Wireless Communication Systems

Modul 5 Fading Mitigation

Faculty of Electrical Engineering
Bandung – 2015

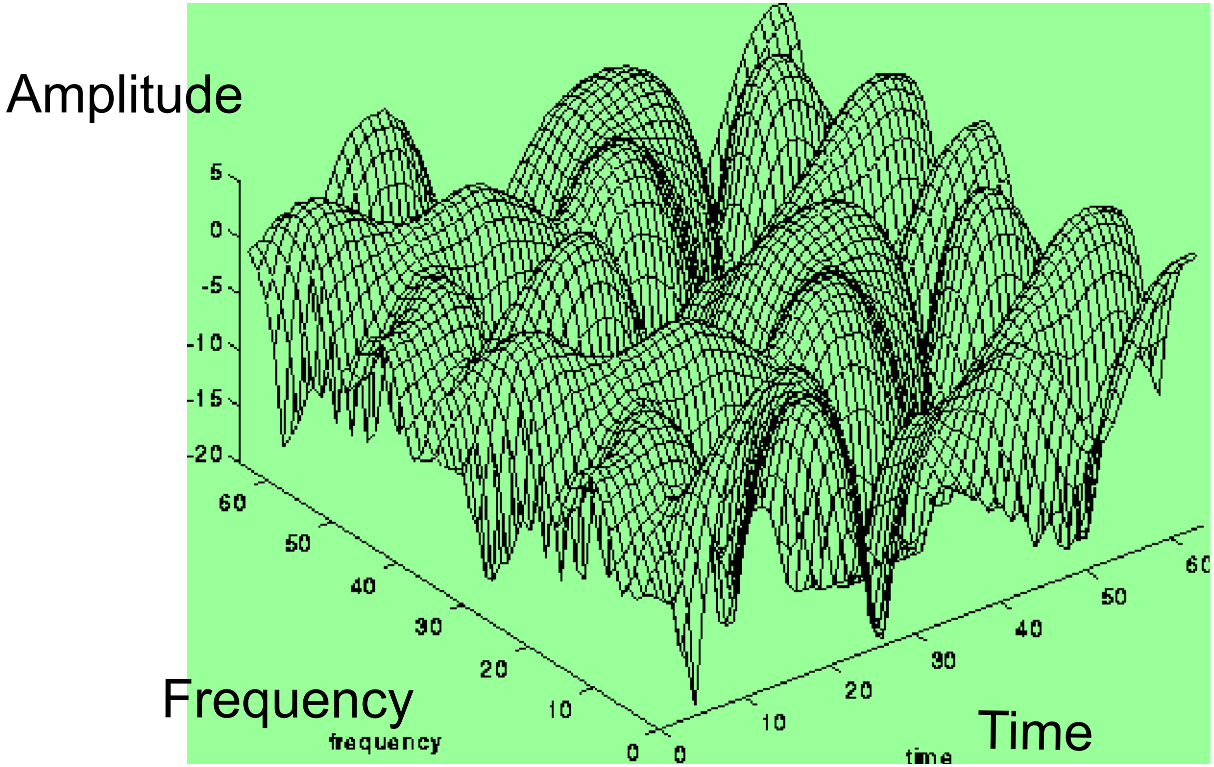
Subject

a. Diversity and Equalization

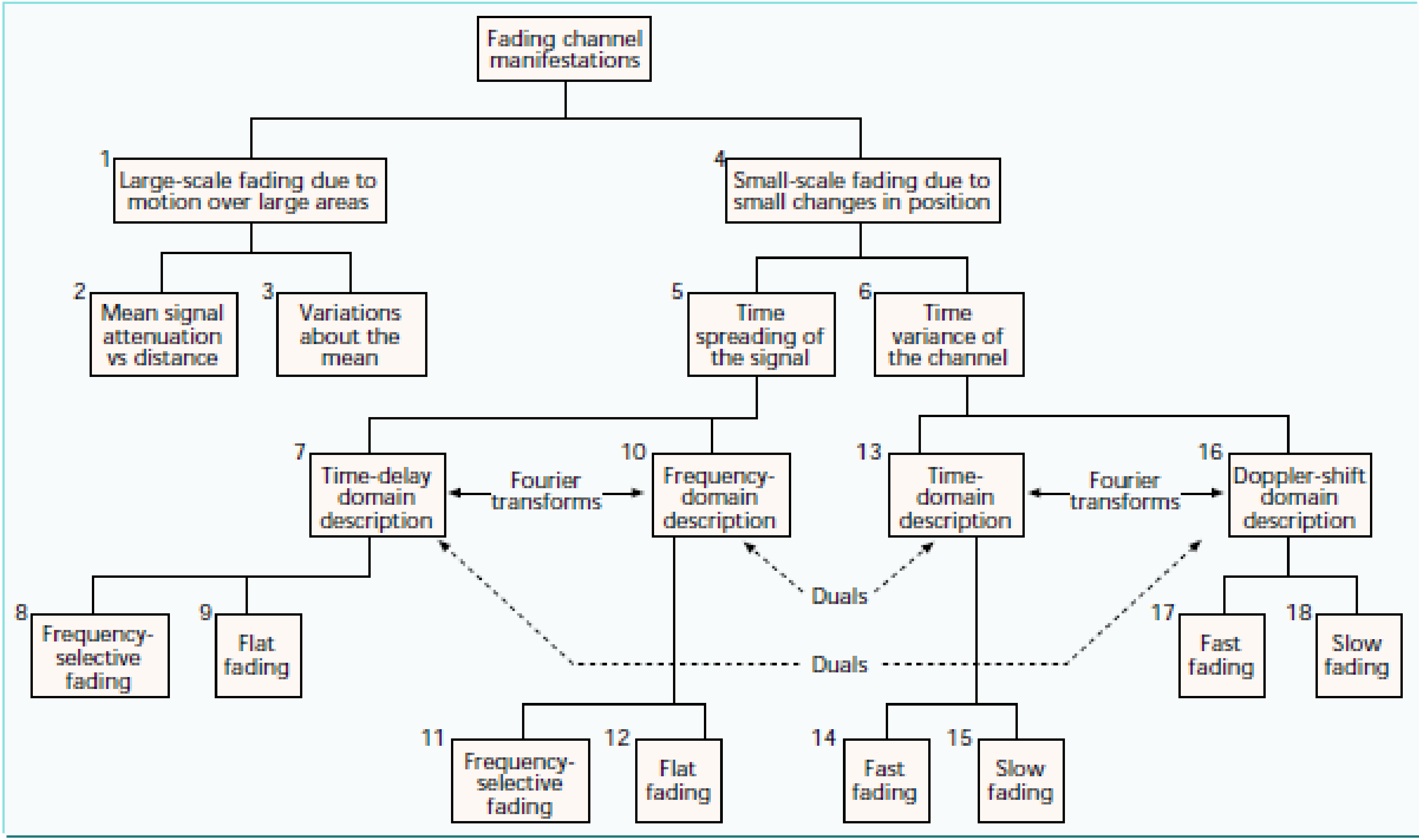
b. Channel Coding

d. Teknik Multicarrier

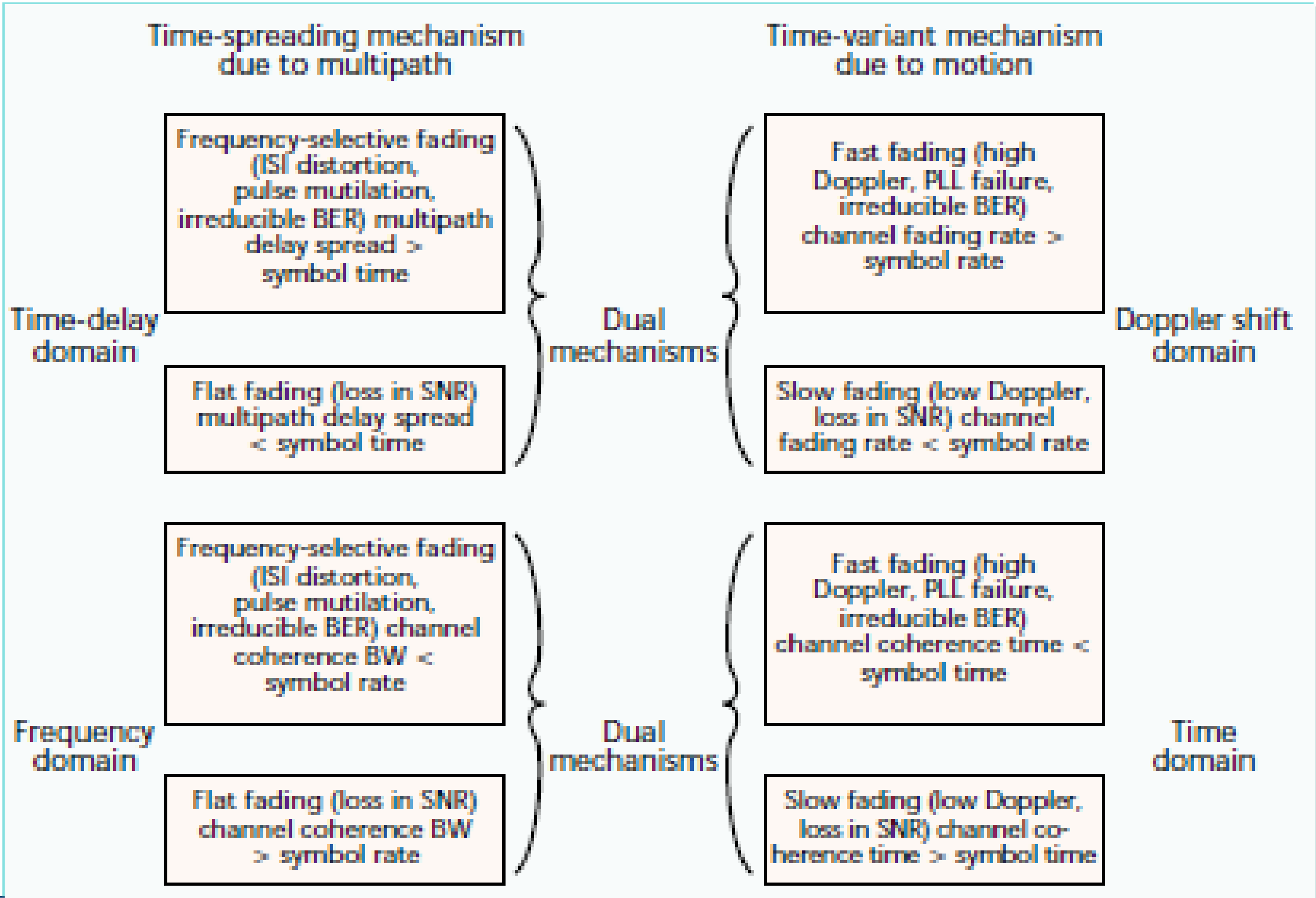
Typical Mobile Radio Propagation Channel



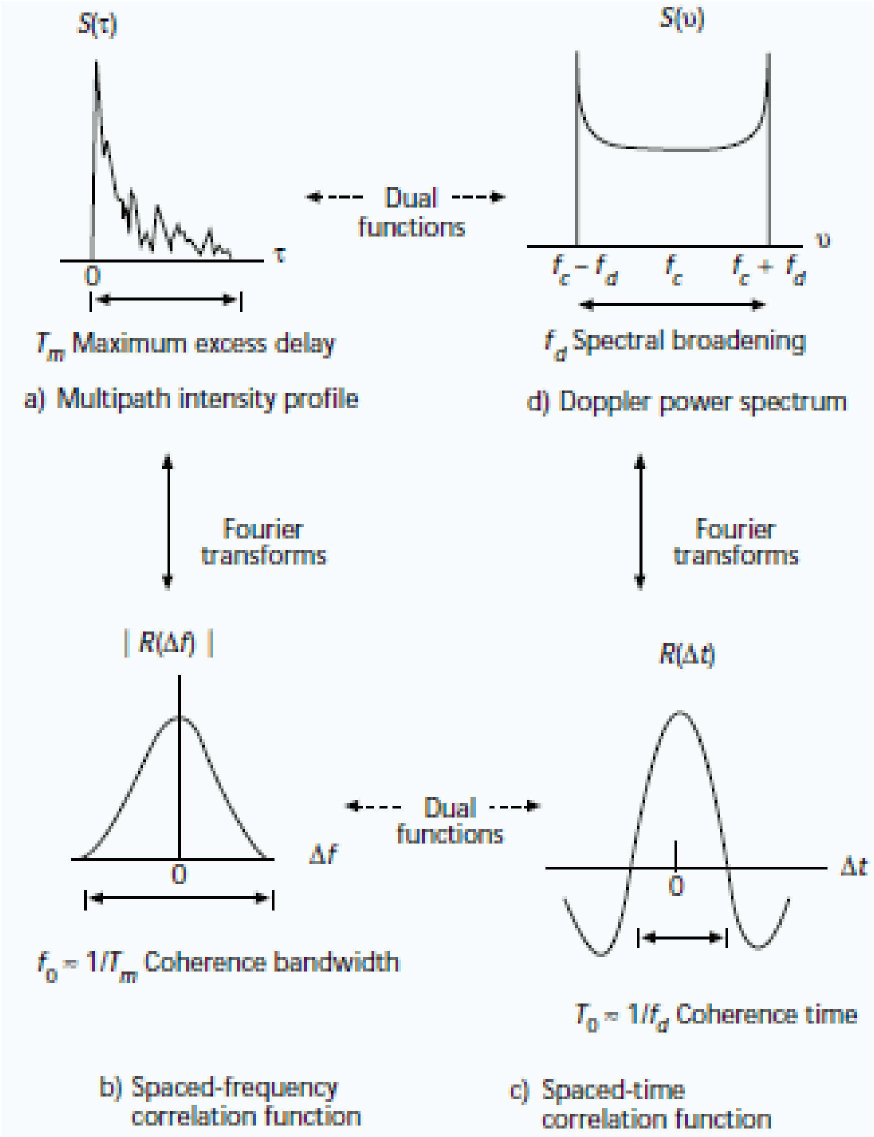
Fading channel manifestations



Small-scale Fading: Mechanisms, Degradation categories, and Effects



Relationships among the channel correlation functions and power density functions



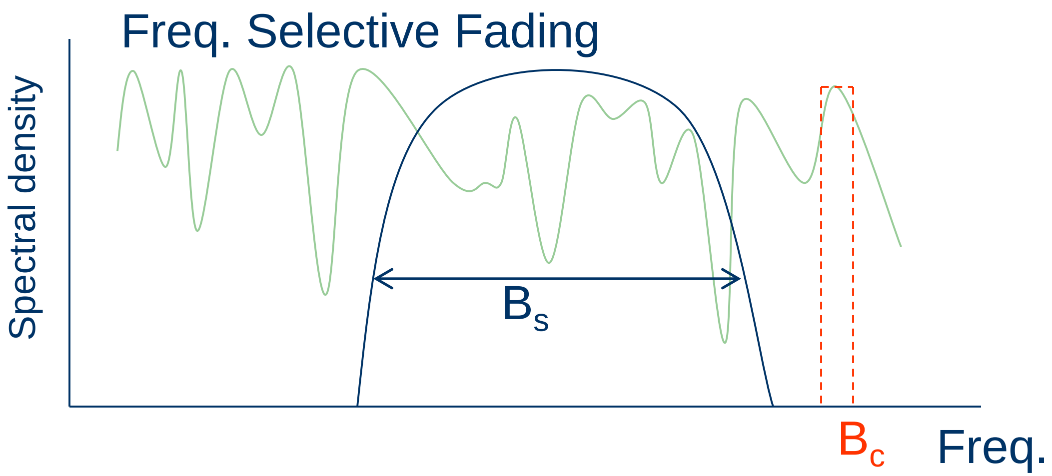
Fading mechanisms

- **Frequency Dispersion**
  - Time variations of the channel are caused by motion of the antenna
  - Channel changes every half a wavelength
  - Moving antenna gives Doppler spread
  - Fast fading requires short packet durations, thus high bit rates
  - Time variations poses requirements on synchronization and rate of convergence of channel estimation
  - Interleaving may help to avoid burst errors
- **Time Dispersion**
  - Delayed reflections cause intersymbol interference (ISI)
  - Channel Equalization may be needed.
  - Frequency selective fading
  - Multipath delay spreads require long symbol times
  - Frequency diversity or spread spectrum may help
- **RSL Fluctuation**
  - Shadowing, obstruction, etc

Time Dispersion and Frequency Dispersion

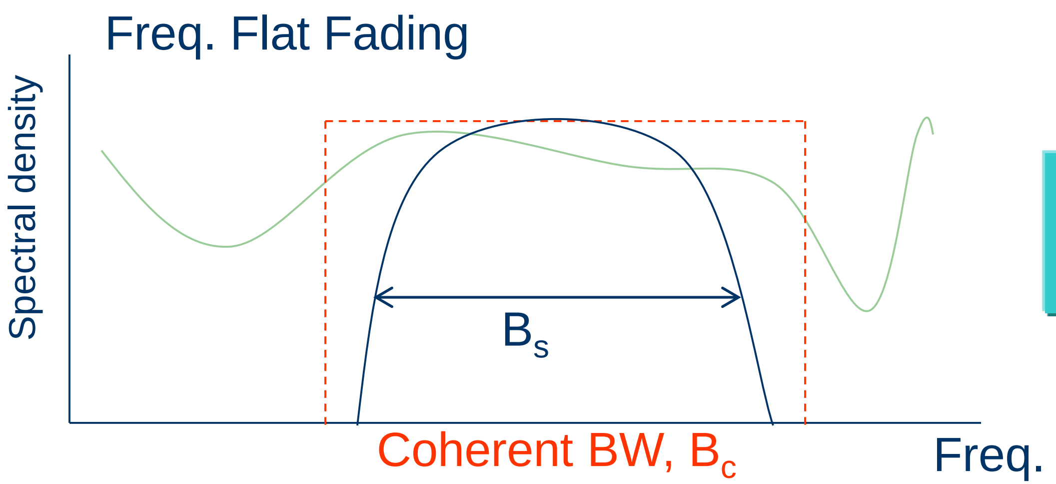
	Frequency Dispersion	Time Dispersion
Time Domain Interpretation	Channel variations Fast Fading Correlation Distance	Delay spread InterSymbol Interference Channel equalization
Frequency Domain Interpretation	Doppler spread Intercarrier Interference	Frequency selective fading Coherence bandwidth

Effect of Fading



TX BW > Channel BW

$B_s > B_c$

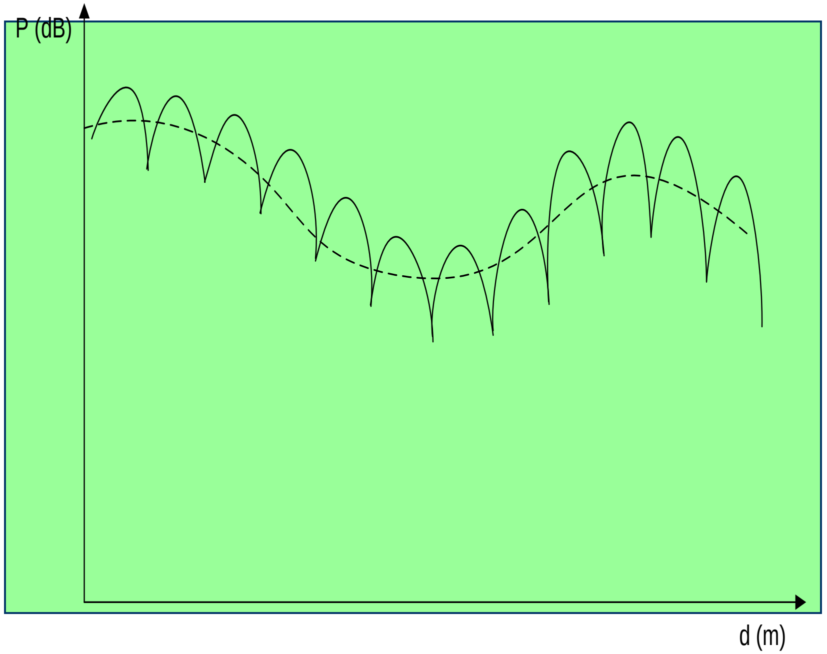


TX BW < Channel BW

$B_s < B_c$

Statistical Fluctuations

- Area-mean power
  - is determined by path loss
  - is an average over 100 m - 5 km
- Local-mean power
  - is caused by local 'shadowing' effects
  - has slow variations
  - is an average over 40 λ (few meters)



- Instantaneous power
  - fluctuations are caused by multipath reception
  - depends on location and frequency
  - depends on time if antenna is in motion
  - has fast variations (fades occur about every half a wave length)

Basic mitigation types

To combat distortion

Frequency-selective distortion

- Adaptive equalization (e.g., decision feedback, Viterbi equalizer)
- Spread spectrum — DS or FH
- Orthogonal FDM (OFDM)
- Pilot signal

Fast-fading distortion

- Robust modulation
- Signal redundancy to increase signaling rate
- Coding and interleaving

To combat loss in SNR

Flat-fading and slow-fading

- Some type of diversity to get additional uncorrelated estimates of signal
- Error-correction coding

Diversity types

- Time (e.g., interleaving)
- Frequency (e.g., BW expansion, spread spectrum FH or DS with rake receiver)
- Spatial (e.g., spaced receive antennas)
- Polarization

Fading Mitigation Techniques

- 3 techniques commonly used to combat the effect of fading without increasing TX Power and BW:
  - Diversity : space/spatial, time, frequency
  - Channel Encoding or *Error protection coding*
  - Equalization
- While Fading Margin and Power Control are used to maintain a good signal reception at Receiver.

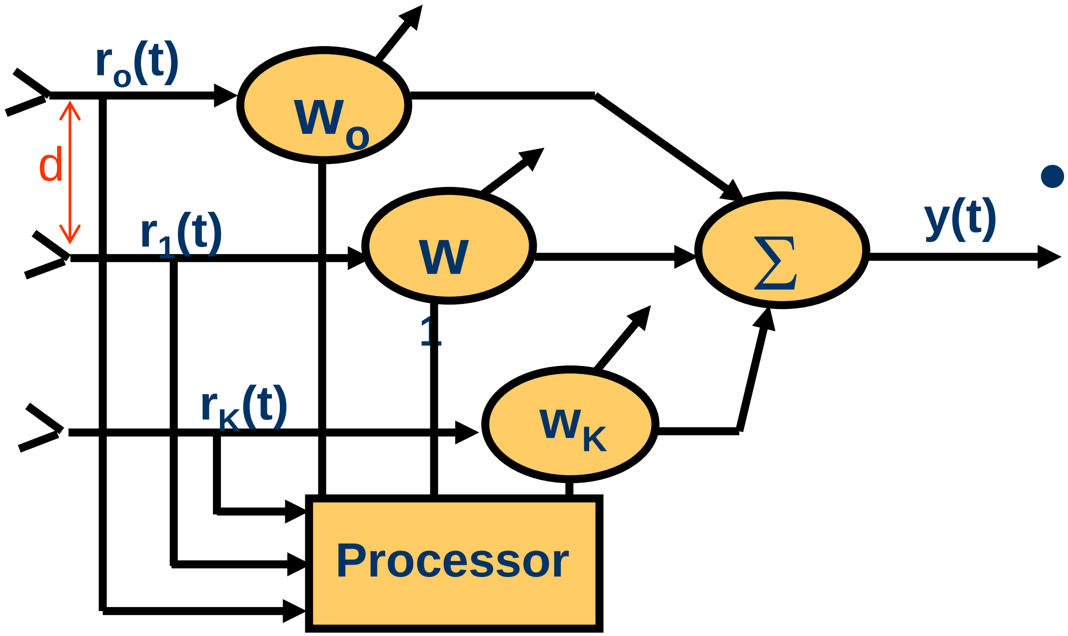
FMT: Diversity

- Diversity exploits the random nature of radio propagation by finding the independent signal paths. If one path undergo a deep fade, another path may have a strong signal.
- Usually employed to reduce the depth and duration of fade experienced by receiver in flat fading channel.
- Types of diversity: spatial, frequency, time, and polarization

Spatial Diversity

- Use two or more receiving antenna
- While one antenna sees a null signal, the others may receive a peak signals.
- The received signals are then combined and processed by an algorithm to get best reception.
- Can be implemented in both BS and MS receiver

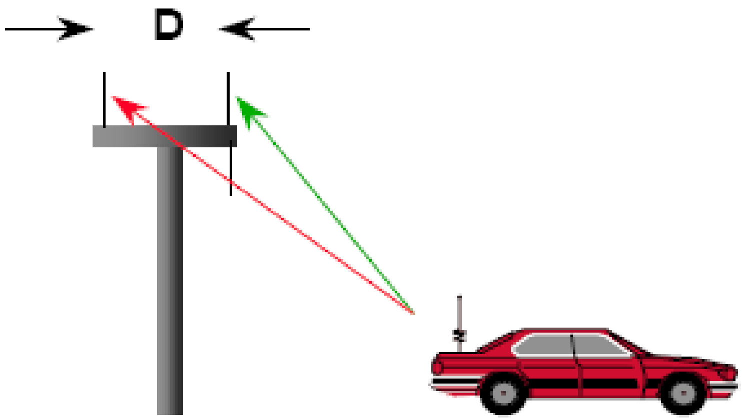
Spatial Diversity

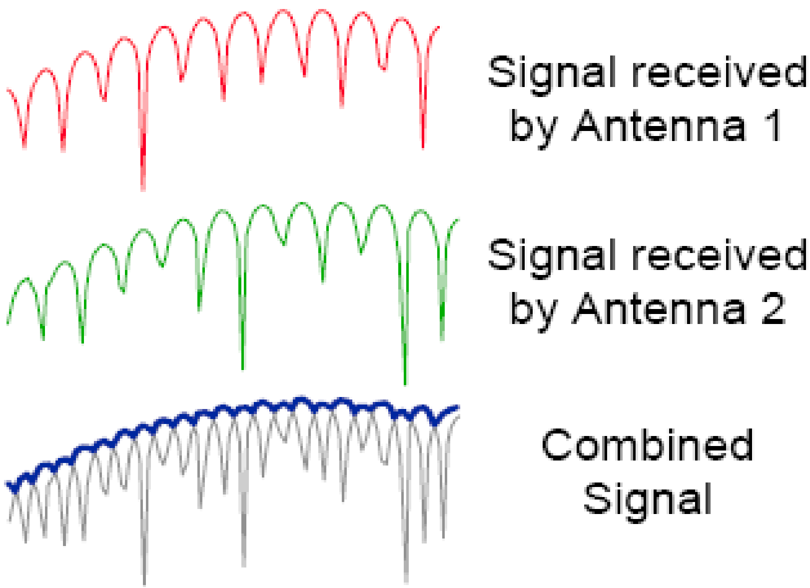


- Antenna is spaced each other by an odd integer multiply of $\lambda/4$, usually $d > 8\lambda$.
- Spatial diversity can improve SNR at receiver by as much as 20 dB to 30 dB.

- Combining algorithm commonly used: Selective, Equal gain, and Maximal ratio combining.

Space Diversity Application Limitations



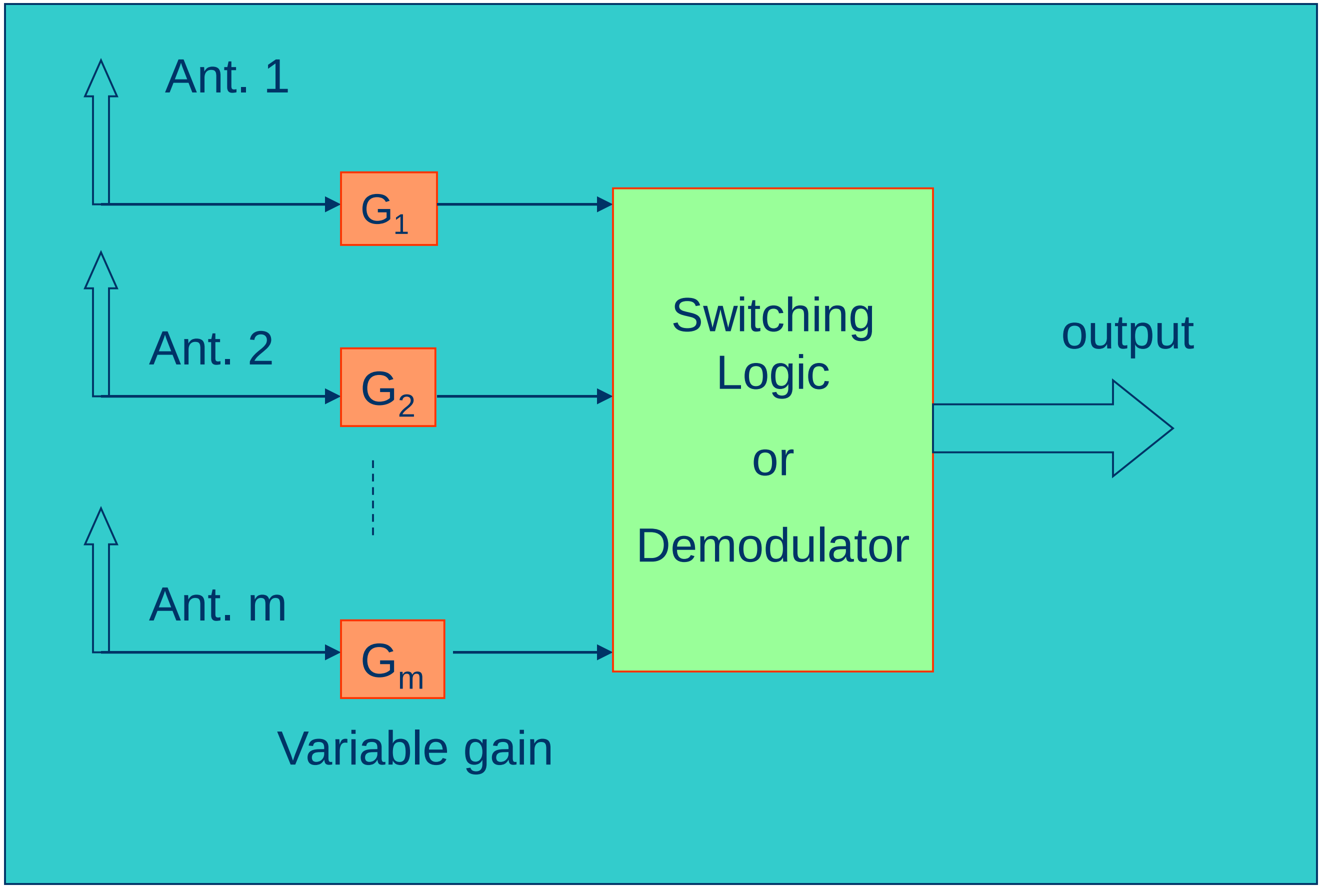


- Space Diversity can be applied only on the receiving end of a link.
- Transmitting on two antennas would:
  - fail to produce diversity, since the two signals combine to produce only one value of signal level at a given point -- no diversity results.
  - produce objectionable nulls in the radiation at some angles
- Therefore, space diversity is applied only on the “uplink”, i.e.., reverse path
  - there isn’t room for two sufficiently separated antennas on a mobile or handheld

Diversity Combining Methods

- **Switching/selection**
  - Memilih sinyal terkuat dari dua sinyal sesaat (*instantaneously*):
    - ~1 dB hysteresis saat pemilihan sinyal
  - Menyebabkan pergeseran fasa random (*random phase shifts*)
    - Akan menjadi problem bagi yang menggunakan modulasi fasa seperti IS-136, IS-95, where switch times between antennas is restricted to the boundaries of data bit fields
  - Struktur paling sederhana, dgn peningkatan C/(I+n) antara 1.5 sampai 4 dB
- **Equal gain**
  - *Adaptive phase shift hardware* digunakan untuk menggeser fasa salah satu kanal , disamakan fasanya dengan fasa kanal yang lain, untuk kemudian dijumlahkan secara koheren
  - 1.5 dB lebih baik dari switching diversity
- **Maximal ratio**
  - Seperti equal gain, tetapi sinyal yang lemah dikuatkan pada level rata-rata yang sama dengan sinyal yang kuat sebelum dijumlahkan
  - Paling kompleks , tetapi tipikalnya 2dB lebih baik dari switching diversity.

Selective Combiner



Selective Combining

- Receiver only select one strongest signal to detect.
- If average SNR of received signal in a branch = Γ, and threshold SNR = γ, then probability that M branches of antenna receive signals with SNR below the threshold is:

$$P(\gamma_i \leq \gamma) = P_M(\gamma) = (1 - e^{-\gamma/\Gamma})^M$$

- In other word, probability that received signal SNR above the threshold is :

$$P(\gamma_i > \gamma) = 1 - P_M(\gamma) = 1 - (1 - e^{-\gamma/\Gamma})^M$$

Selective Combining

Example: 4 antenna diversity is used. If average SNR is 20 dB, determine the probability that SNR will drop below 10 dB (bad reception), and also that good reception (SNR above 10 dB) will mostly take place. Compare with single antenna receiver!

Answer:

Threshold SNR = γ = 10 dB, Γ = 20 dB, γ/Γ = 0.1

$$P_4(\gamma_i \leq 10 \text{ dB}) = (1 - e^{-0.1})^4 = 0.000082, \text{ and}$$

$$P_4(\gamma_i > 10 \text{ dB}) = 1 - (1 - e^{-0.1})^4 = 0.999918 \text{ or } 99.9918\%$$

With single antenna:

$$P\,(\gamma_i \leq 10 \text{ dB}) = (1 - e^{-0.1}) = 0.095, \text{ and}$$

$$P\,(\gamma_i > 10 \text{ dB}) = 1 - (1 - e^{-0.1}) = 0.905 \text{ or } 90.5\%$$

Improvement factor about 3 order in magnitude!

Selective Combining

Perbaikan SNR:

$$\frac{\gamma}{\Gamma} = \sum_{k=1}^{M} \frac{1}{k}$$

Pada contoh di atas:

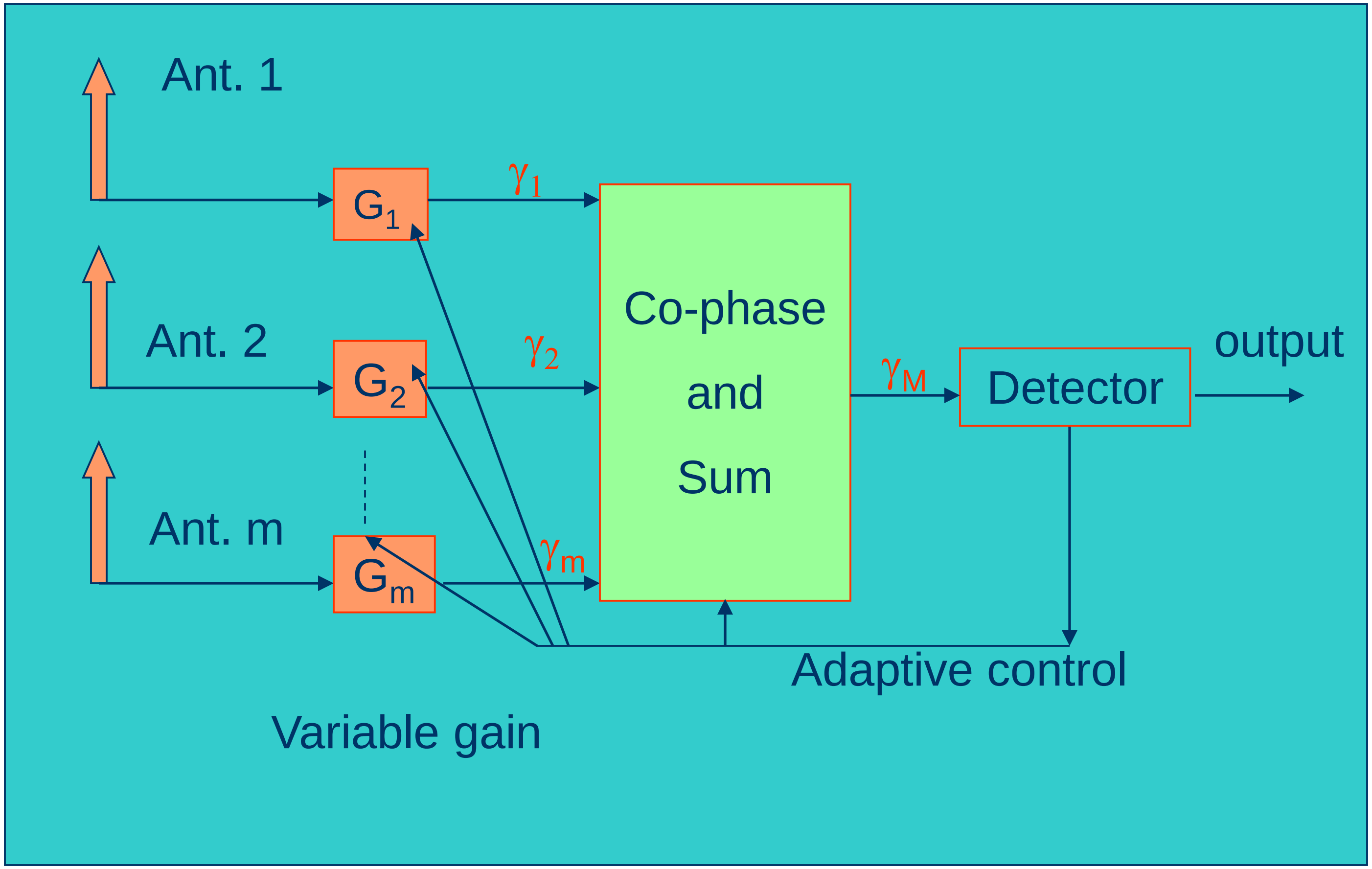
$$\frac{\gamma}{\Gamma} = \sum_{k=1}^{M} \frac{1}{k} = 1 + 0.5 + .333 + 0.25 = 2.083 \times$$

Improvement factor about <u>twice</u> in SNR!

Equal Gain Combining

- If weight of each branch is set to unity and co-phased, Max. ratio combining become equal gain combining.
- Less complex with slightly lower performance than max. ratio combining.
- Without continuously adapt each weight of branches differently, it allows receiver to exploit received signals simultaneously.

Max. Ratio Combiner



Max. Ratio Combining

- Signals from each branch/antenna are co-phased and individually weighted to provide coherent addition to get optimal SNR.
- Probability that received signal SNR below threshold is:

$$P(\gamma_M \le \gamma) = 1 - e^{-\gamma/\Gamma} \sum_{k=1}^{M} \frac{(\gamma/\Gamma)^{k-1}}{(k-1)!}$$

- Probability of good reception:

$$P(\gamma_M > \gamma) = e^{-\gamma/\Gamma} \sum_{k=1}^{M} \frac{(\gamma/\Gamma)^{k-1}}{(k-1)!}$$

Maximal Ratio Combining

SNR improvement:

$$\gamma_M = \sum_{k=1}^{M} \Gamma = M \ \Gamma$$

$$\frac{\gamma_M}{\Gamma} = M$$

In the example above :

$$\frac{\gamma_M}{\Gamma} = M = 4\times$$

Probability (good signal)=

$e^{-0.1}(1+0.1+0.1^2/2+0.1^3/6)=0.9999961531$

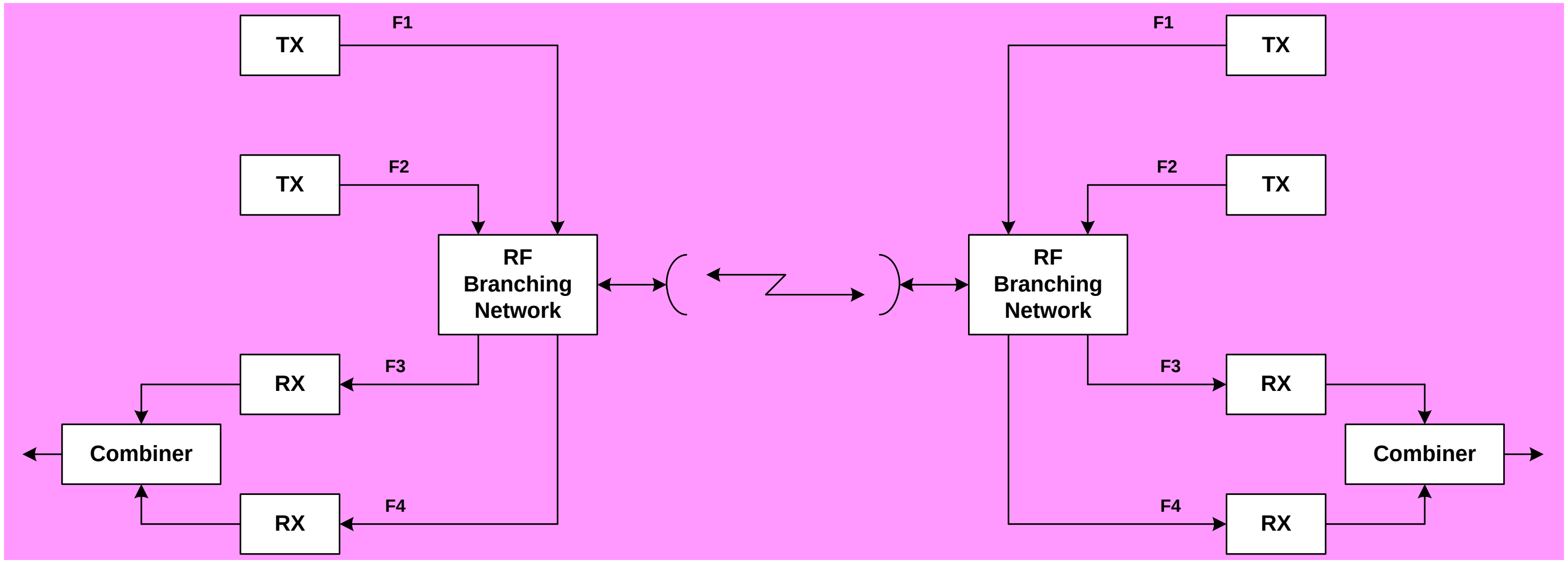
Improvement factor about <u>four times</u> in SNR!

Frequency Diversity

- Use two or more carrier frequency for transmission with spacing about 2 – 5 % f_o.
- Need to employ two or more Transmitter and Receiver
- Improvement factor :

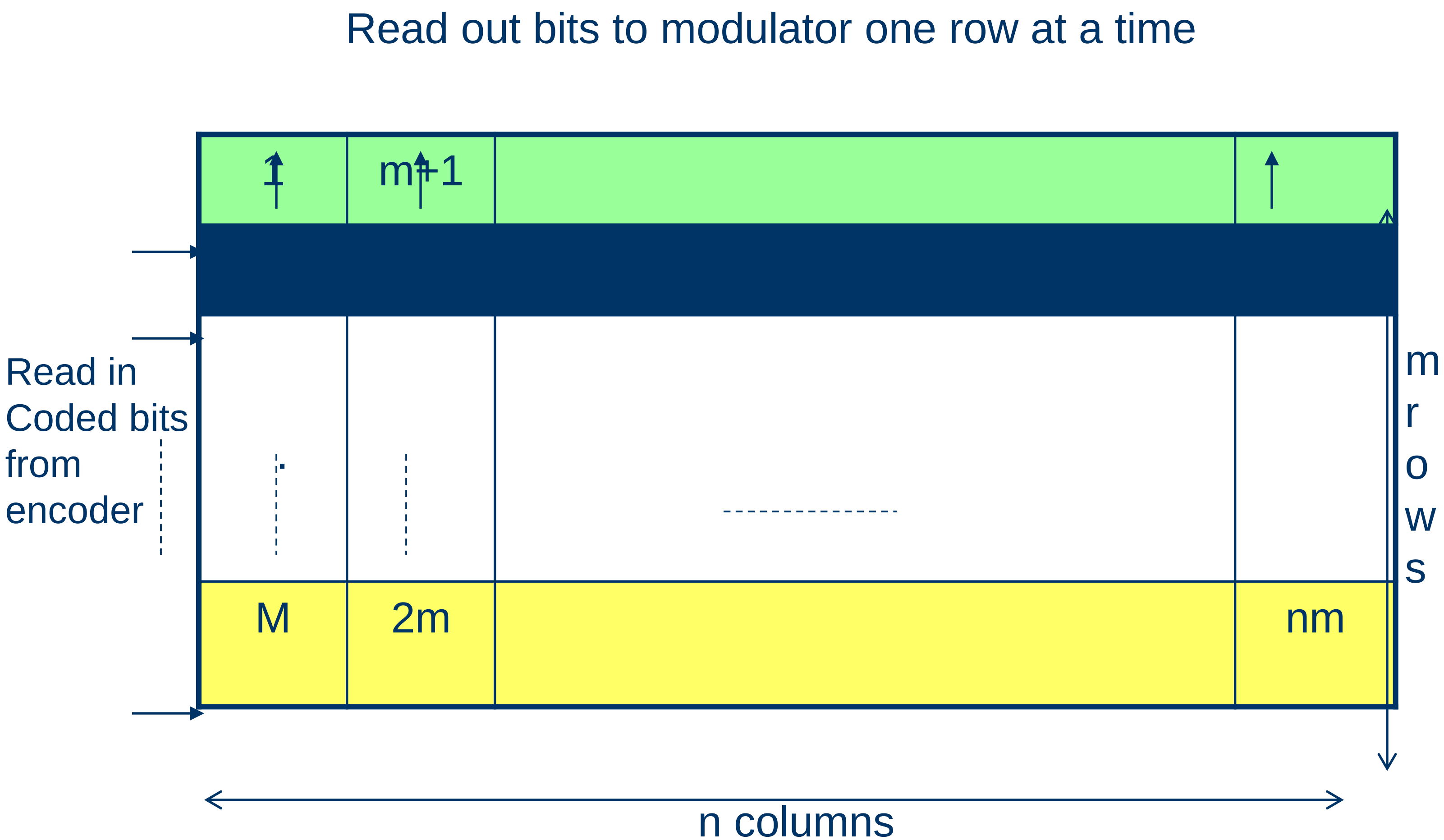
$$I_f \approx \frac{0.8\,\Delta f\,10^{F/10}}{f^2\,d}$$

where Δf = frequency separation (GHz)
F = fade depth (dB)
f = carrier frequency (GHz) $(2 \le f \le 11)$
d = hop length (km) $(30 \le d \le 70)$

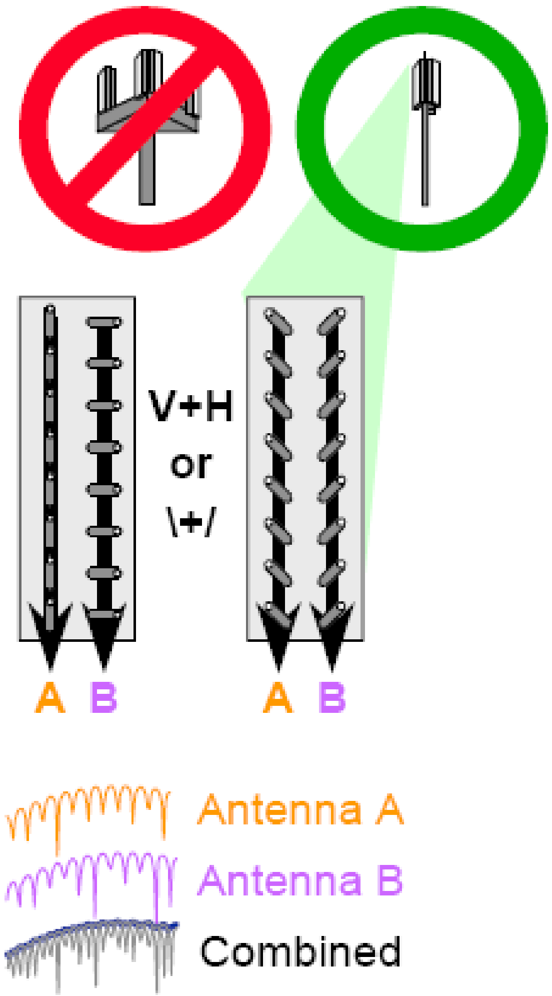


Time Diversity

- Interleaver



Using Polarization Diversity
Where Space Diversity Isn't Convenient



- Sometimes zoning considerations or aesthetics preclude using separate diversity receive antennas
- Dual-polarized antenna pairs within a single radome are becoming popular
  - Environmental clutter scatters RF energy into all possible polarizations
  - Differently polarized antennas receive signals which fade independently
  - In urban environments, this is almost as good as separate space diversity
- Antenna pair within one radome can be V-H polarized, or diagonally polarized
  - Each individual array has its own independent feedline
  - Feedlines connected to BTS diversity inputs in the conventional way; TX duplexing OK

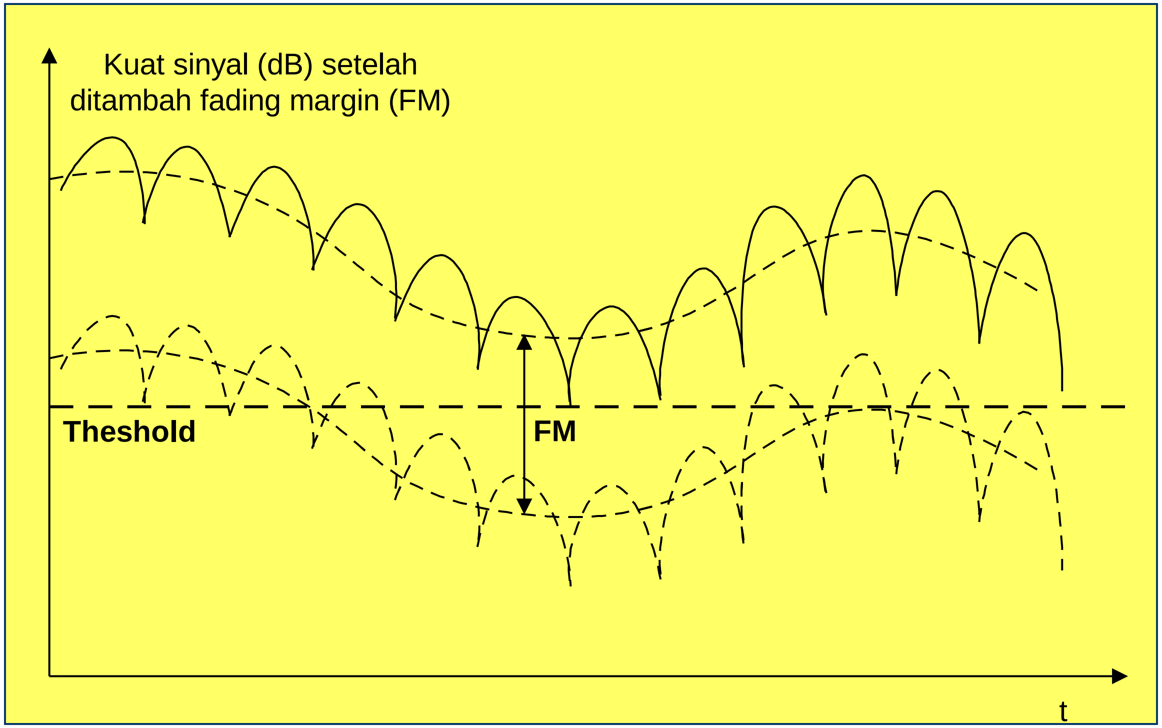
Channel Encoding

- Channel encoding is done by encode the data into a special form, and introduce redundancies in the transmitted data.
- It protects data/information from error and distortion introduced by the channel.
- Redundant bits increase data rate hence the bandwidth, but improve BER performance especially in fading channel.
- Reduce BW efficiency of the link in high SNR condition, but provide excellent performance in low SNR condition
- Two types mostly used: ***Block Codes, Convolutional Codes and Turbo Codes***

- Channel Coding meningkatkan kinerja hubungan small scale dengan penambahkan bit data dalam pesan yang dikirimkan sehingga jika terjadi suatu pelemahan seketika itu terjadi dalam saluran, data masih dapat dipulihkan pada penerima
- Channel coding digunakan oleh penerima untuk mendeteksi atau memperbaiki beberapa (atau semua) dari kesalahan terdapat pada saluran dalam urutan tertentu bit pesan

Fading Margin

- Fading margin depends upon target *availability* of the link/ coverage.
- Greater *availability* requires larger fading margin.



Fading Margin

If fading margin FM applied to the link, then probability that RSL at receiver separated at distance R above the threshold can be written as:

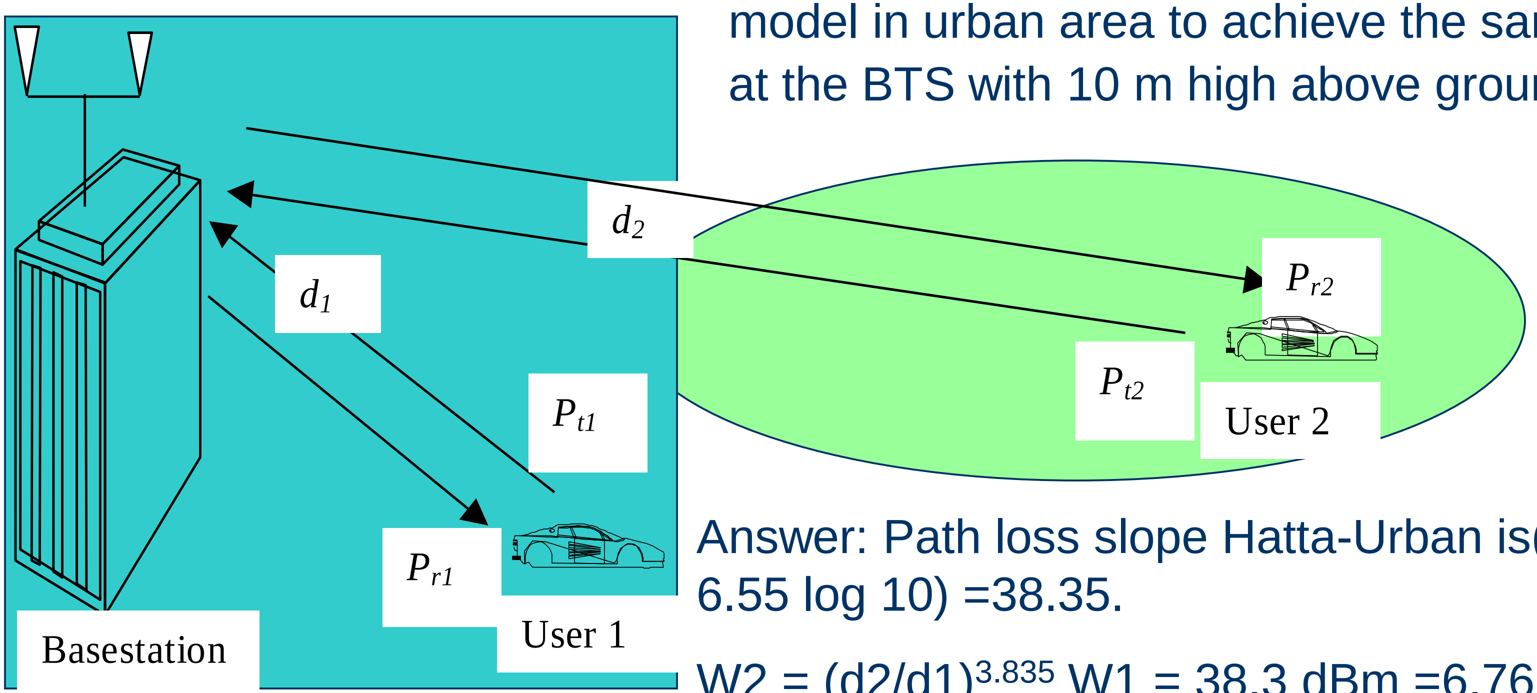
$$P_{Th}(R) = P(m \geq Th) = \int_{Th}^{\infty} p(m)dm = \frac{1}{2} - \frac{1}{2}\operatorname{erf}\left(\frac{FM}{\sigma_m \sqrt{2}}\right)$$

Fading margin improve signal reception hence the link performance, in an expense of increasing transmission power.

Power Control

- Mitigating the effect of shadowing and near-far problem

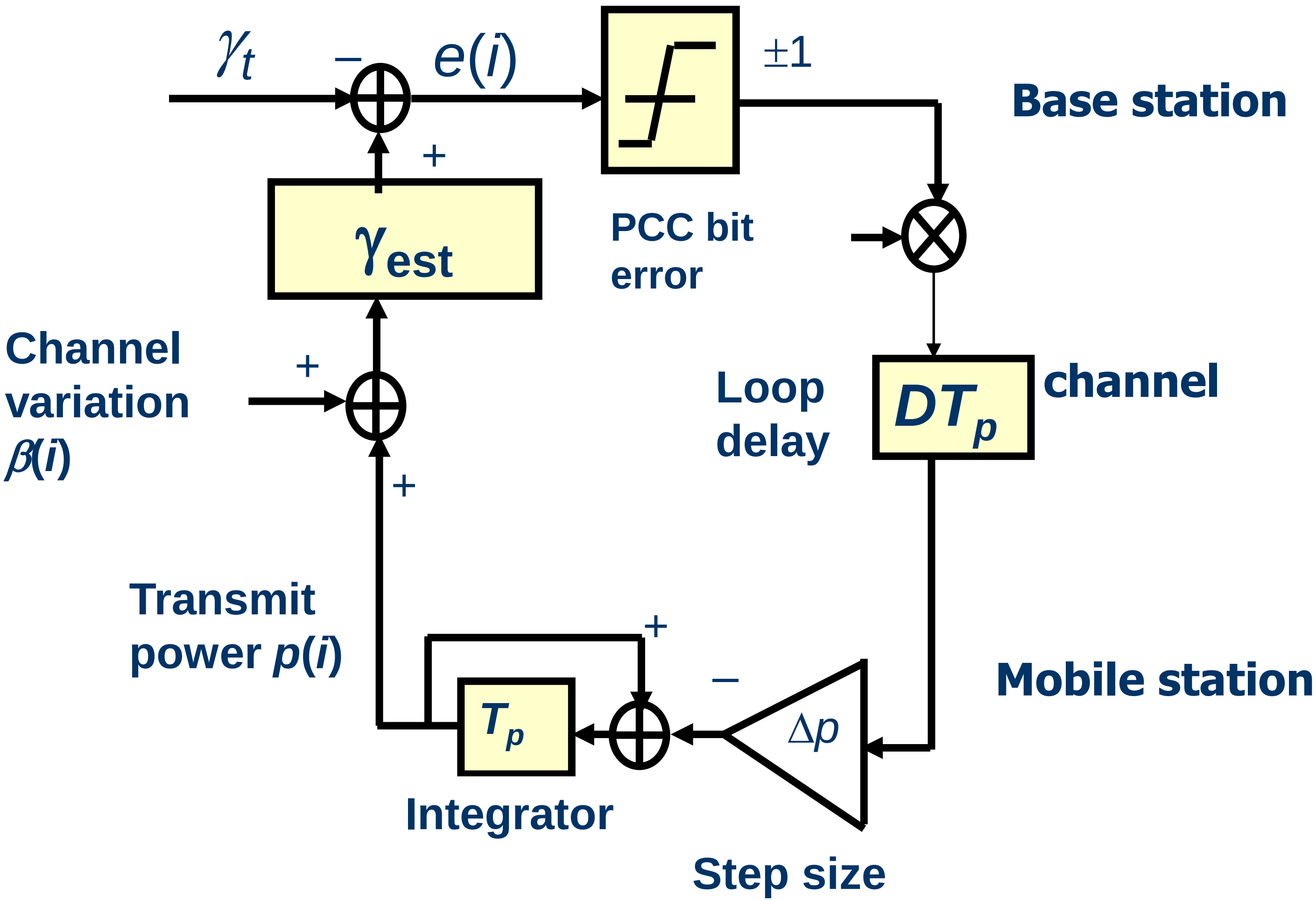
If user 1 at 3 km from BTS transmitting with 100 mWatt, how much power is needed by user 2 at 9 km away from BTS using Okumura Hatta model in urban area to achieve the same power at the BTS with 10 m high above ground level?



Answer: Path loss slope Hatta-Urban is(44.9 – 6.55 log 10) =38.35.

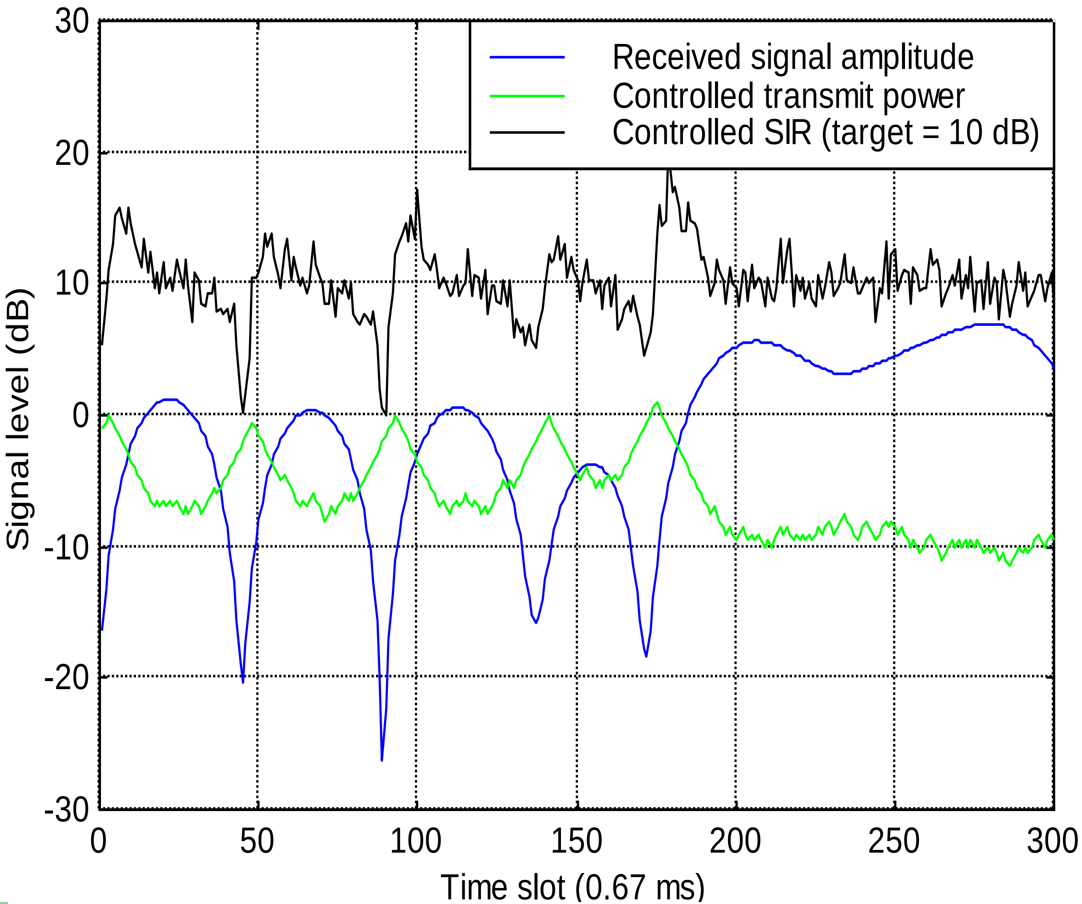
W2 = $(d2/d1)^{3.835}$ W1 = 38.3 dBm =6.76 Watt

Small Scale Fading Mitigation - Power Control



Power Control

- Rayleigh fading



Channel is estimated at the receiver, then Tx is instructed to adjust Tx power according to the estimated channel (e.g. SNR).

Problem:

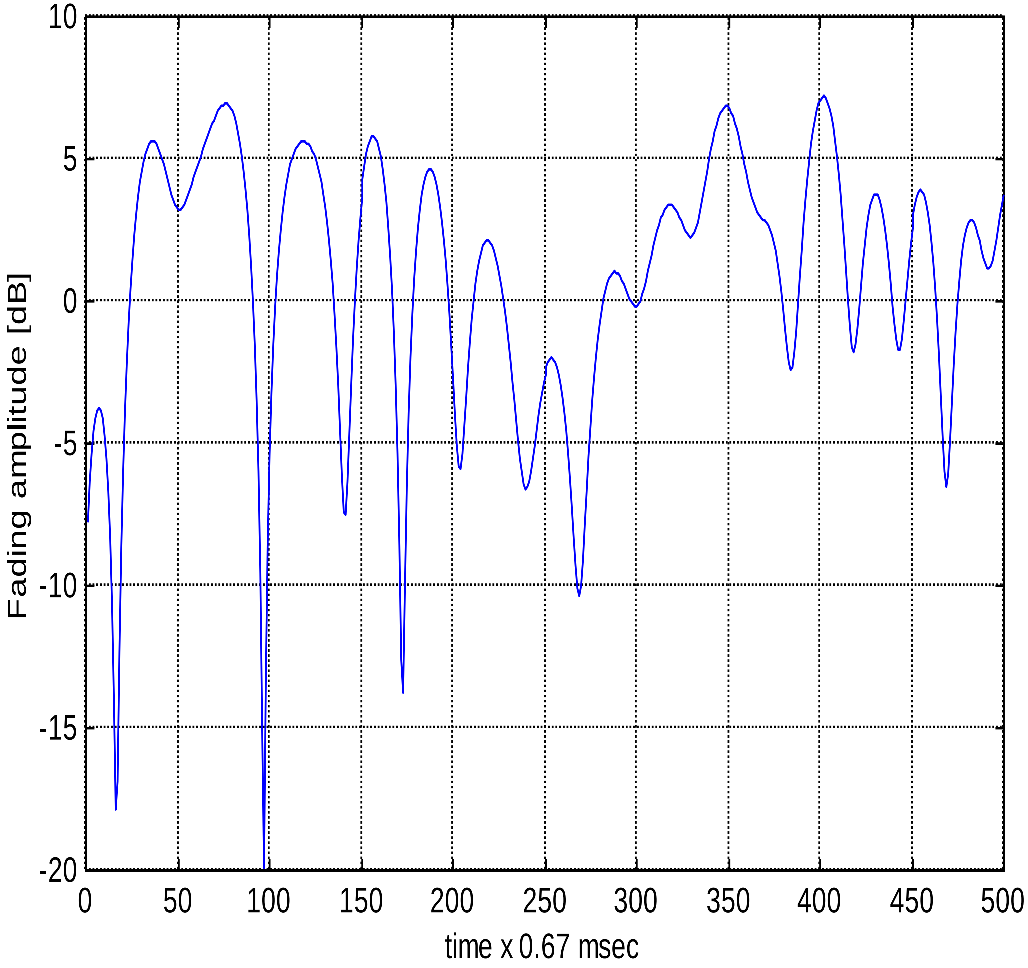
Control rate >> fading rate

Control step size → single step or variable step

What is the benefit/drawbacks of single or variable step size ?

Small Scale Fading Mitigation - Power Control

- Example for fading rate fd= 5o Hz (vehiche speed 30 km/hr at 1.8 GHz).



Fading channel

$$\overline{P_e} = BER = \frac{1}{2}\left(1 - \sqrt{\frac{\bar{\gamma}/2}{1+\bar{\gamma}/2}}\right)$$

$$= \frac{1}{2}\left(1 - \sqrt{\frac{\overline{E_b/I_0}}{1+\overline{E_b/I_0}}}\right)$$

AWGN channel

$$\overline{P_e} = BER = Q\left[\sqrt{2\frac{E_b}{N_0}}\right]$$

Small Scale Fading Mitigation - Power Control

Example

- To achieve a satisfactory power control performance when a vehicle moving at 30 km/h (carrier freq = 1.8 GHz) the rate of power control is at least 30 times higher than the fading rates.
  - Compute the minimum signalling rate required for power control.
  - If the voice channel is transmitted at 9.6 kbps, what percentage of band width is lost due to power control with (a) fixed step algorithm (b) variable step with 3 bit algorithm
  - If the deepest fading is 30 dB below its average level, what is the incremental power ajustment (step size) if fixed step adjustment is employed to equalize the deepest fading.

Mengatasi *Large Scale Fading*

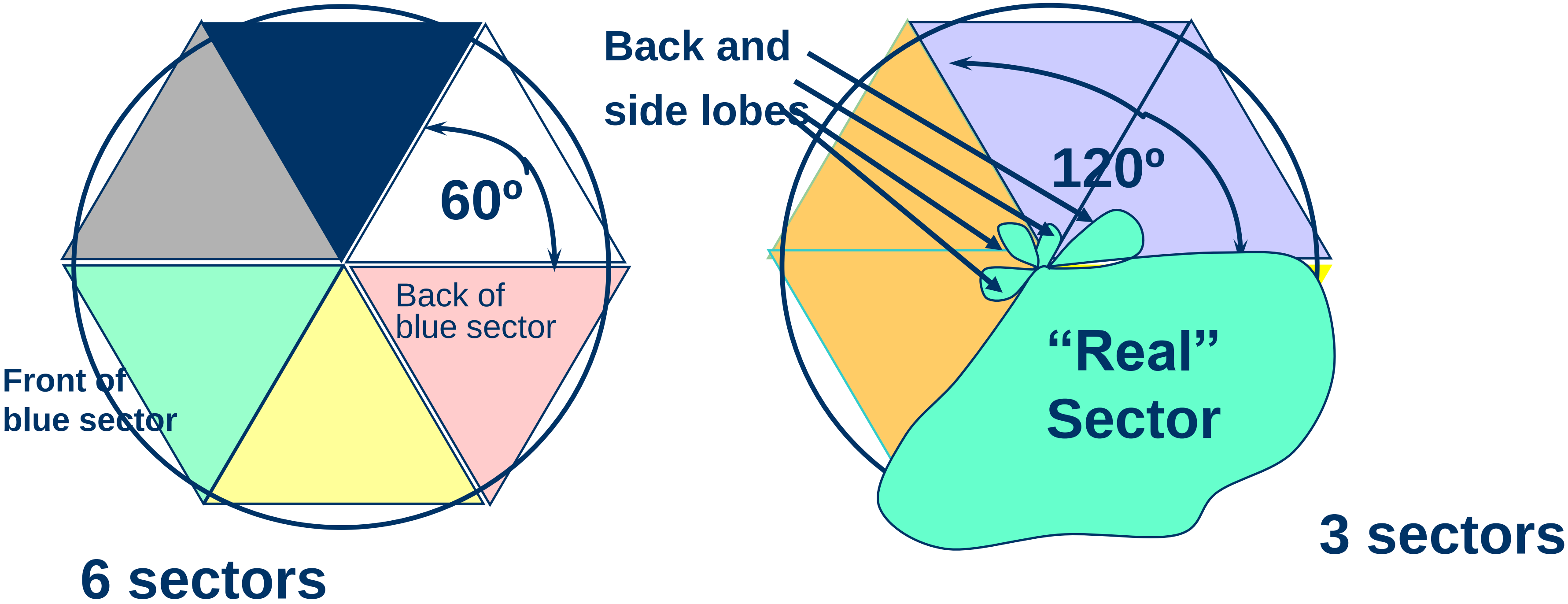
Antena Sektoral dan Smart Antenna

- Narrow sector akan mengurangi Co-channel interference
  - Mengijinkan pengulangan frekuensi yang lebih dekat secara geografis
  - Sehingga: lebih banyak carrier per-sel → lebih besar kapasitas
- Tetapi… sering *back* dan *side lobe* menjadi problem
  - Menghasilkan "spot" *co-channel interference*
    - Merupakan interferensi tak terduga yang sulit diidentifikasi dan diatasi
  - "smart antennas" (*adaptive phased arrays*) dapat mengatasi persoalan ini lebih baik (tetapi *high cost*)

Mengatasi *Large Scale Fading*

Antena Sektoral dan Smart Antenna

- Representasi hexagon ideal → idealnya tidak ada “back” antenna signal pada arah uplink maupun downlink



Real sectored cells are non-ideal in several ways. One important difference: There is non-negligible power radiated in the back and side regions, and the amount of such back and side “lobe” power is greater for narrow sectors than for wide angle sectors.

Teknik-Teknik Anti *Frequency Selective Fading*

Teknik ***anti frequency selective fading*** diperlukan jika bandwidth sinyal lebih besar dari bandwidth koheren kanal seperti yang sudah dijelaskan pada bagian sebelumnya.

Teknik-teknik yang biasa dilakukan [PEI 97] adalah :

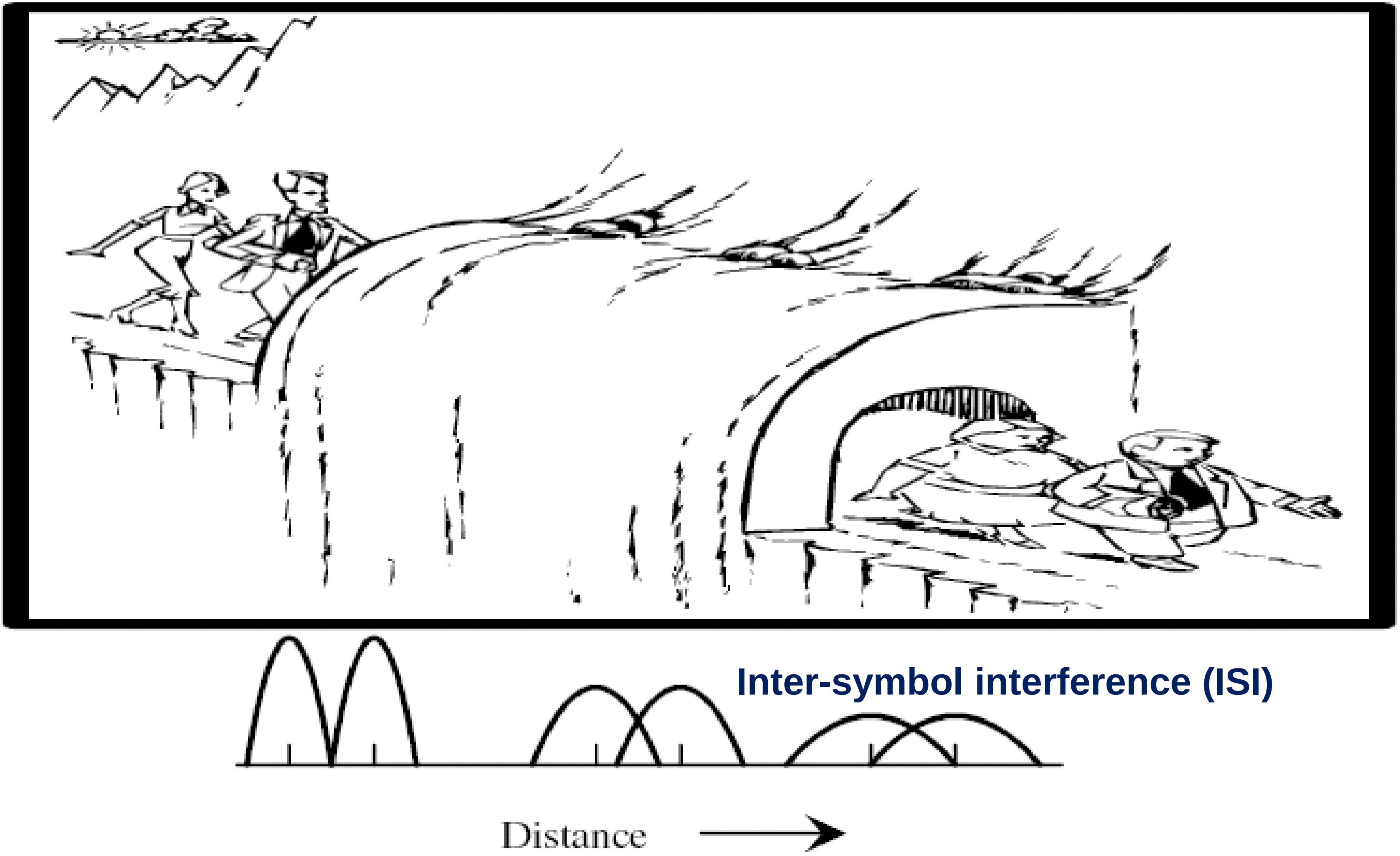
- **Decision Feedback Equalizer** dengan RLS Algorithm (algoritma Kalman), Fast Kalman Algorithm, dan juga Tap Gain Interpolasi
- **Adaptive Array Antenna ➔ beamforming**
- **Rake Diversity** untuk sinyal *spread spectrum*
- **Multicarrier technique**
- dll

Pertanyaan :
Sejauh mana unjuk kerja masing-masing perangkat tersebut dalam memperbaiki *frequency selective fading* ? Pelajarilah dan diskusikan dengan teman anda

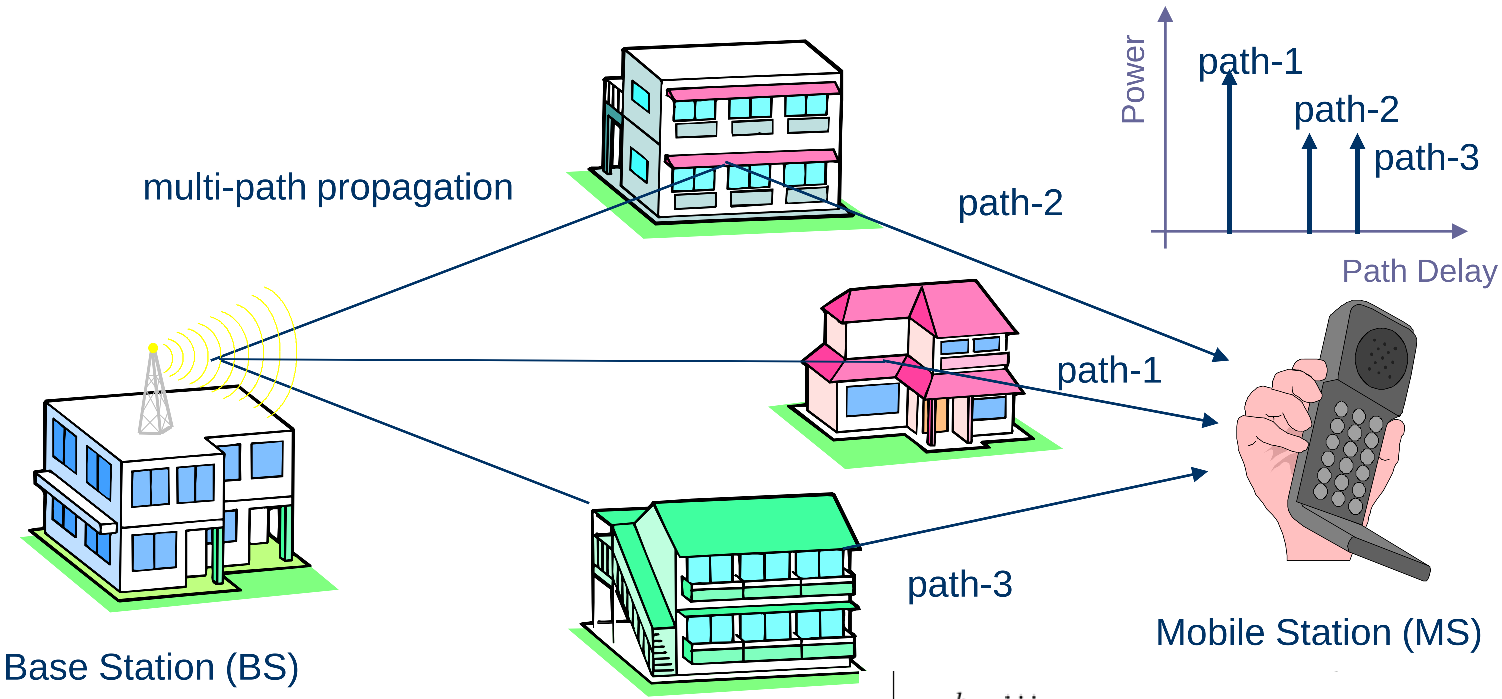
Mengatasi *Small Scale Fading* - *InterSymbol Interference (ISI)*

- Ketika multipath delay spread mulai lebih besar 20% dari durasi symbol , ISI dapat menjadi problem. Untuk mengatasi ISI...
- **Pertama**, receiver terpasang dengan *adaptive equalizer*
  - *Adaptive equalizer* (and also the similar “RAKE receiver” used for CDMA) produces delayed copy/ies of the received signal waveform and use(s) these copy/ies to cancel the physically delayed radio signals
  - Equalixer ini mendeteksi/mengetahui efek multipath delay pada deretan training bit yang diketahui, dan menggunakan informasi itu untuk mengatasi ISI pada deretan bit informasi dengan cara memberikan replika delay internal pada sinyal
- **Kedua**, penggunaan *error protection codes* (*channel coding*) untuk mendeteksi/mengkoreksi error (baik yang disebabkan ISI ataupun fading)
- ***You know ?* …. ISI tak dapat diatasi dengan penguatan sinyal.**

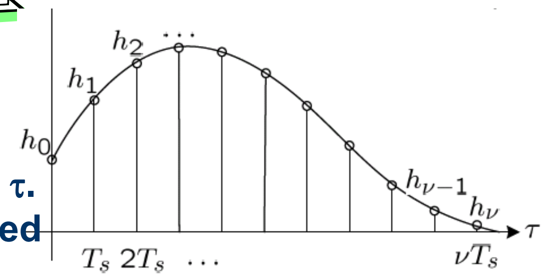
Attenuation, Dispersion Effects: ISI!



Multipaths: Power-Delay Profile



Channel Impulse Response:
Channel amplitude |h| <u>correlated</u> at delays τ.
Each "tap" value @ kTs Rayleigh distributed
(actually the sum of several sub-paths)



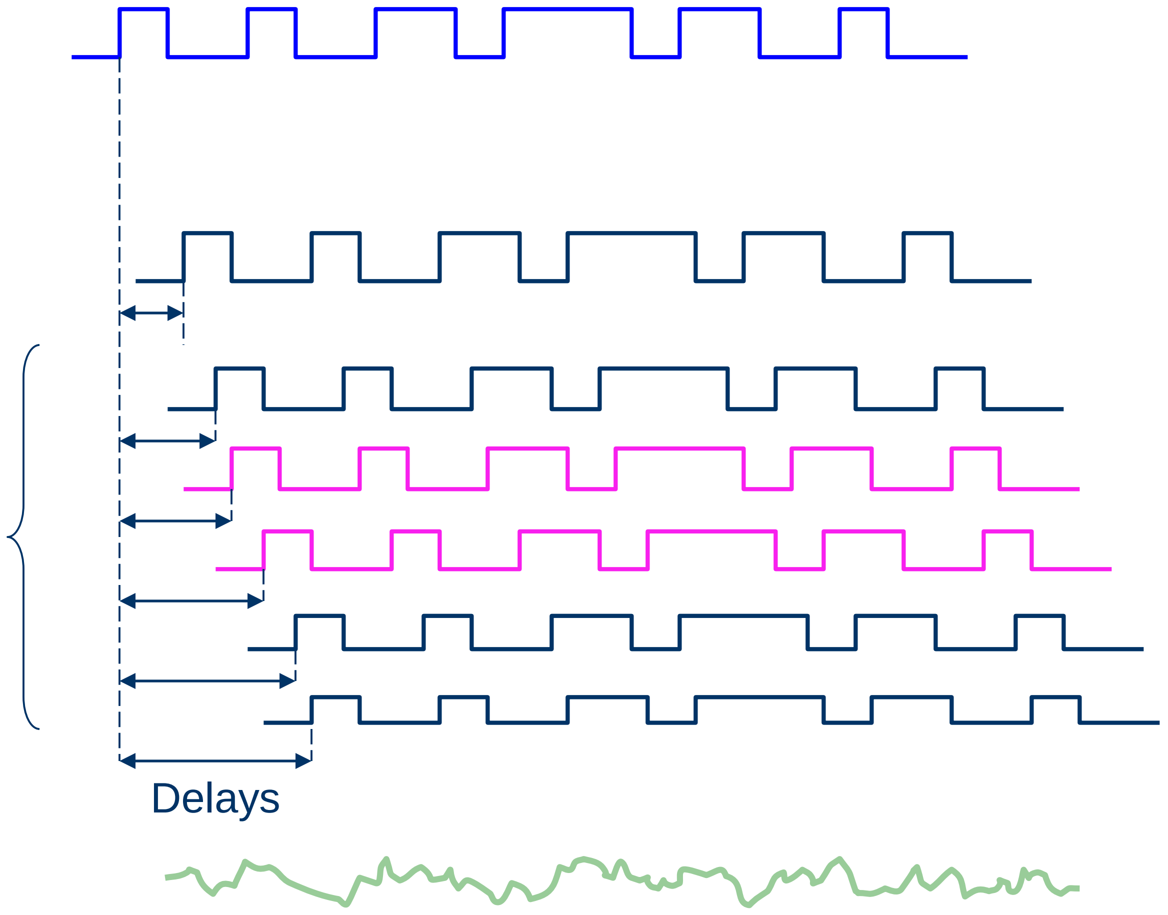
Inter-Symbol-Interference (ISI) due to Multi-Path Fading

Transmitted signal:

Received Signals:

Line-of-sight:

Reflected:



The **symbols add up** on the channel

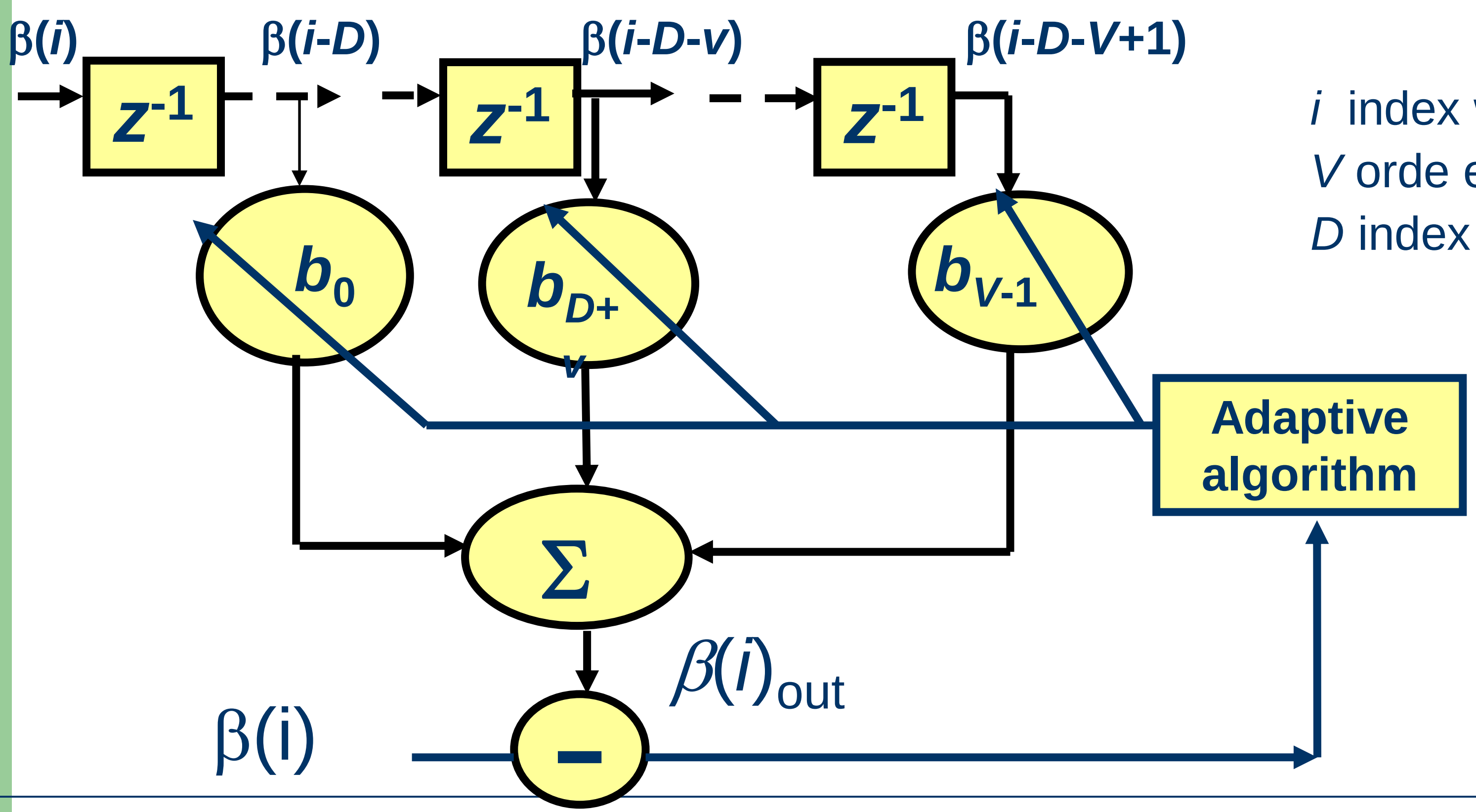
→ **Distortion!**

Types of Equalizer

- **Linear:**
  - Transversal filter (Zero forcing, LMS, RLS, fast RLS, Sq. root RLS)
  - Lattice Filter (Gradient RLS)
- **Non Linear:**
  - DFE (LMS, RLS, Fast RLS, Sq. root RLS)
  - ML Symbol Detection
  - MLSE

Channel Equalizer

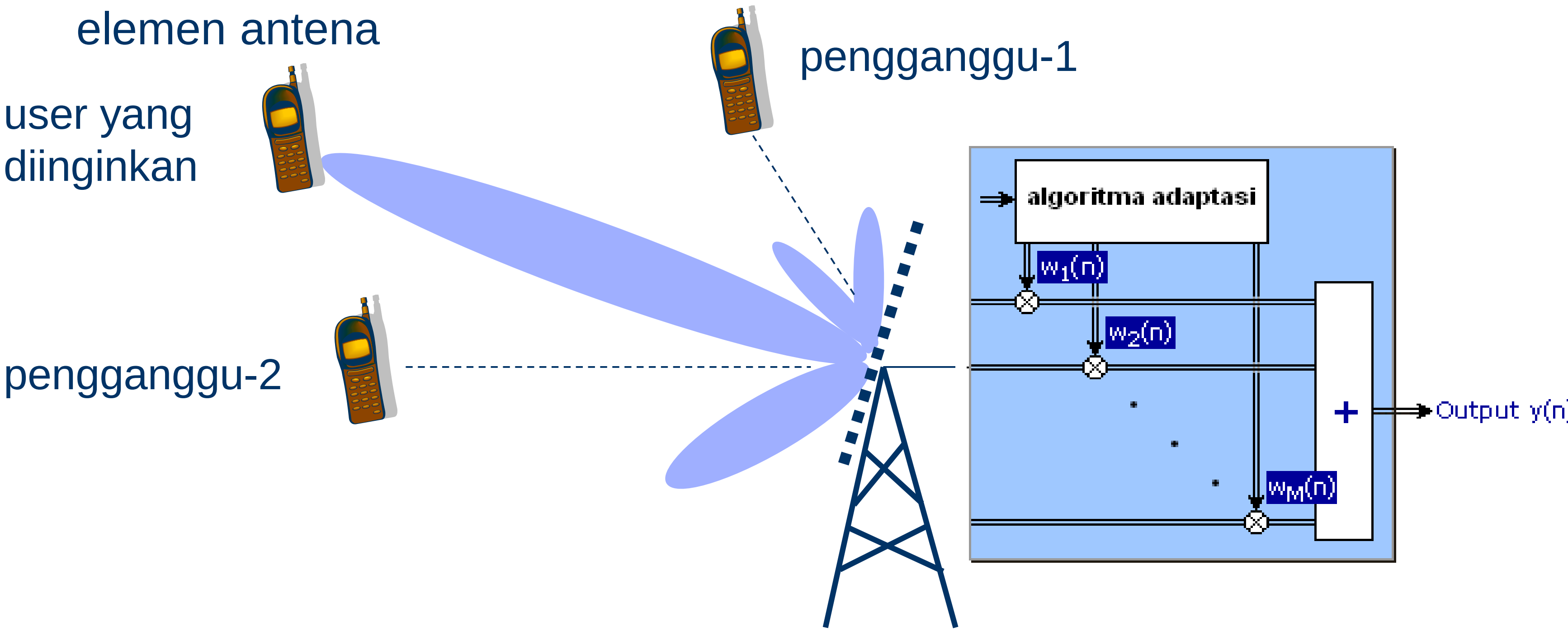
- Channel equalizer diperlukan untuk mengkompensasi ISI yang disebabkan kanal multipath (*Freq. Selective Fading Channel*).
- Karena *multipath fading channel* bersifat dynamic random → equalizer hrs bersifat **adaptif**



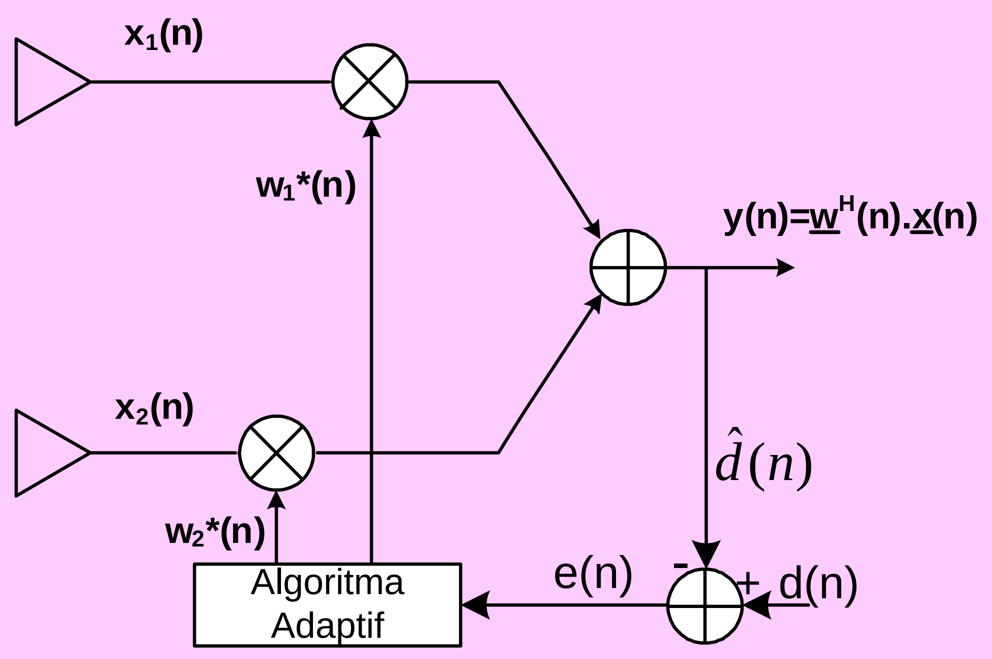
i index waktu
V orde equalizer
D index delay

Beamforming

- *Beamforming* adalah proses pembentukan beam menuju ke arah user yang diinginkan serta menekan sinyal pengganggu dari arah lain. Dengan demikian, *beamforming* bisa dikatakan sebagai spatial filtering sinyal
- Pembentukan beam ke arah sinyal yang diinginkan bisa dilakukan dengan memberikan pembobotan dengan algoritma adaptif pada elemen antena



Beamforming dengan kriteria MMSE (Minimum Mean Squared Error)



- MSE, E{|e(n)|²} diminimumkan. Disini *e(n)* adalah

$$e(n) = d(n) - \underline{w}^H . \underline{x}(n)$$

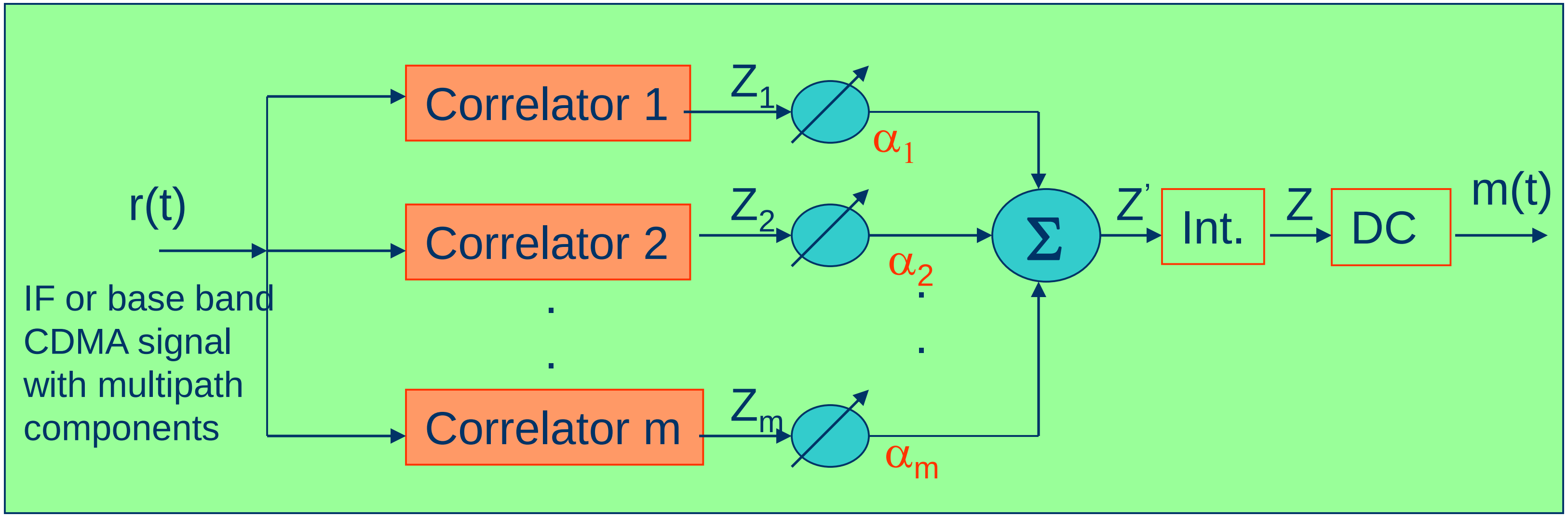
- Solusi optimum Wiener diberikan oleh

$$\underline{w}_{opt} = \underline{R}_{xx}^{-1} . \underline{r}_{xd}$$

$$\underline{R}_{xx} = E\left[\underline{x}(n)\underline{x}^H(n)\right]$$ adalah matriks kovarians sinyal terima

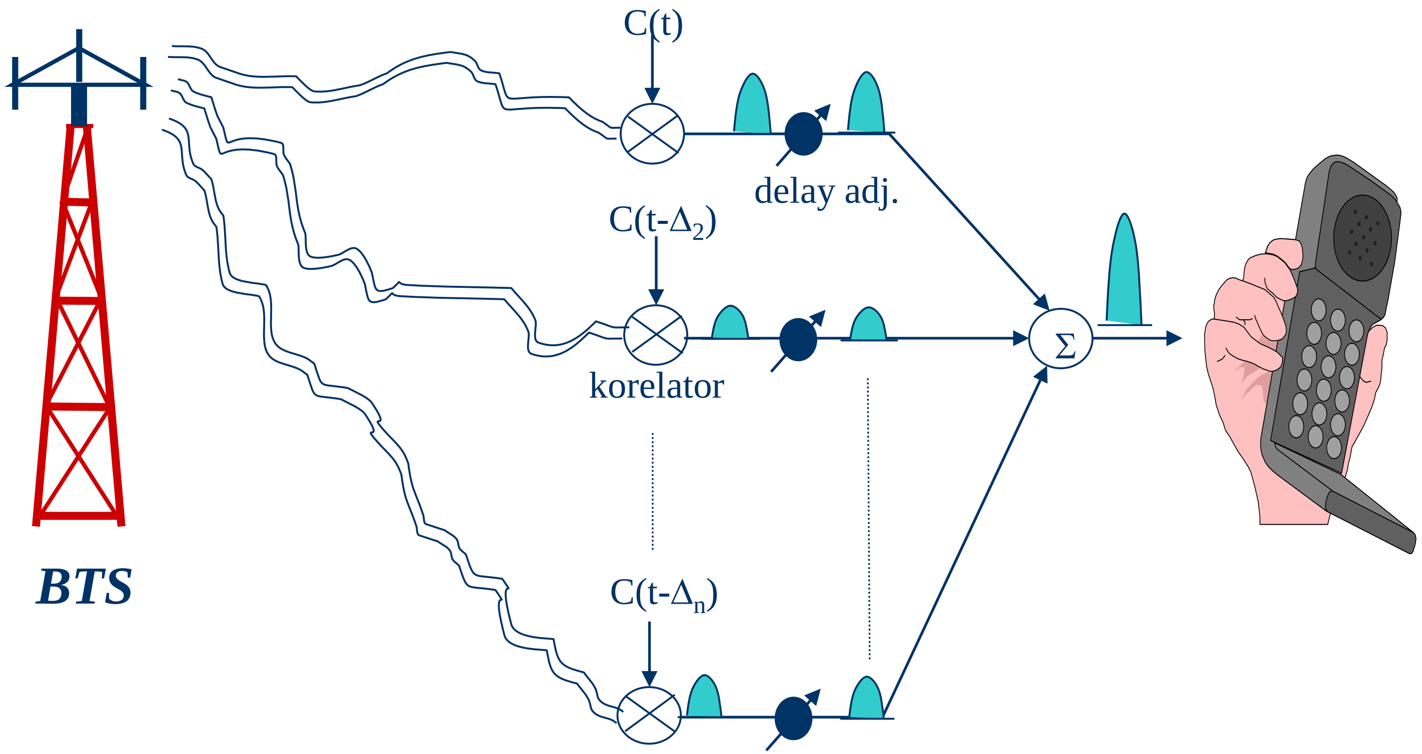
$$\underline{r}_{xd} = E\left[\underline{x}(n)d^*(n)\right]$$ adalah vektor kroskorelasi antara vektor sinyal terima $\underline{x}$ dan sinyal referensi *d* .

CDMA RAKE Receiver



Since chip rate of CDMA much greater than coherence BW, delay spread merely provide a multiple delayed version of signals at receiver. Instead of causing ISI, RAKE receiver attempts to collect multipath signals, process it by separate correlator receiver, and combine the signals to have a better detection.

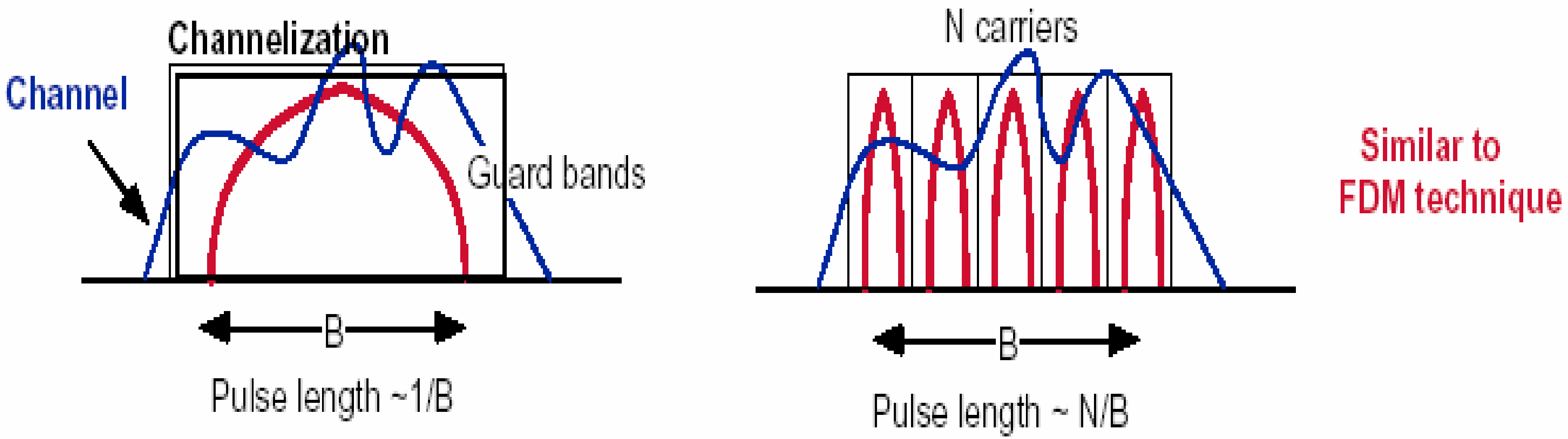
Rake receiver



Multicarrier CDMA:

➔*Gabungan OFDM dan CDMA*

Modulation techniques: monocarrier vs. multicarrier

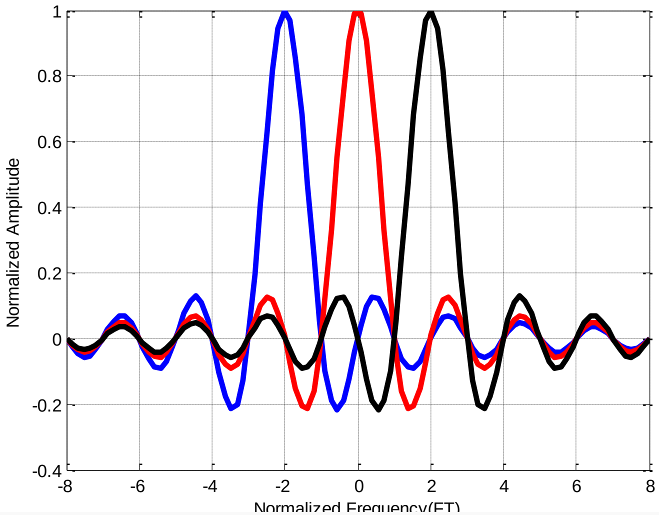


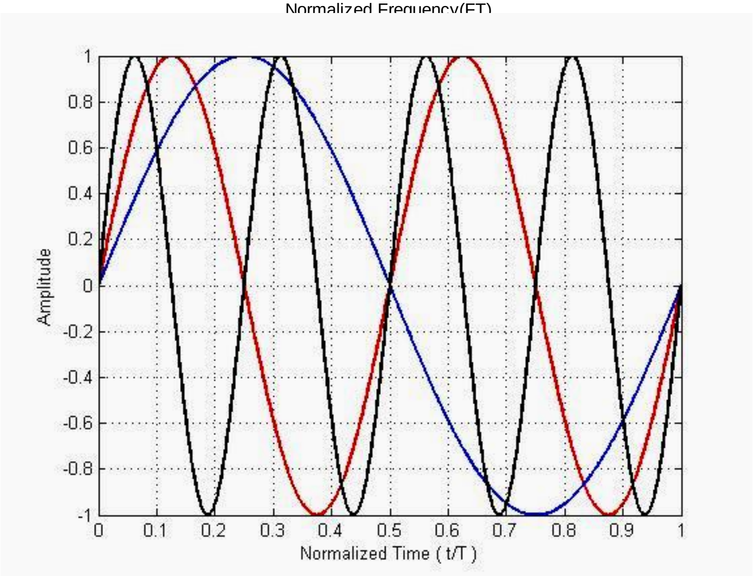
– Data are transmitted over **only one carrier**

– Data are shared among **several carriers** and simultaneously transmitted

OFDM

- membagi data serial kecepatan tinggi menjadi data paralel kecepatan rendah
- Data paralel tersebut dibawa oleh masing-masing *subcarrier*
- Antar *subcarrier* satu dengan yang lain saling orthogonal





Kasus-Kasus *Fading Mitigation*

How do systems handle Doppler Spreads?

- **Analog**
  - Carrier frequency is low enough to avoid problems
- **GSM**
  - Channel bit rate well above Doppler spread
  - TDMA during each bit / burst transmission the channel is fairly constant.
  - Receiver training/updating during each transmission burst
  - Feedback frequency correction
- **DECT**
  - Intended to pedestrian use:
  - only small Doppler spreads are to be anticipated for
  - Original DECT concept did not standardize an equalizer
- **IS95**
  - Downlink: Pilot signal for synchronization and channel estimation
  - Uplink: Continuous tracking of each signal

Kasus-Kasus *Fading Mitigation*

How do systems handle delay spreads? → fenomena ISI

Analog

- Narrowband transmission

GSM

- Adaptive channel equalization
- Channel estimation training sequence

DECT

- Use the handset only in small cells with small delay spreads
- Diversity and channel selection can help a little bit
  "pick a channel where late reflections are in a fade"

IS95

- Rake receiver separately recovers signals over paths with excessive delays

Digital Audio Broacasting

- OFDM multi-carrier modulation
  The radio channel is split into many narrowband (ISI-free) subchannels

Typical Delay Spreads

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

- 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 $T_{RMS} < 2\ \mu sec$

- 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

Kasus-Kasus *Fading Mitigation*

How to handle fast multipath fading?

Analog

- User must speak slowly

GSM

- Error correction and interleaving to avoid burst errors
- Error detection and speech decoding
- Fade margins in cell planning

DECT

- Diversity reception at base station

IS95

- Wideband transmission averages channel behaviour

This avoids burst errors and deep fades

How to handle long fades when the user is stationary?

Analog

- Disconnect user

GSM

- Slow frequency hopping
- Handover, if appropriate
- Power control

DECT

- Diversity at base station
- Best channel selection by handset

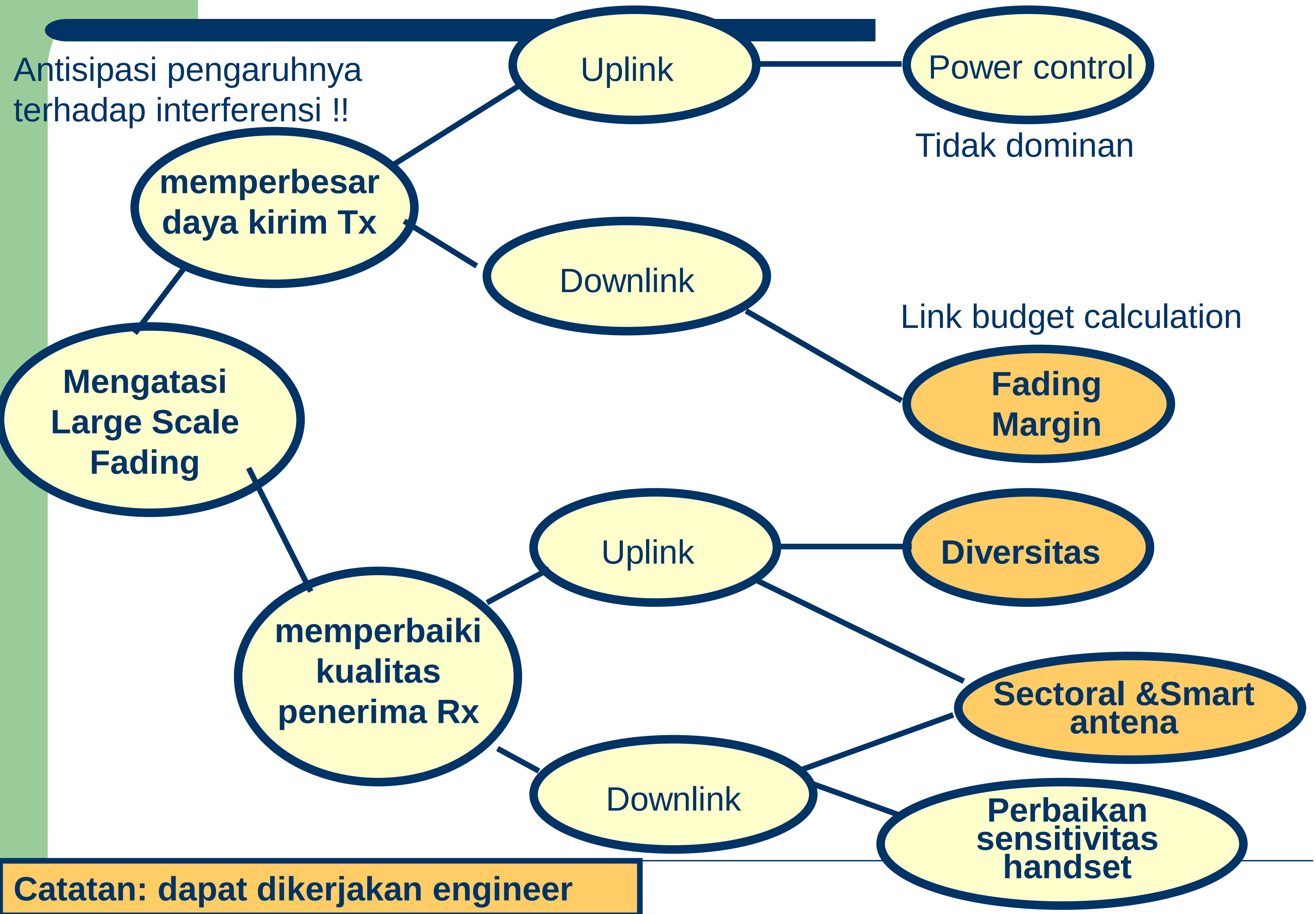
IS95

- Wide band transmission avoids most deep fades (at least in macro-cells)
- Power control

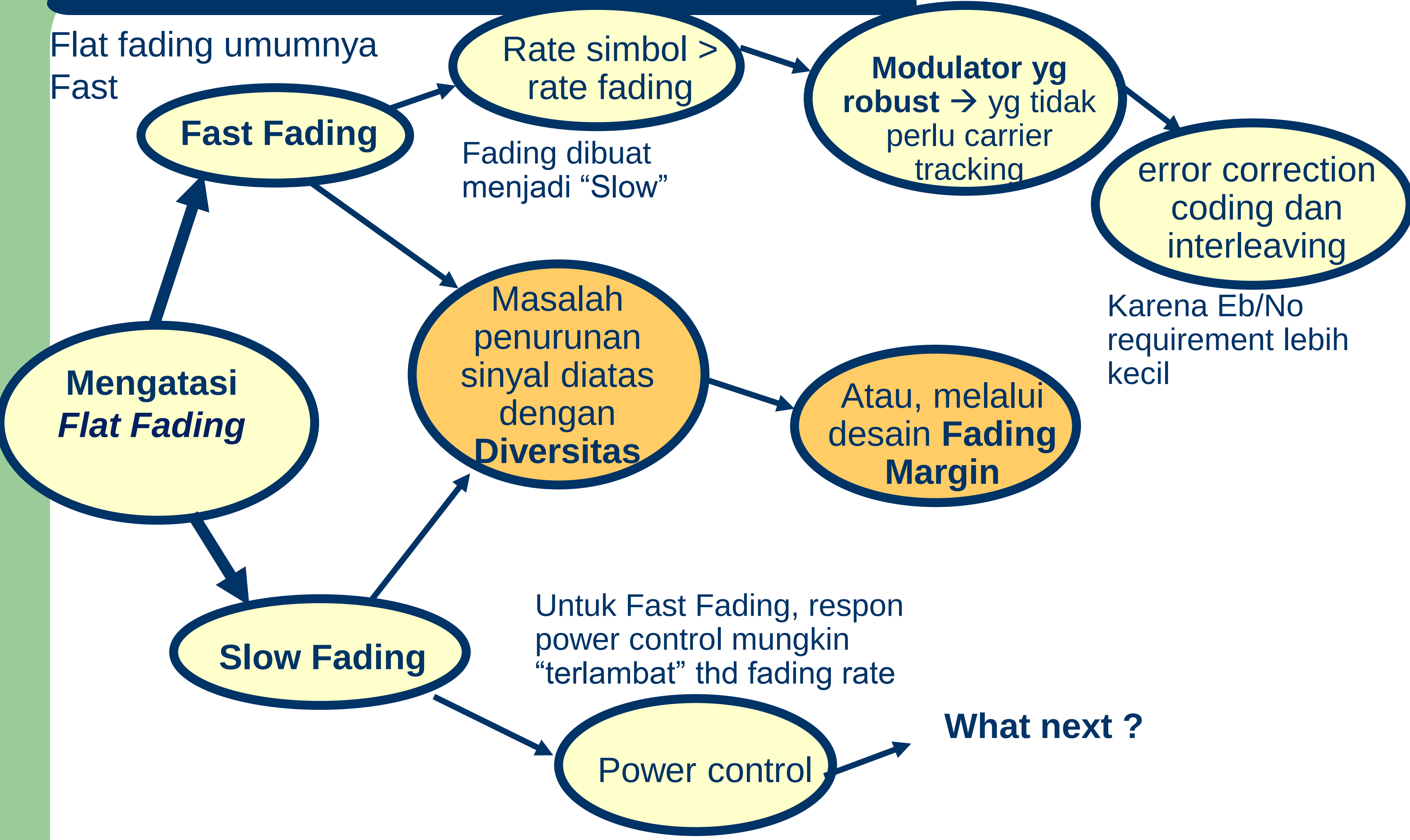
Wireless LANs

- Frequency Hopping, Antenna Diversity

Mengatasi *Large Scale Fading*



Mengatasi *Small Scale Fading*

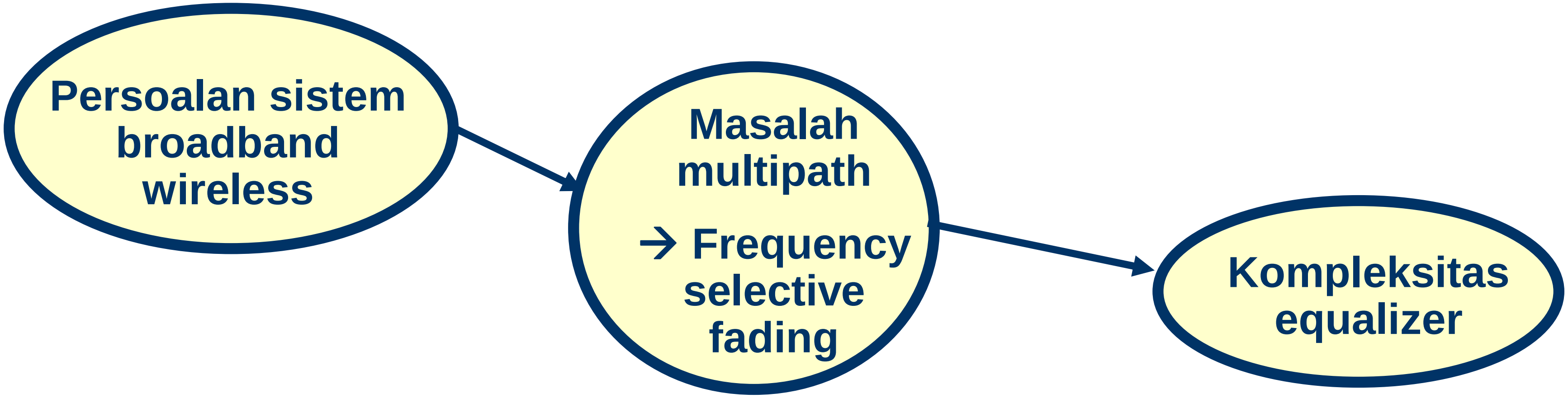


Catatan: dapat dikerjakan engineer

Mengatasi *Small Scale Fading*

Frequency Selective Fading, terjadi karena bandwidth sinyal lebih besar dari bandwidth koheren kanal

Sehingga persoalan fading frekuensi selektif terjadi pada sistem broadband wireless



Kesimpulan singkat, fading akan diatasi dengan berbagai cara :

- **Fading Margin** dalam desain cakupan RF
- **Diversitas: space, time, frequency**
  - Receive antenna diversity: Fading jarang terjadi pada 2 lokasi secara simultan, khususnya pada jarak kelipatan ganjil seperempat panjang gelombang
- **Interleaving**, suatu bentuk dari diversitas waktu
- ***Error protection coding*, (atau *channel coding*)** → dengan menambahkan bit-bit redundant