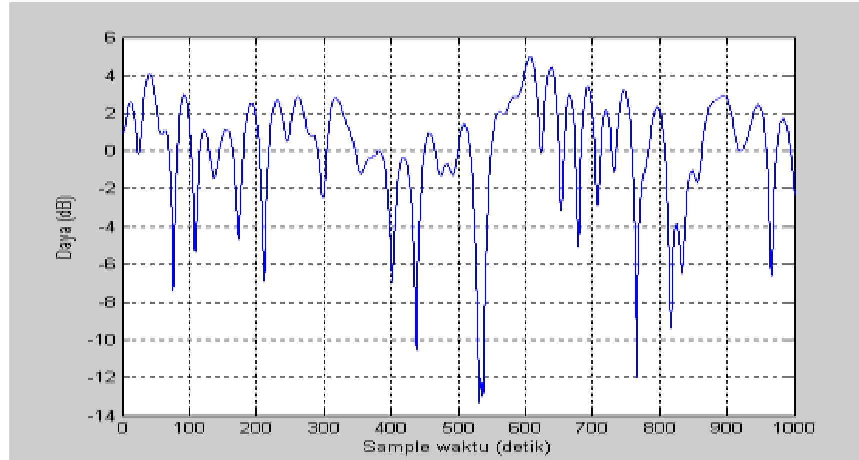
Vector sum of received signals

Simulation Result (1)
Signal Analysis on Rayleigh Channel

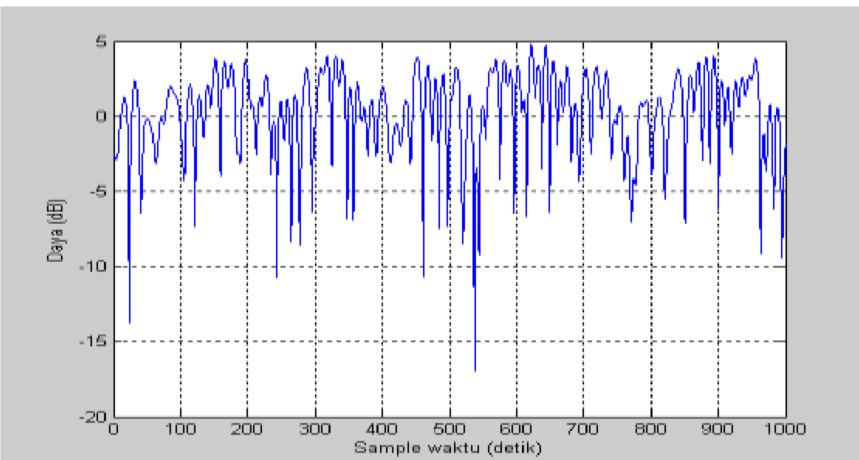
Mobile station speed 5km/hour,fd=4,023Hz



mobile station speed25km/hour, fd=20,27Hz



Mobile station speed 100km/hour, fd=80,52Hz



- **Amplitude fluctuation (Fading) will increase as the mobile station (MS) speed increase, it can be seen as follow:**
  - **MS speed 5km/hour, fd=4,023Hz.**
    Received signal will achieve maximal attenuation 11db, amplitude fluctuation is not occurs many times.
  - **MS speed 25km/hour, fd=20,27Hz.**
    Received signal will achieve maximal attenuation 13dB, amplitude fluctuation is more often than MS 25km/hour.
  - **MS speed 100km/hour, fd=80,52Hz.**
    Maximal attenuation 17dB, amplitude fluctuation is the most often in this three experiment.

Small Scale Multipath Propagation

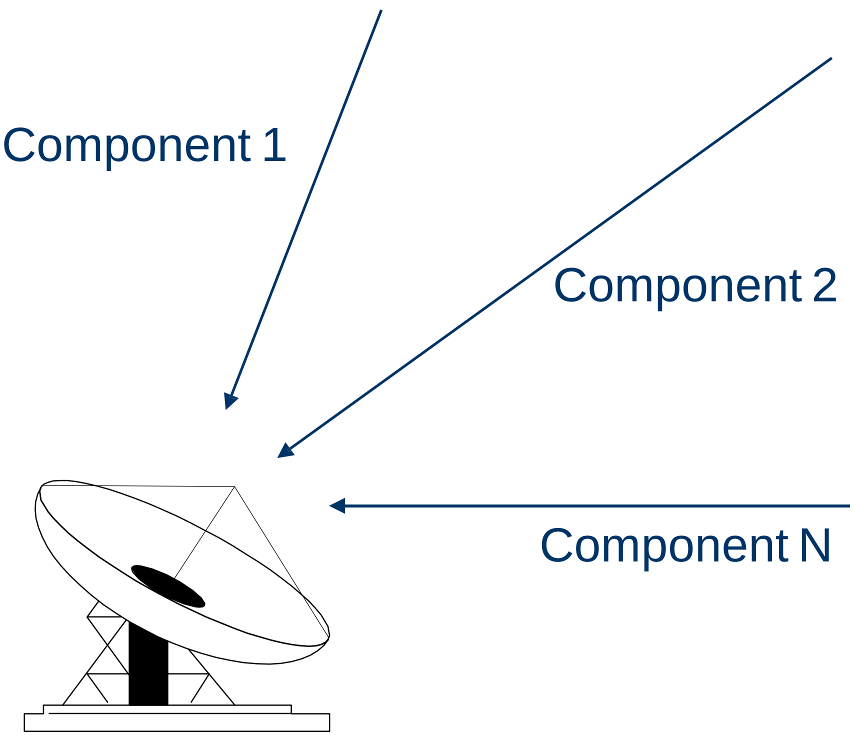
- Effects of multipath
  - Rapid changes in the signal strength
    - Over small travel distances, or
    - Over small time intervals
  - Random frequency modulation due to varying Doppler shifts on different multiples signals
  - Time dispersion (echoes) caused by multipath propagation delays
- Multipath occurs because of
  - Reflections
  - Scattering

Multipath

- At a receiver point
  - Radio waves generated from the same transmitted signal may come
    - from different directions
    - with different propagation delays
    - with (possibly) different amplitudes (random)
    - with (possibly) different phases (random)
    - with different angles of arrival (random).
  - These multipath components combine vectorially at the receiver antenna and cause the total signal
    - to fade
    - to distort

Multipath Components

Radio Signals Arriving from different directions to receiver

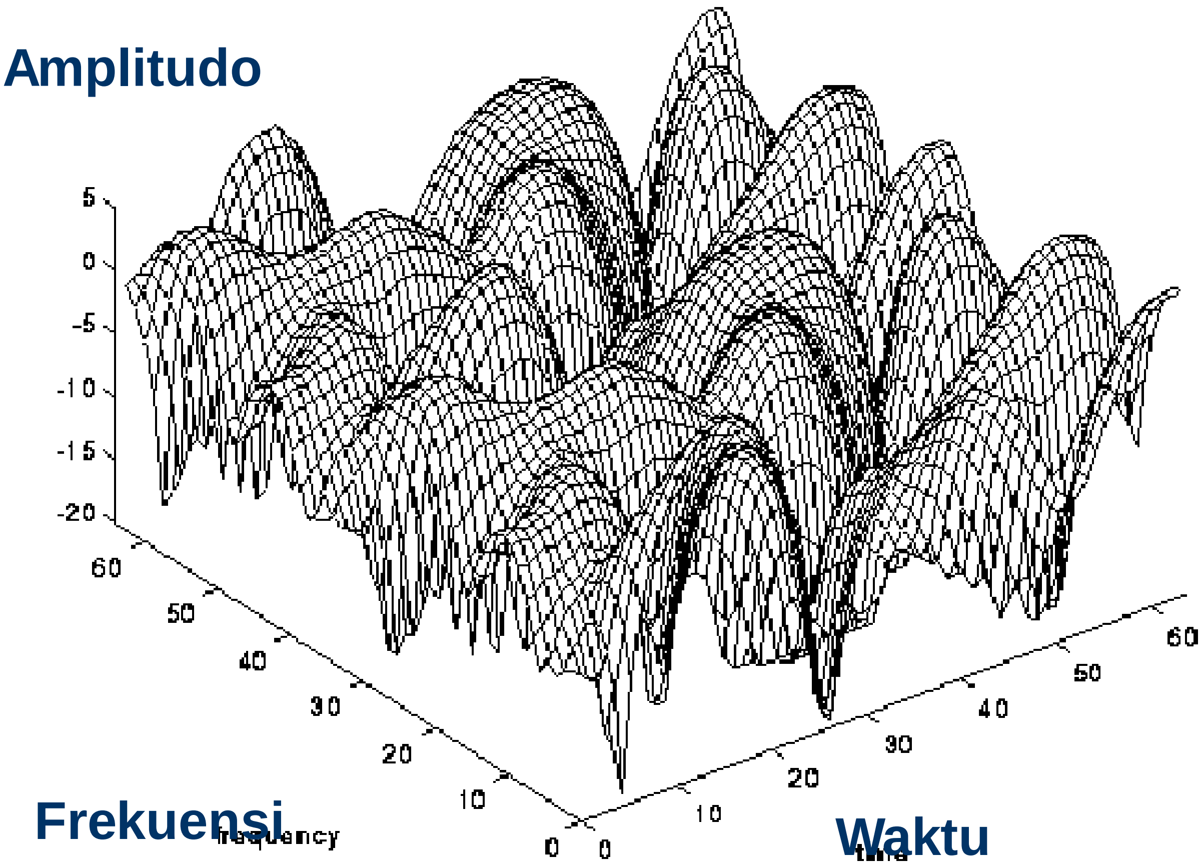


Receiver may be stationary or mobile.

Mobility

- Other Objects in the radio channels may be mobile or stationary
- If other objects are stationary
  - Motion is only due to mobile
  - Fading is purely a spatial phenomenon (occurs only when the mobile receiver moves)
  - The spatial variations as the mobile moves will be perceived as temporal variations
    - $\Delta t = \Delta d / v$
- Fading may cause disruptions in the communication

Small Scale Fading



- Amplitudo sinyal terima tergantung dari lokasi dan frekuensi

- Jika antena bergerak, maka lokasi x akan berubah linear terhadap waktu *t* (*x* = *v* *t*)

Parameters:

- probability of fades
- duration of fades
- bandwidth of fades

Small Scale Fading

Faktor-Faktor Yang Mempengaruhi Small Scale Fading

Kecepatan MS

- Gerak relatif antara Base Station dengan MS menghasilkan modulasi frekuensi random berkaitan dengan pergeseran frekuensi Doppler yang berbeda untuk tiap lintasan multipath.
- Doppler shift bisa positif dan negatif tergantung dari posisi pergerakan MS terhadap RBS

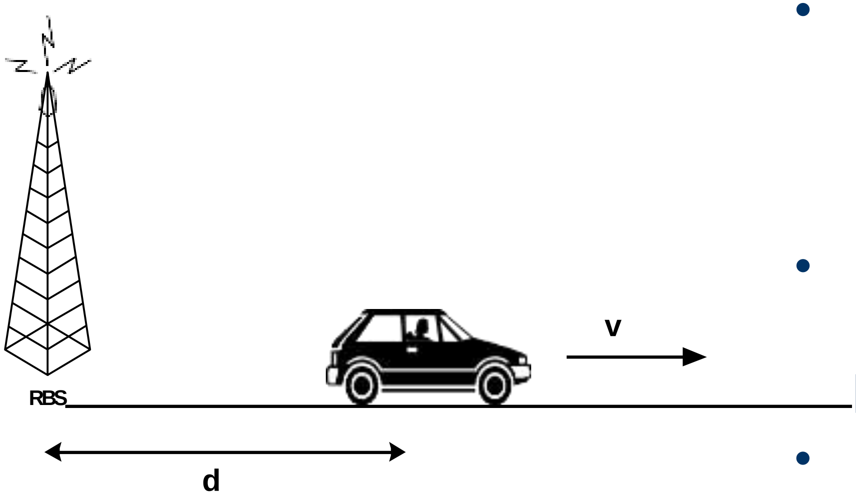
Kecepatan Obyek Pemantul

- Jika obyek-obyek bergerak dalam suatu kanal radio, maka akan menghasilkan pergeseran Doppler yang berubah terhadap waktu , yang berbeda untuk tiap komponen multipath.
- Jika pergerakan benda lebih besar dibandingkan gerakan MS sendiri, maka akan mendominasi small scale fading

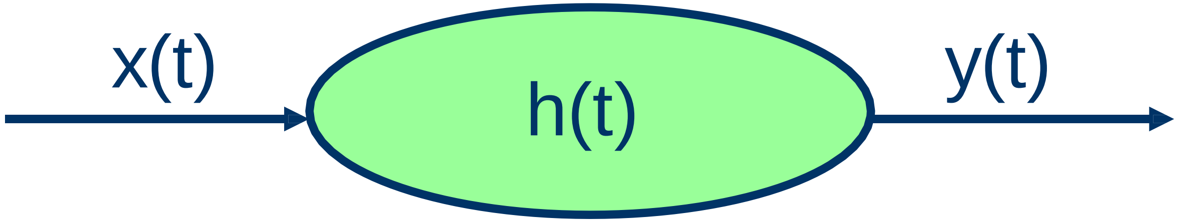
Lebar pita transmisi sinyal

Pita frekuensi yang relatif lebih lebar dibandingkan bandwidth kanal multipath, akan mengalami *frequency selective fading*.

Model Respon Impulse Kanal Multipath

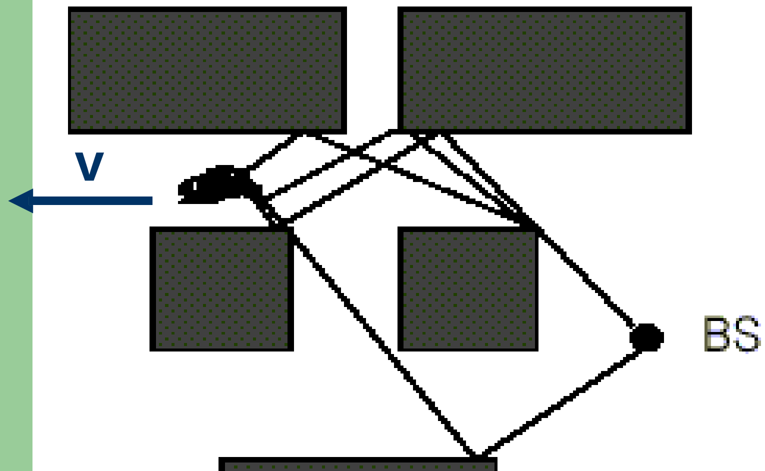


- Variasi sinyal sesaat (*small scale variation*) sinyal komunikasi bergerak secara langsung berhubungan dengan respon impulse dari kanal radionya.
- Respon impulse ini merupakan karakteristik kanal yang memuat informasi sifat-sifat kanal radio.
- Karakteristik kanal perlu diketahui untuk mengetahui unjuk kerja sistem komunikasi dalam kanal radio
- Kanal radio mobile memiliki sifat ***Linear Time Varying Channel***



Small Scale Fading … multipath signal analysis

Assumptions : Vehicles move → affected Doppler effect

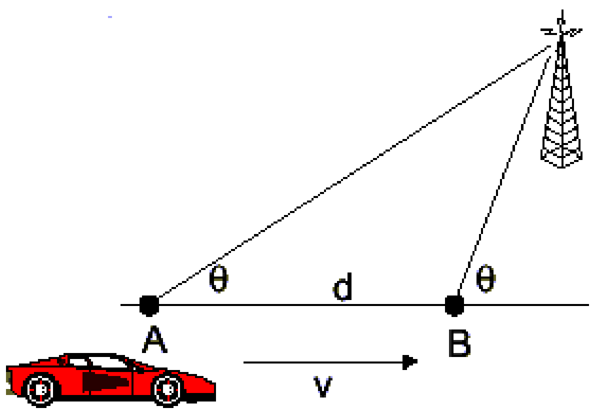


Signals received from MS that no movement can be expressed

$$e_r(t) = \sum_{k=1}^{N} a_k \cos\left(2\pi f_0 t + \phi_k\right)$$

For the mobile MS, $\mathbf{f_0} \rightarrow \mathbf{f_k}$, because the frequency received for each of the different paths

$$e_r(t) = \sum_{k=1}^{N} a_k \cos\left(2\pi f_k t + \phi_k\right)$$



where,

$$f_k = \frac{v}{\lambda} \cos \theta_k$$

→ Complicated but interesting!

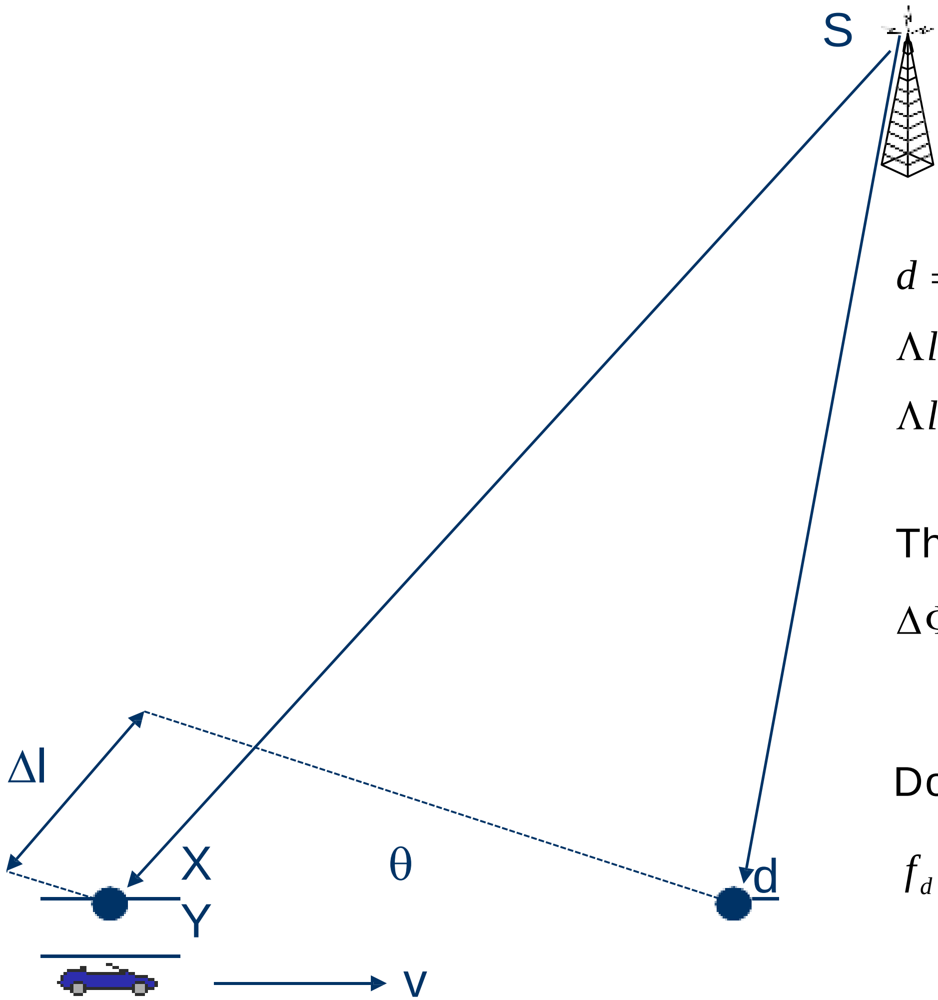
Small Scale Fading — Time Varying Model

- Variasi kanal (karena gerakan) → ***Doppler spread***
- Doppler spread f_D → ***channel coherence time*** T_C .
- ***Channel coherence time*** adalah suatu selang waktu dimana kanal diperhatikan (dapat dianggap) tidak berubah terhadap waktu (time invariant).
- Dalam kata lain: ***Channel coherence time*** adalah waktu dimana 2 sinyal terima memiliki korelasi amplitudo yang kuat
- Jika periode simbol (*reciprocal BW*) lebih besar dari coherence time → artinya kanal akan berubah selama periode simbol tersebut → terjadi ***fast fading***.

Doppler Effect

- When a transmitter or receiver is moving, the frequency of the received signal changes, i.e. İt is different than the frequency of transmission. This is called Doppler Effect.
- The change in frequency is called Doppler Shift.
  - It depends on
    - The relative velocity of the receiver with respect to transmitter
    - The frequenct (or wavelenth) of transmission
    - The direction of traveling with respect to the direction of the arriving signal.

Doppler Shift – Recever is moving



$$d = |XY|$$

$$\Delta l = |SX| - |SY| = d\cos\theta$$

$$\Delta l = v\Delta t\cos\theta$$

The phase change in the received signal :

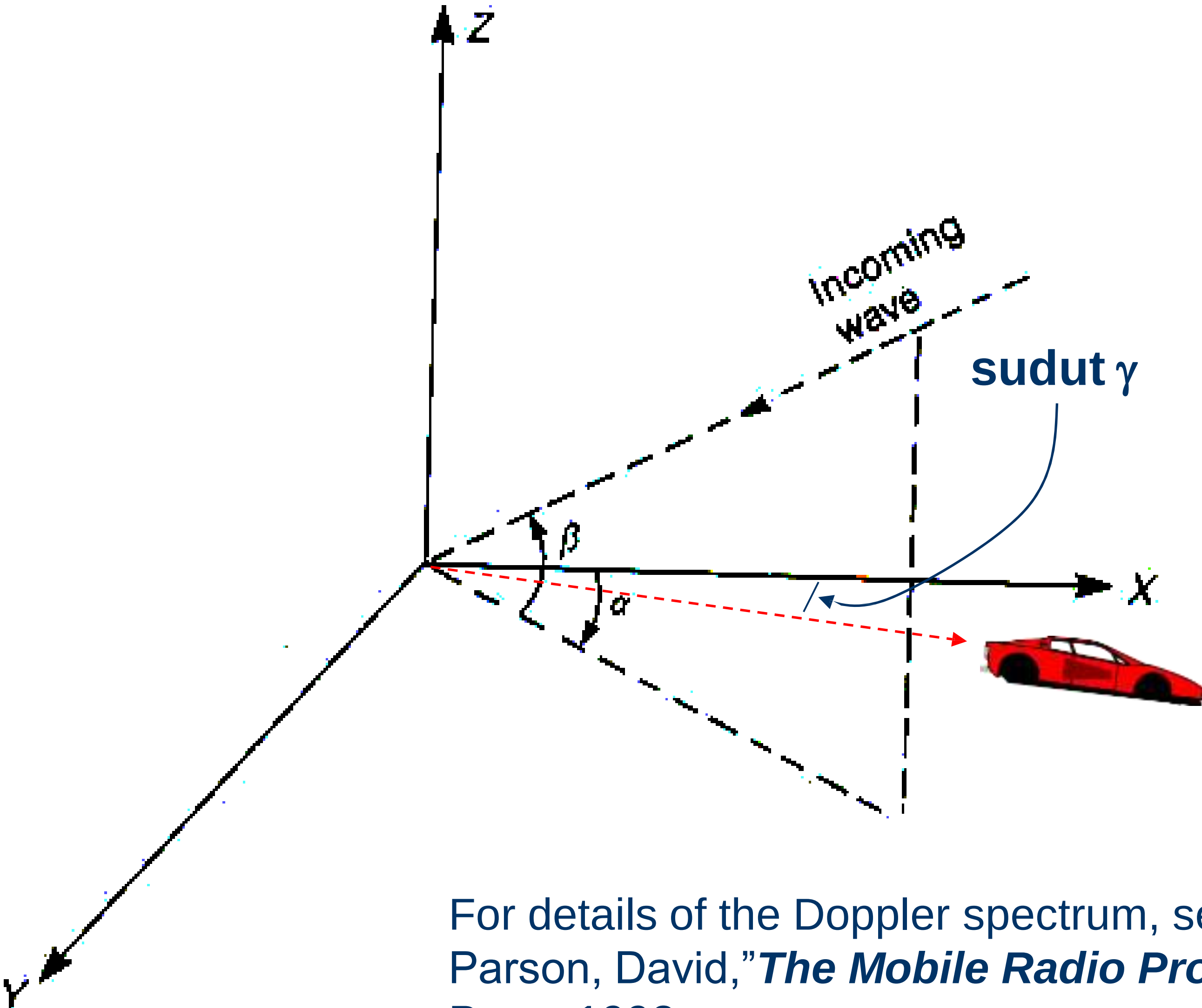
$$\Delta\Phi = \frac{\Delta l}{\lambda}2\pi = \frac{2\pi v\Delta t}{\lambda}\cos\theta$$

Doppler shift (The apparent change in frequency) :

$$f_d = \frac{1}{2\pi}\frac{\Delta\Phi}{\Delta t} = \frac{v}{\lambda}\cos\theta$$

Amobile receiver is traveling from point X to point Y

Small Scale Fading … multipath signal analysis



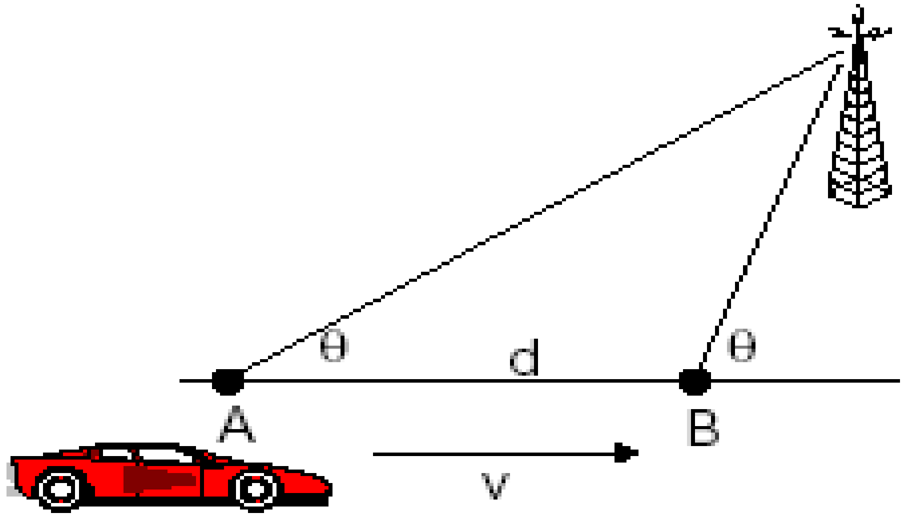
$$f_k = \frac{v}{\lambda}\cos\theta_k$$

$$\boxed{f_k = \frac{v}{\lambda}\cos(\gamma - \alpha_k)\cos\beta_k}$$

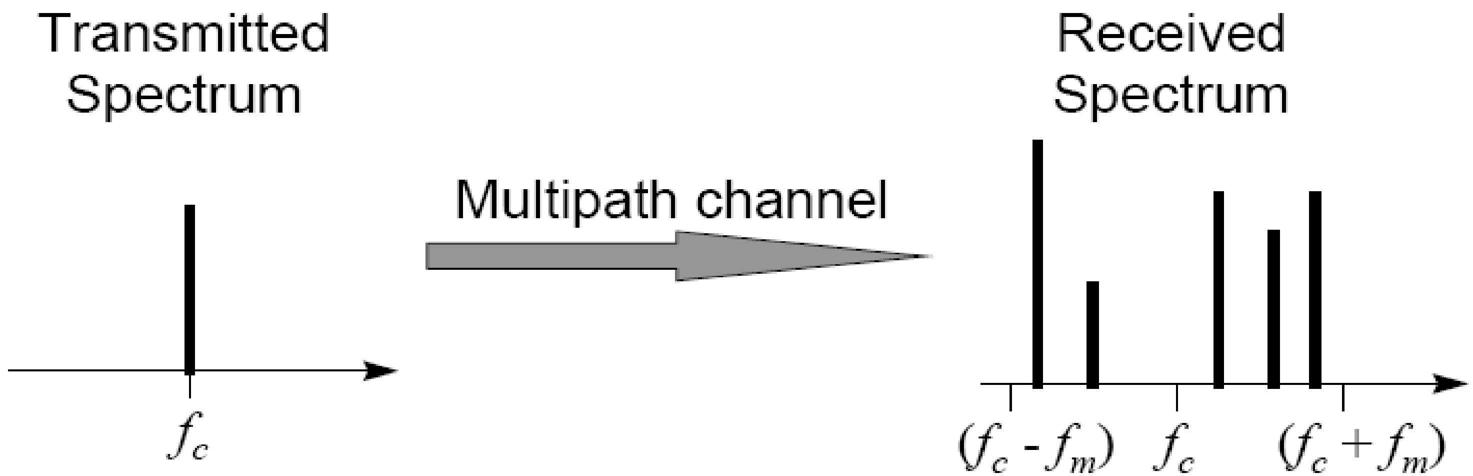
For details of the Doppler spectrum, see the :
Parson, David,"*The Mobile Radio Propagation Channel*", Pentech Press,1992

Pergeseran *doppler*

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



- v = kecepatan pergerakan relatif
- λ = panjang gelombang frekuensi *carrier*
- θ = sudut antara arah propagasi sinyal datang dengan arah pergerakan antena
- jika $\theta = 0^0$, maka $f_{d,max} = f_m = v/\lambda$

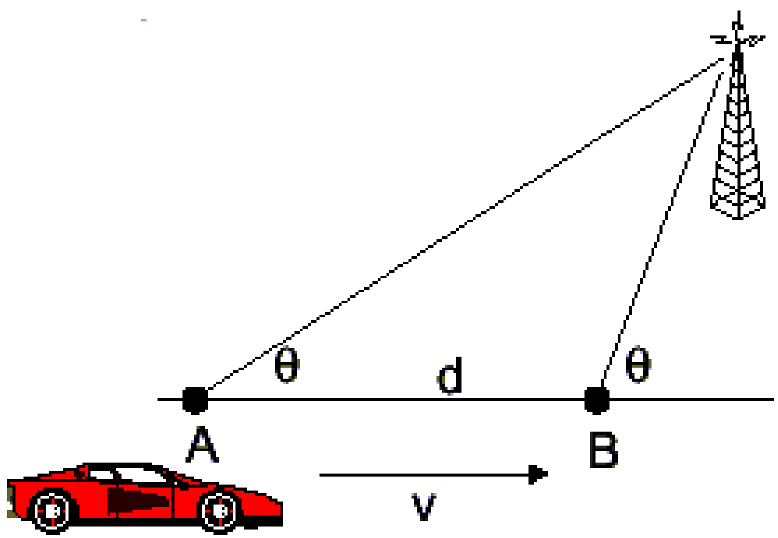


Doppler Spread dan *Coherence Time*

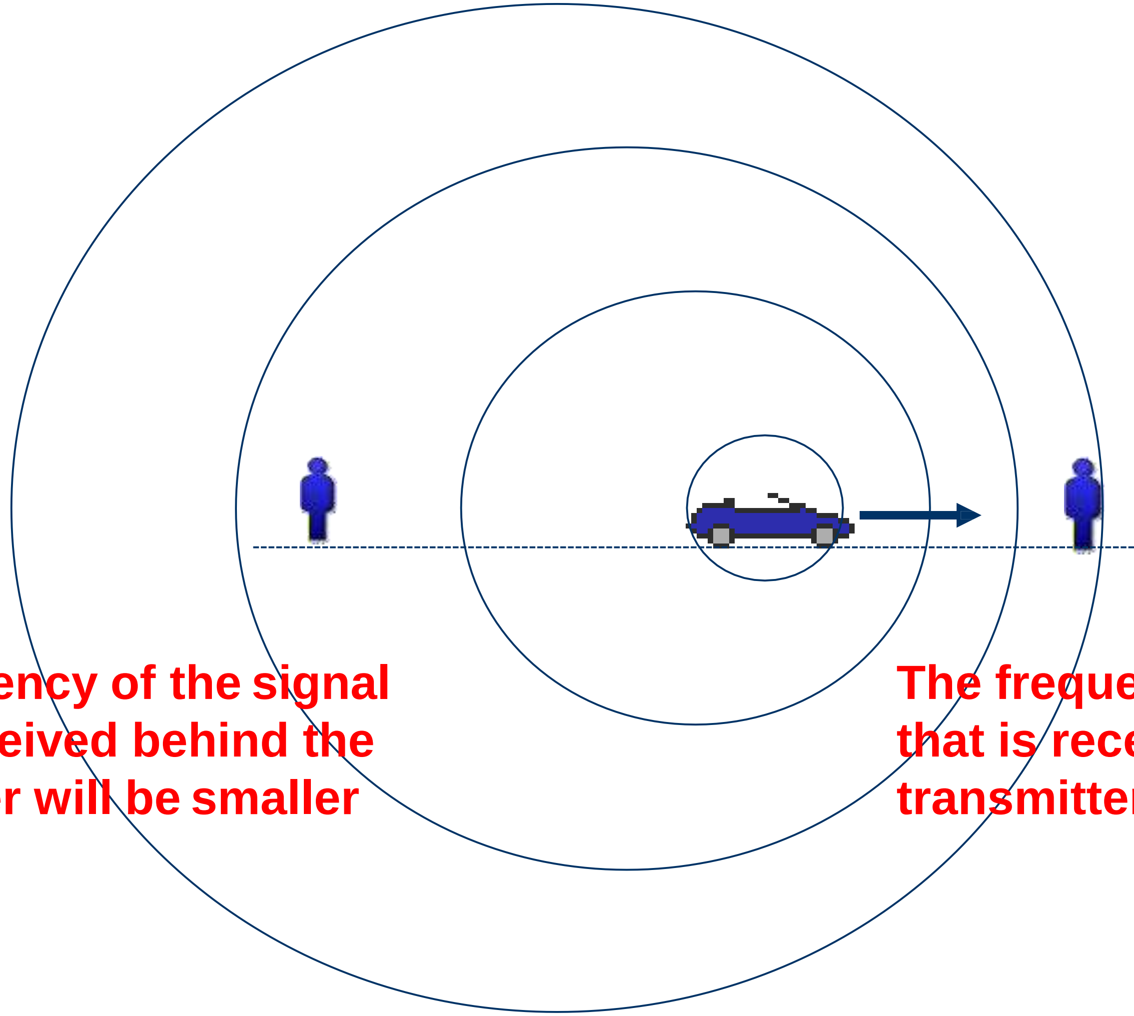
Latar belakang : Pergeseran Doppler (Doppler Shift)

- ***Doppler shift* (pergeseran doppler)** adalah pergeseran frekuensi yang disebabkan pergerakan penerima.
- *Doppler shift* meningkatkan bandwidth sinyal yang ditransmisikan

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



Doppler Shift – Transmitter is moving



The frequency of the signal that is received behind the transmitter will be smaller

The frequency of the signal that is received in front of the transmitter will be bigger

Doppler Shift

- The Dopper shift is positive
  - If the mobile is moving toward the direction of arrival of the wave
- The Doppler shift is negative
  - If the mobile is moving away from the direction of arrival of the wave.

Small Scale Fading – Multipath channel parameter - Doppler Effect

- ***Doppler spread ,*** $\mathbf{f_m}$ **,** is the maximum Doppler shift

$$f_m = \frac{v}{\lambda}$$

V = meters/sec
λ = meters
f_m = Hertz

→ maximum, cos θ = 1

- **Coherence Time,** $\mathbf{T_C}$:

$$T_C = \sqrt{\frac{9}{16\pi f_m^{\,2}}} = \frac{0.423}{f_m}$$

Equation is an approximation using a correlation of 0.5

- If the speed of symbol is greater than $\mathbf{1/T_C}$, then the signal is not distorted due to movement of the user channel

Typical Delay Spreads

Macrocells $T_{RMS} < 8\ \mu\text{sec}$

- GSM (256 kbit/s) uses an equalizer
- IS-54 (48 kbit/s): no equalizer
- In mountanous regions delays of 8 μsec and more occur

  GSM has some problems in Switzerland

Microcells $T_{RMS} < 2\ \mu\text{sec}$

- Low antennas (below tops of buildings)

Picocells $T_{RMS} < 50$ nsec - 300 nsec

- Indoor: often 50 nsec is assumed
- DECT (1 Mbit/s) works well up to 90 nsec

  Outdoors, DECT has problem if range > 200 .. 500 m

Small Scale Fading – Multipath channel parameters - time dispersion parameters

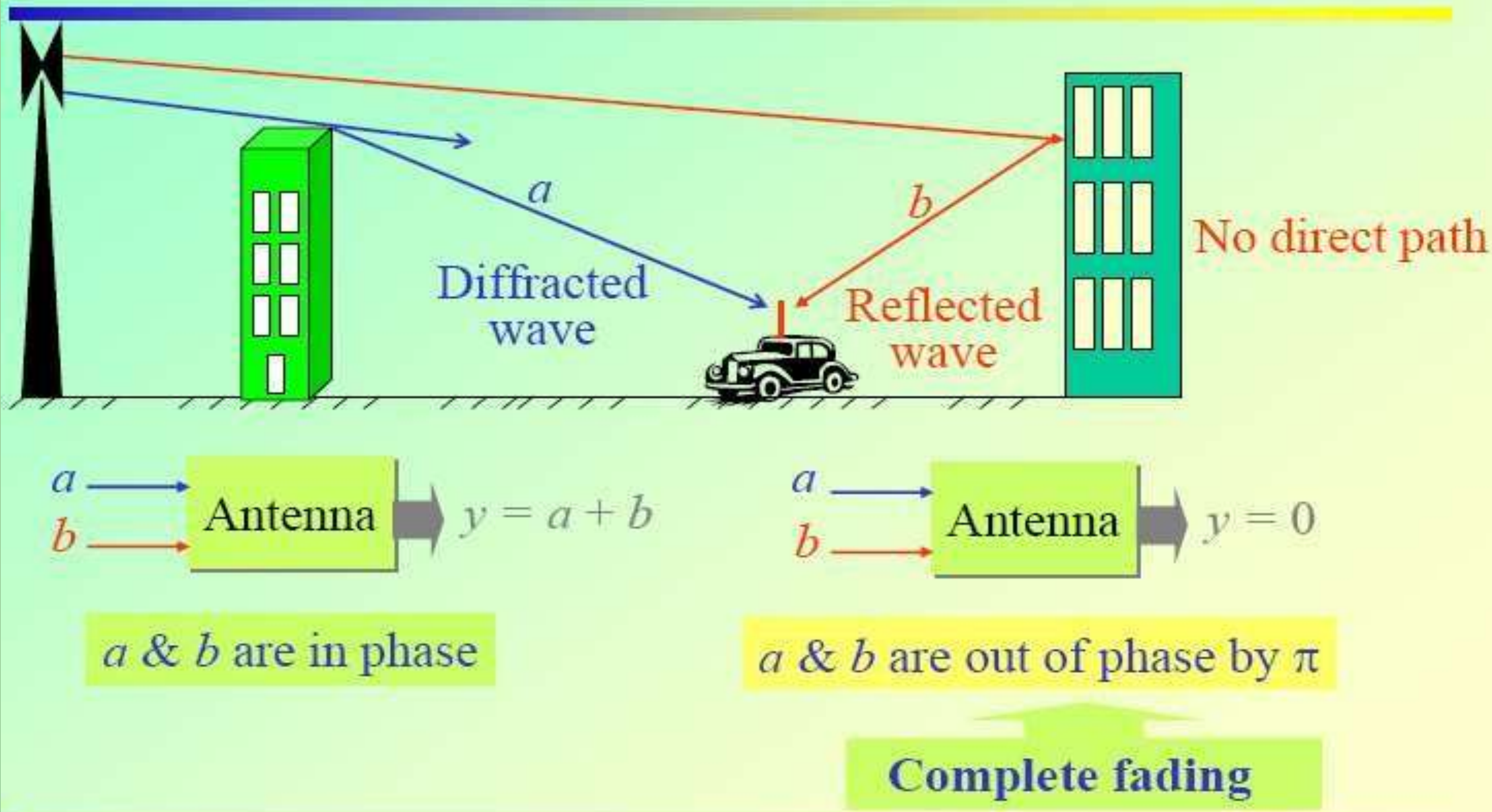
Table 5.1 Typical Measured Values of RMS Delay Spread

Environment	Frequency (MHz)	RMS Delay Spread (σ_τ)	Notes	Reference
Urban	910	1300 ns avg. 600 ns st. dev. 3500 ns max.	New York City	[Cox75]
Urban	892	10–25 μs	Worst case San Francisco	[Rap90]
Suburban	910	200–310 ns	Averaged typical case	[Cox72]
Suburban	910	1960–2110 ns	Averaged extreme case	[Cox72]
Indoor	1500	10–50 ns 25 ns median	Office building	[Sal87]
Indoor	850	270 ns max.	Office building	[Dev90a]
Indoor	1900	70–94 ns avg. 1470 ns max.	Three San Francisco buildings	[Sei92a]

Impulse Response Model of a Multipath Channel

- The wireless channel charcteristics can be expressed by impulse response function
- The channel is time varying channel when the receiver is moving.
- Lets assume first that time variation due strictly to the receiver motion ($t = d/v$)
- Since at any distance d = vt, the received power will ve combination of different incoming signals, the channel charactesitics or the impulse response funcion depends on the distance d between trandmitter and receiver

Multipath Propagation - Fading



Multipath Propagation - *contd.*

- Assuming the receiver is stationary and there is no direct path.

The received signal can be expressed as a sum of delayed components or in terms of phasor notation (sinusoidal components):

Pulse train

$$e_r(t) = \sum_{i=1}^{N} a_i p(t - t_i),$$

A single pulse

$$e_r(t) = \sum_{i=1}^{N} a_i \cos(2\pi f_c + \phi_i)$$

Where:

- a_i is the amplitude of the scattered signal
- $p(t)$ is the transmitted signal (pulse) shape
- t_i is the time taken by the pulse to reach the receiver
- N is the number of different paths taken by the signal to reach receiver
- f_c is the carrier frequency

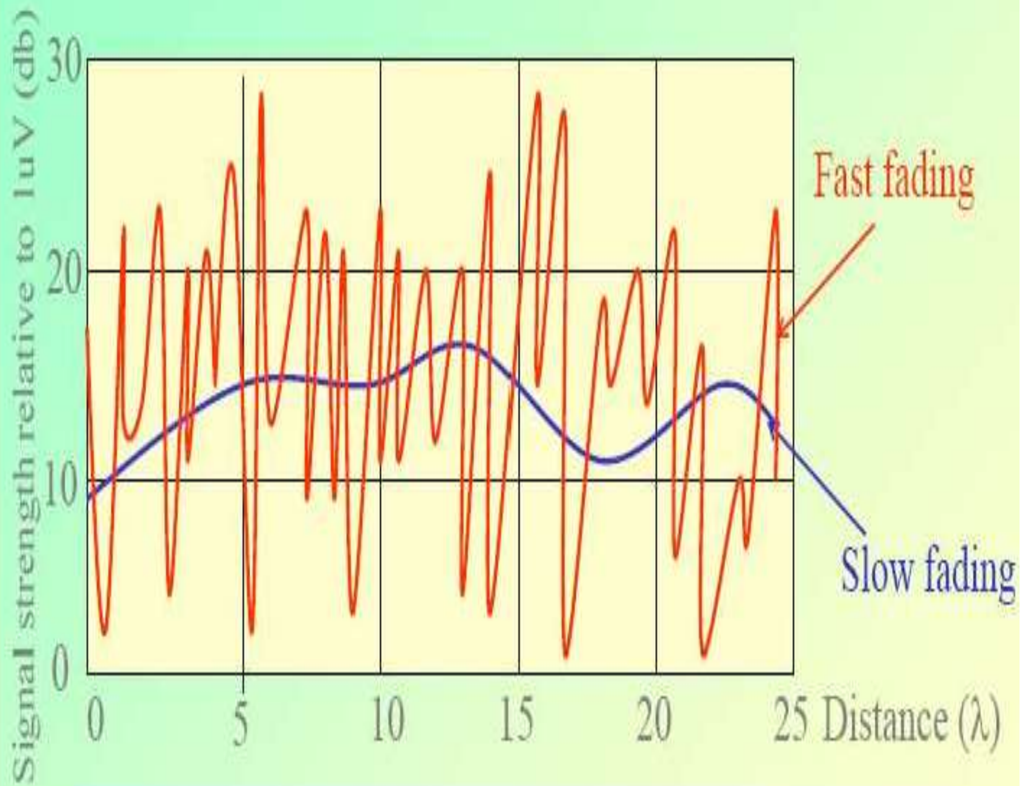
Fading

- Fading is due to multipath propagation.
- Is a spatially varying phenomenon, which becomes **time varying phenomenon** only when the mobile is moving.

There are two types:

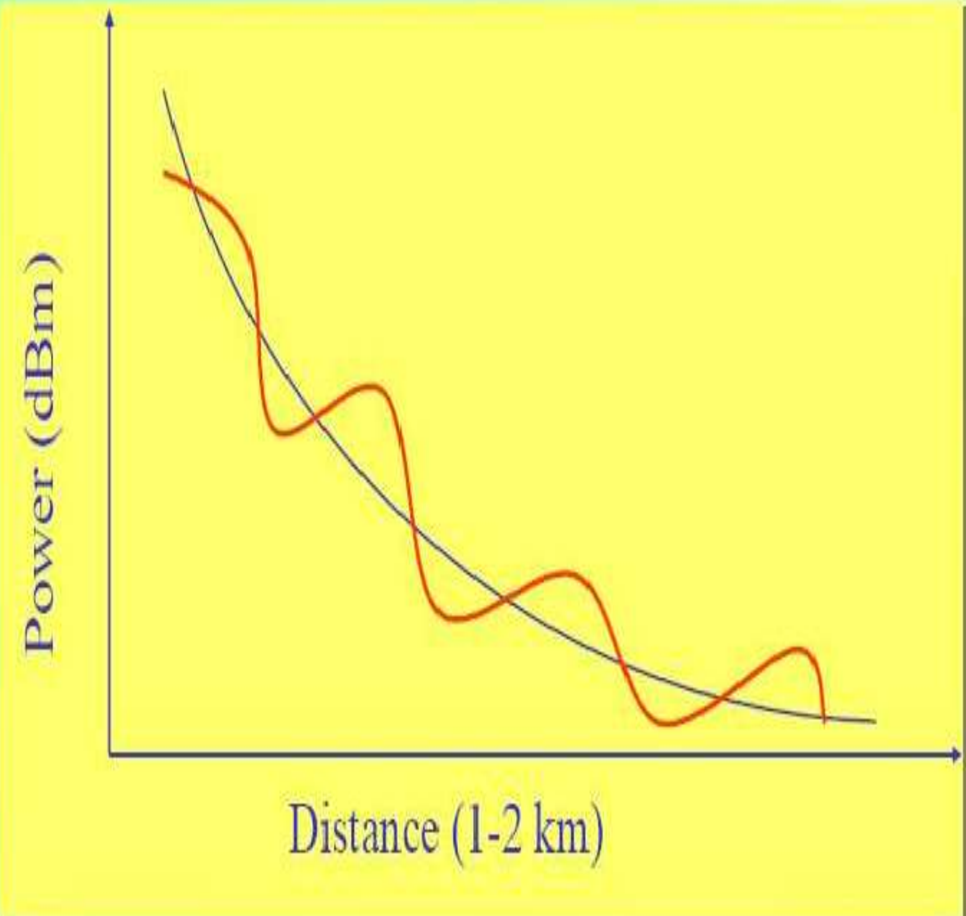
- Slow (Long) Term
- Fast (Short) Term *(Also known as Rayleigh fading)*

Fading - *contd.*



Exact representation of fading characteristics is not possible, because of infinite number of situation.

Fading - Slow (Long) Term



Fading - Slow (Long) Term - *contd.*

- Slower variation in mean signal strength
- Produced by movement over much longer distances
- Caused by:
  - **Terrain configuration (hill, flat area etc.):** Results in local mean (long term fading) attenuation and fluctuation.
  - **The built environment (rural and urban areas etc.), between base station and the mobile unit:** Results in local mean attenuation

Fading- Fast (Short) Term - *contd.*

- **Describes the c**onstant amplitude fluctuations in the received signal as the mobile moves.
- Caused by multipath reflection of transmitted signal by local scatters (houses, building etc.)
- Observed over distances = $\lambda/2$
- Signal variation up to 30 dB.
- Is a frequency selective phenomenon.
- Can be described using **Rayleigh statistics** if no line of sight exists.
- Can be described using **Rician statistics** if line of sight exists.
- Causes random fluctuations in the received power, and also distorts the pulse carrying the information.

Fading- Fast (Short) Term - *contd.*

A received signal amplitude is given as the sum of delayed components. In terms of phasor notation it is given as:

$$e_r(t) = \sum_{i=1}^{N} a_i \cos(2\pi f_c + \phi_i)$$

Or

$$\boxed{e_r(t) = \cos(2\pi f_c t) \sum_{i=1}^{N} a_i \cos(\phi_i) - \sin(2\pi f_c t) \sum_{i=1}^{N} a_i \sin(\phi_i)}$$

In-phase

Quadrature

Fading- Fast (Short) Term - *contd.*

The phase ϕ_i can be assumed to be uniformly distributed in the range $(0, 2\pi)$, provided the locations of buildings etc. are completely random.

This for large N, the amplitude of the received signal is:

$$e_r(t) = X \cos(2\pi f_c t) - Y \sin(2\pi f_c t)$$

where $$X = \sum_{i=1}^{N} a_i \cos(\phi_i), \quad y = \sum_{i=1}^{N} a_i \sin(\phi_i)$$

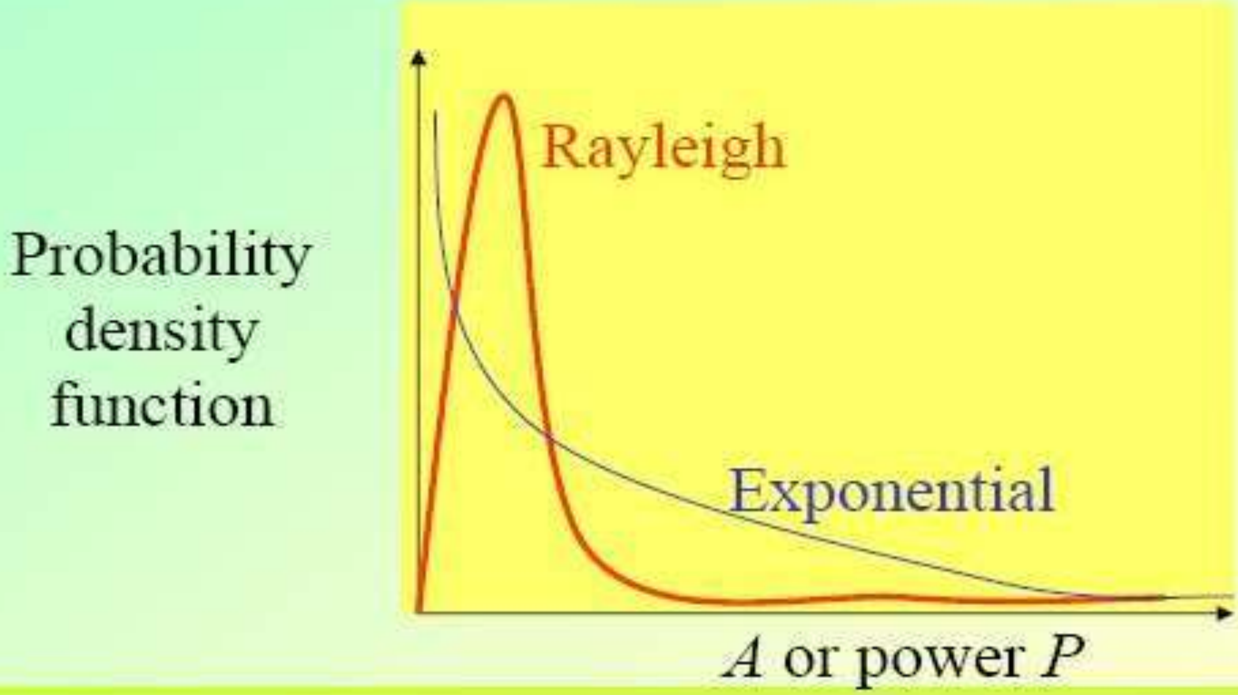
X and Y are independent, identically distributed Gaussian random variables.

Fading- Fast (Short) Term - *contd.*

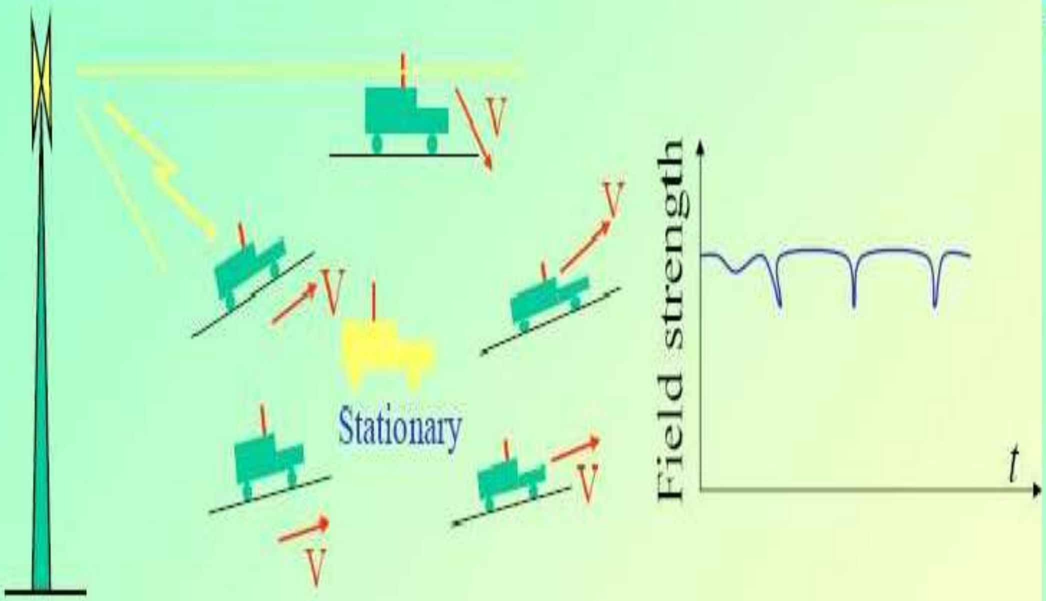
The envelope of the received signal is:

$$A = (X^2 + Y^2)^{0.5}$$

Which will be Rayleigh distributed.

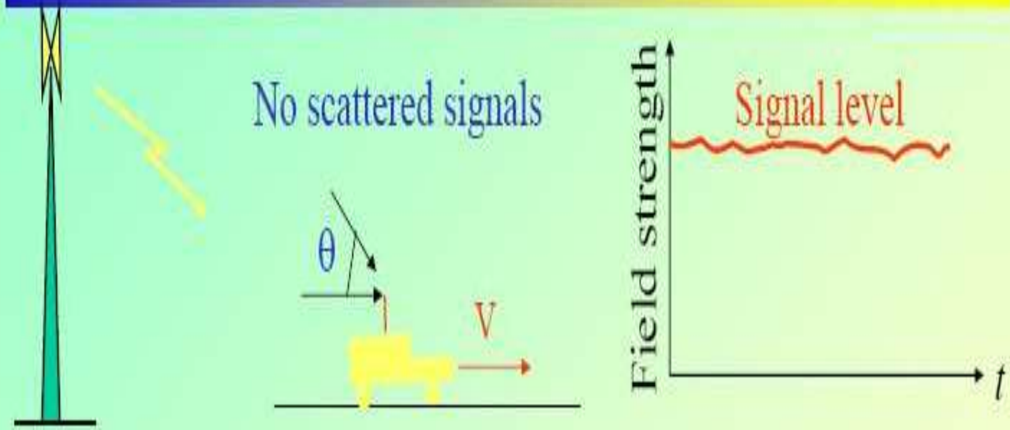


Fast Fading – Cases 1: Stationary Mobile



- Mobile is stationery surrounded by moving cars.
- The number of fading depends on the :
  - Traffic flow
  - Distance between the mobile and moving cars

Fast Fading – Cases 2: Non-stationary Mobile



The received signal at the mobile is:

$$S_r = Ae^{j(2\pi f_t - \beta x \cos\theta)}$$

$x = Vt$

Amplitude

Wave number $=2\pi/\lambda$

Transmitting frequency

Fast Fading – Cases 2: Doppler Frequency

Substituting for β and x, the expression for the received signal is

$$s_r = Ae^{j2\pi(f_t - \frac{V}{\lambda}\cos\theta)t}$$

The Doppler frequency

$$f_D = \frac{V}{\lambda}\cos\theta$$

The received signal frequency

$$f_r = f_t - \frac{V}{\lambda}\cos\theta$$

Fast Fading – Cases 2: Doppler Frequency

- When $\theta = 0^o$ (mobile moving away from the transmitter)

$$f_r = f_t - V/\lambda$$

- When $\theta = 90^o$ (I.e. mobile circling around)

$$f_r = f_t$$

- When $\theta = 180^o$ (mobile moving towards the transmitter)

$$f_r = f_t + V/\lambda$$

Coherence Bandwidth

- Adalah ukuran statistik suatu range frekuensi pada kanal yang dapat dianggap **“flat”** atau bandwidth diantara 2 frekuensi yang memiliki potensi kuat dalam korelasi amplitudo.
- Semua kompunen spektrum dalam range bandwidth koheren dapat diperhatikan (dapat dianggap) mendapatkan gain dan fasa yang linier
- **Bandwidth koheren sebaiknya diukur**, tetapi bisa didekati dengan persamaan :

$$B_c \approx \frac{1}{50\sigma_\tau}$$

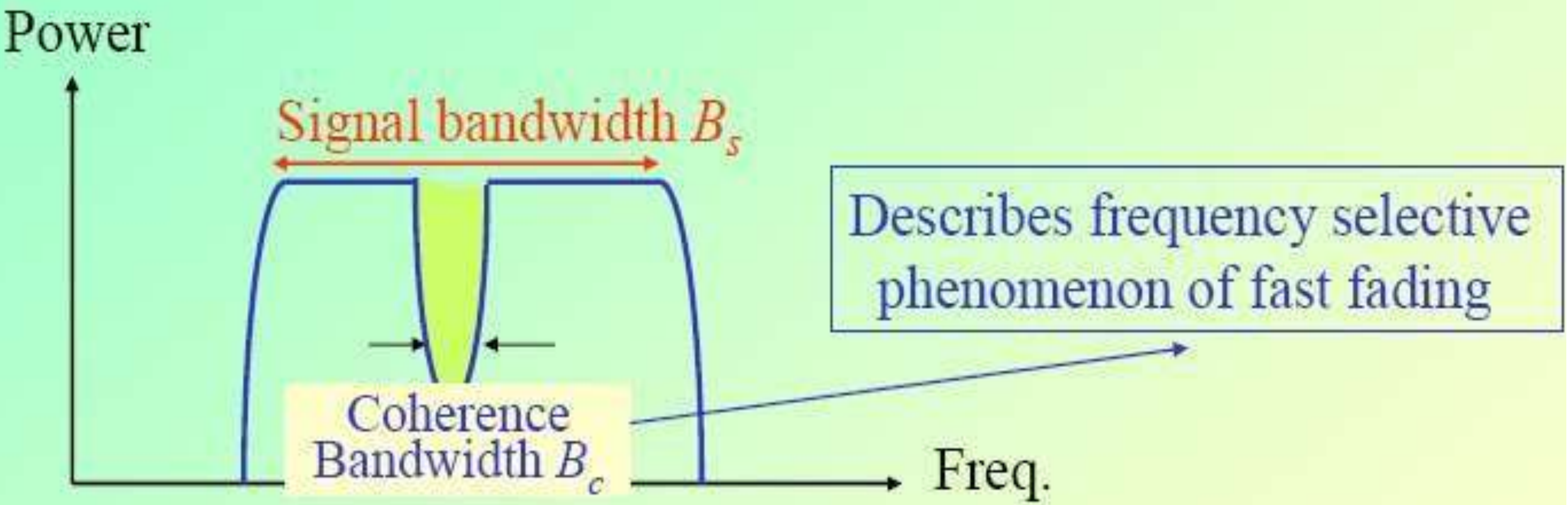
For correlation greater than 0.9

atau

$$B_c \approx \frac{1}{5\sigma_\tau}$$

For correlation greater than 0.5

Fading in Digital Mobile Communications



Effect of frequency selective fading on the received signal spectrum

Fading in Digital Mobile Communications

- If $B_s >> B_c$, then a notch appears in the spectrum. Thus resulting in **inter-symbol interference (ISI)**.

- To overcome this, an **adaptive equaliser** (AE) with inverse response may be used at the receiver. Training sequences are transmitted to update AE.

- If $B_s << B_c$, then flat fading occurs, resulting in a **burst of error**.

- **Error correction coding** is used to overcome this problem.

Intersymbol Interference (ISI):

- **Ketika multipath delay spread lebih besar dari 20% durasi simbol, ISI dapat menjadi problem. Untuk mengatasi ISI …**
- **Pertama**, receiver dipasangi dengan *adaptive equalizer*

Equalizer ini menguji efek delay multipath pada deretan training bit yang diketahui, selanjutnya menggunakan informasi hasil pengujian ini untuk mengatasi efek delay multipath pada deretan bit-bit informasi sesungguhnya

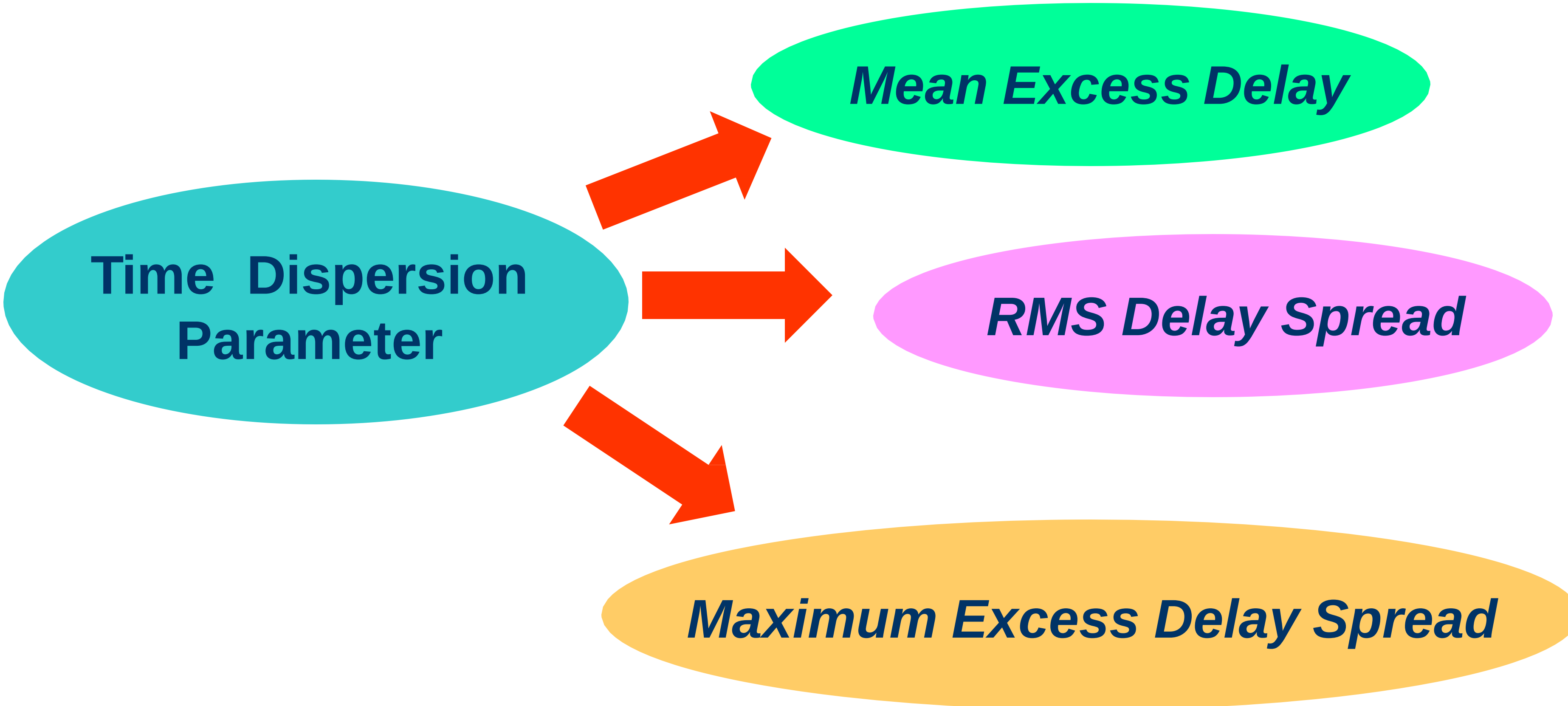
- **Kedua,** menggunakan kode-kode proteksi error (channel coding) untuk mendeteksi dan mengkoreksi error
- **Catatan :** ISI tidak bisa diatasi dengan memperbesar kuat sinyal !!

Multipath Propagation - Dispersion

- **Dispersion over time:** Interference with "neighbor" symbols, resulting in Inter Symbol Interference (ISI)

- The signal arrived at the receiver directly and phase shifted
  - Distorted signal depending on the phases of the different parts

Small Scale Fading



C. Small Scale Fading – Multipath channel parameters - time dispersion parameters

Mean Excess Delay :

→ The first moment of *power delay profile*

$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)}$$

RMS Delay Spread :

→ Square root of second central moment of power delay profile

→ RMS Delay Spread is the standard deviation of excess delay and

→ The average deviation from the mean excess delay

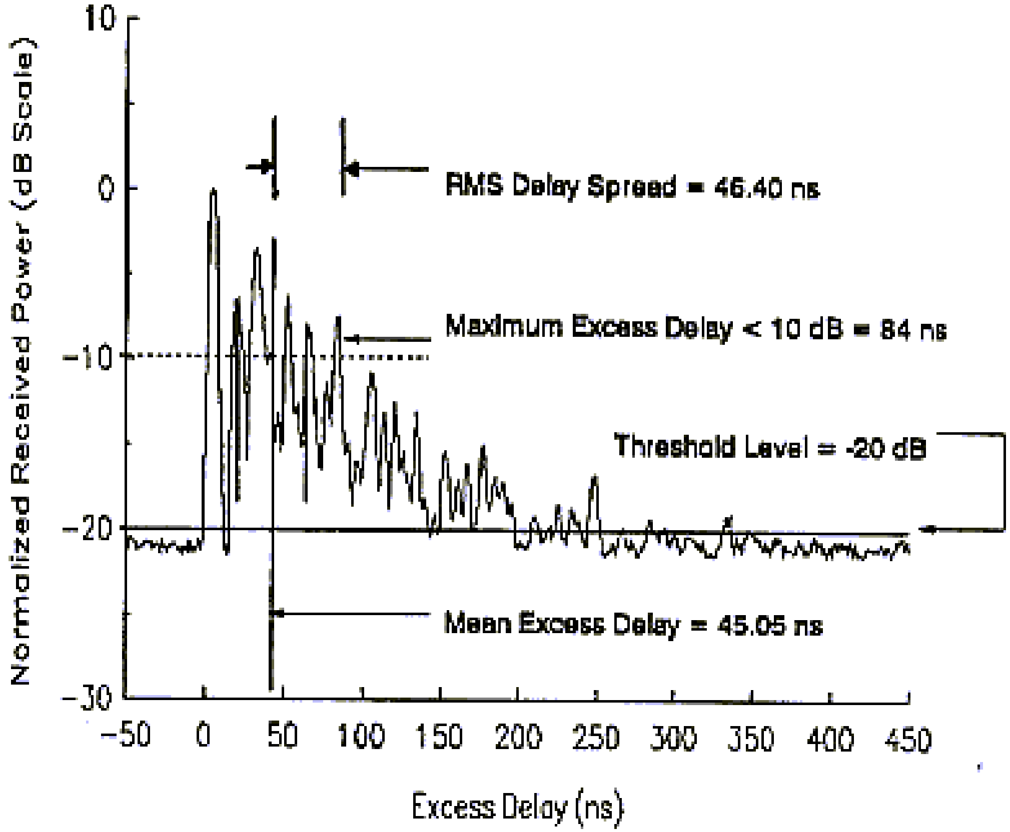
$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2}$$

$$\overline{\tau^2} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k^2}{\sum_k P(\tau_k)}$$

C. Small Scale Fading – Multipath channel parameters - time dispersion parameters

Maximum Excess Delay Spread

→time delay during multipath energy down by X dB (typically 10 dB), below the maximum value



$\sigma_\tau \approx 3.0\mu s$ (urban)

$\sigma_\tau \approx 0.5\mu s$ (suburban)

$\sigma_\tau \approx 0.2\mu s$ (rural)

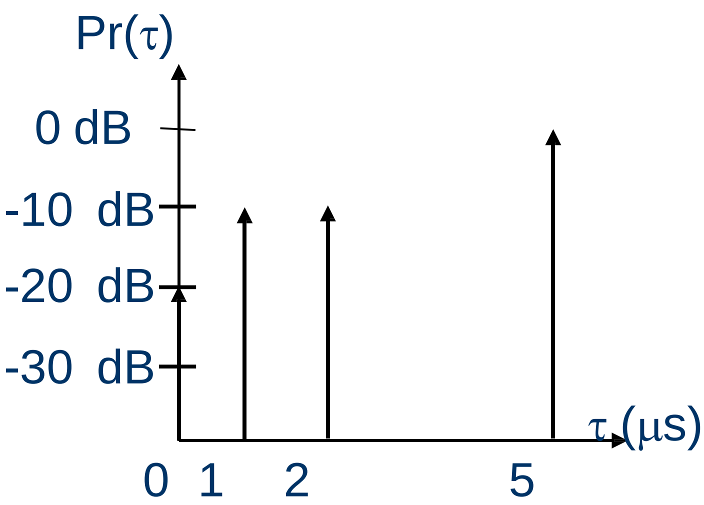
Source: Wireless Communications by Rappoport, P. 163

C. Small Scale Fading – Multipath channel parameters - time dispersion parameters

Example:

Calculate the mean excess delay and rms delay spread of a multipath channel. Multipath profile is given in the following figure. Give a recommendation whether the multipath channel is suitable for AMPS and GSM without using equalizer?

Answer:



Mean excess delay,

$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)}$$

$$\bar{\tau} = \frac{(1)(5)+(0.1)(1)+(0.1)(2)+(0.01)(0)}{(0.01+0.1+0.1+1)} = 4.38\,\mu s$$

Second moment of delay profile,

$$\overline{\tau^2} = \frac{(1)(5)_2 + (0.1)(1)_2 + (0.1)(2)_2 + (0.01)(0)_2}{(0.01+0.1+0.1+1)} = 21.07\,\mu s^2$$

C. Small Scale Fading – Multipath channel parameters - time dispersion parameters

RMS delay spread,

$$\sigma_\tau = \sqrt{21.07 - (4.38)^2} = 1.37\ \mu s$$

Coherence bandwidth,

$$B_C \approx \frac{1}{5\sigma_\tau} = 146\ \text{kHz}$$

Thus,

For AMPS (RF channel BW = 30 kHz), RF channel BW <BW so it does not require coherent equalizer

For GSM (RF channel BW = 200 kHz), RF channel BW> BW coherent, thus requiring equalizer