

Mobile Communications

Part X- Fading Mitigation

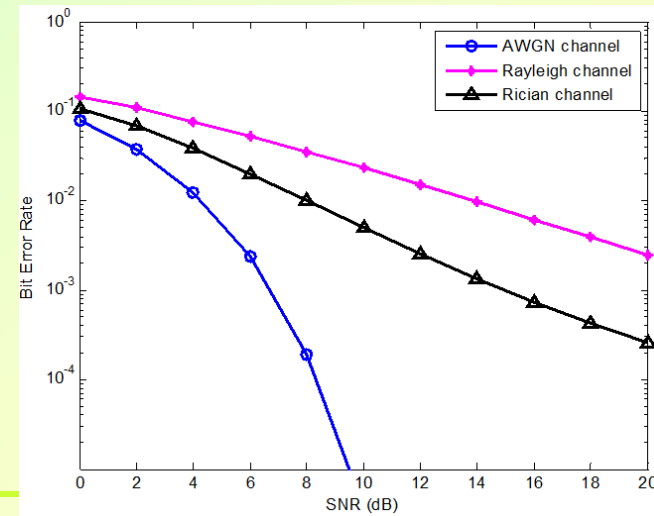
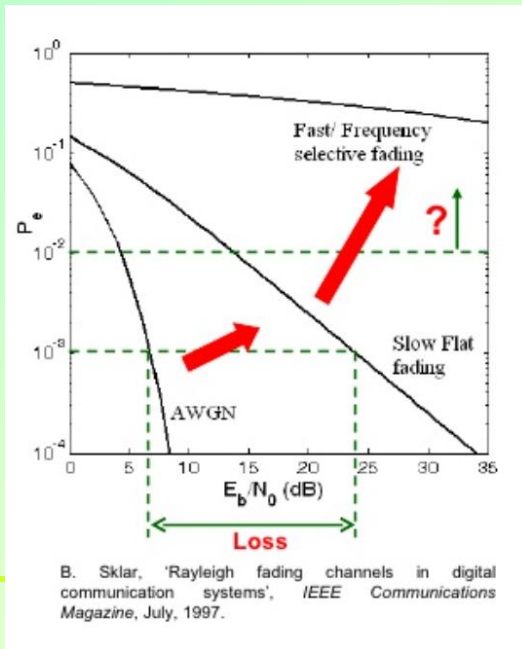
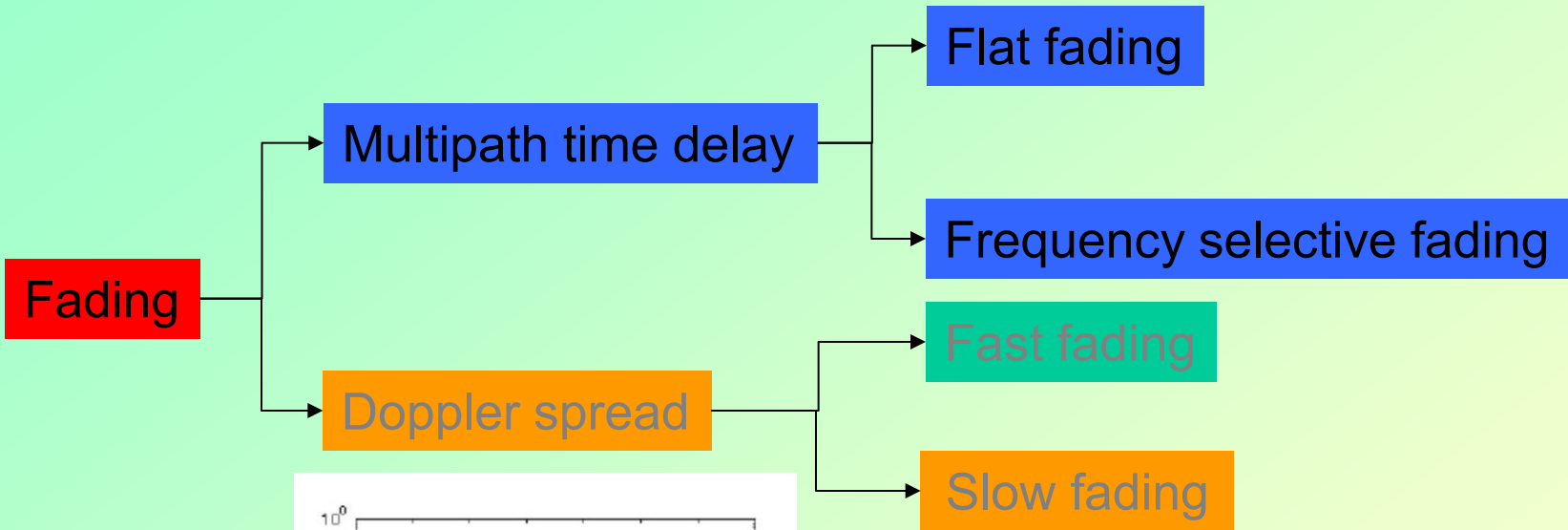
Professor Z Ghassemlooy



Contents

- Diversity
- Diversity types
- Analysis
- Summary

Fading – Small Scale



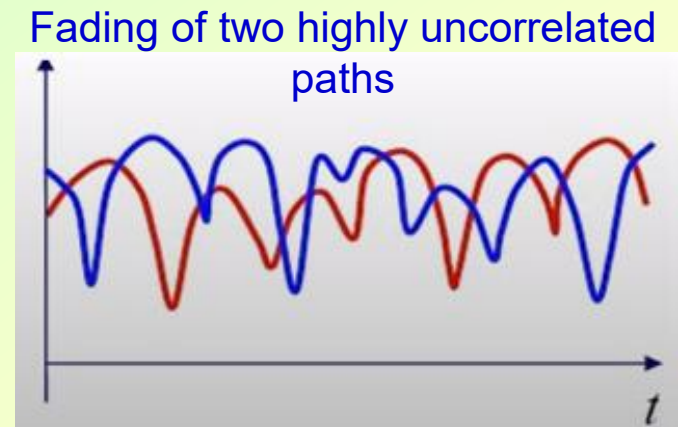
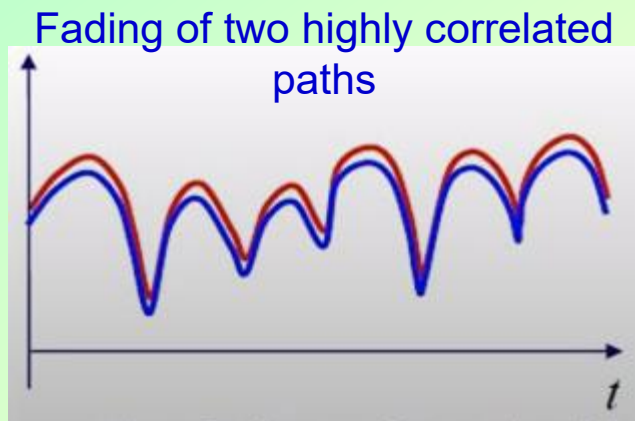
Mitigation Techniques for the Multipath Fading Channel

- A single link communications is highly vulnerable to deep fading, thus total link loss. Thus the need for mitigation schemes:
 - **Diversity**
 - **Equalization**
 - **Coding**
 - **Etc.**
- These techniques improve the link performance
 - Effectiveness of each scheme will depend on the practical cases
 - Must consider cost and complexity

Diversity

- Which:

- Rely on multiple independent samples of the received signal to combat deep fading at low cost
- Adopt multiple independent samples to reduce the BER
 - At least one path will not experience deep fading
- Independent samples maybe obtained via spatial diversity
- The mean power available from each path should be almost the same



Diversity - Types

Independent samples maybe obtained via:

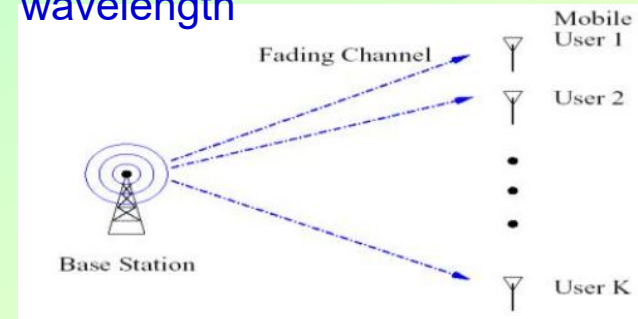
▪ Space diversity

- Signals at the same frequency using two or three antennas located several wavelengths apart and connected to two or three radio Rx's.
- The receiver with the strongest signal is elected
- **Disadvantage: Uses two or more antennas, therefore the need for a large site.**

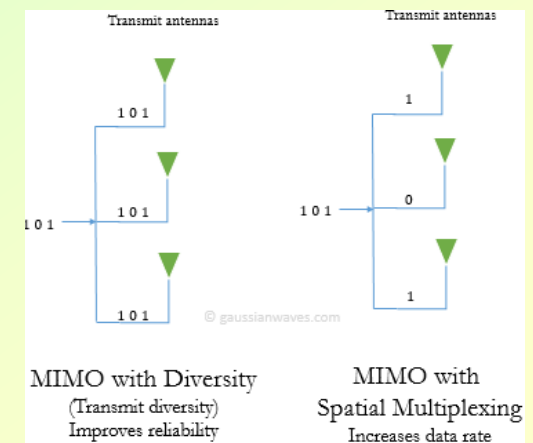
▪ Frequency diversity

- Signals at different frequencies received by the same antenna very rarely fade simultaneously. Thus the use of several carrier frequencies or the use of a wideband signal to combat fading.
- A single aerial connected to a number Rx's - **each tuned to a different frequency, whose outputs are connected in parallel. The receiver with the strongest instantaneous signal will provide the output.**
- **Disadvantage: Uses two or more frequencies to transmit the same signal.**

Separated on the order of $\frac{1}{2}$ wavelength

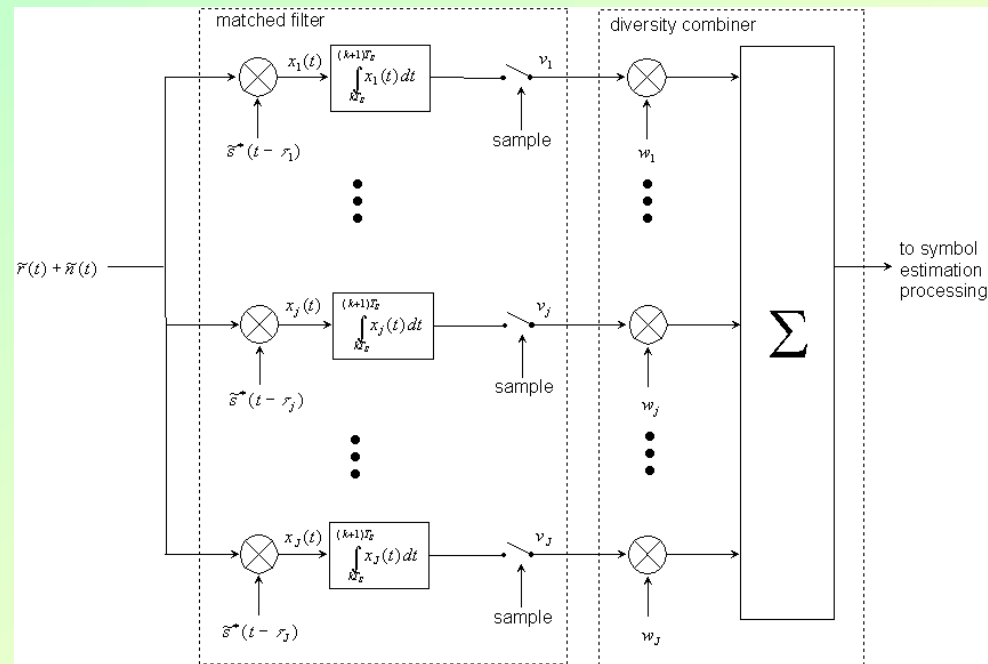


The instantaneous and average SNR may be improved by 20 to 30 dB



Diversity - Types

- **Time diversity** - Spread out the effects of errors through interleaving and coding
- **Polarization diversity**
- **Multipath diversity**
 - Consider the tapped delay line model of a channel
 - A RAKE receiver estimates the delay and amplitude of the delay profile
 - Obtains independent samples
 - Thus providing a form of time diversity.
 - Only a few 2-3 samples provide significant performance improvement
 - IS-95 cell systems use a RAKE receive in both the base stations and hand sets



R.E. Ziemer 2002

Diversity - Types

- Multipath diversity
 - Consider the tapped delay line model of a channel shown previously
 - If multipaths can be put together coherently at the receiver, diversity improvement results
 - This is what the RAKE receiver does (see next viewgraph)

Mitigation Techniques for the Multipath Fading Channel

▪ Equalization

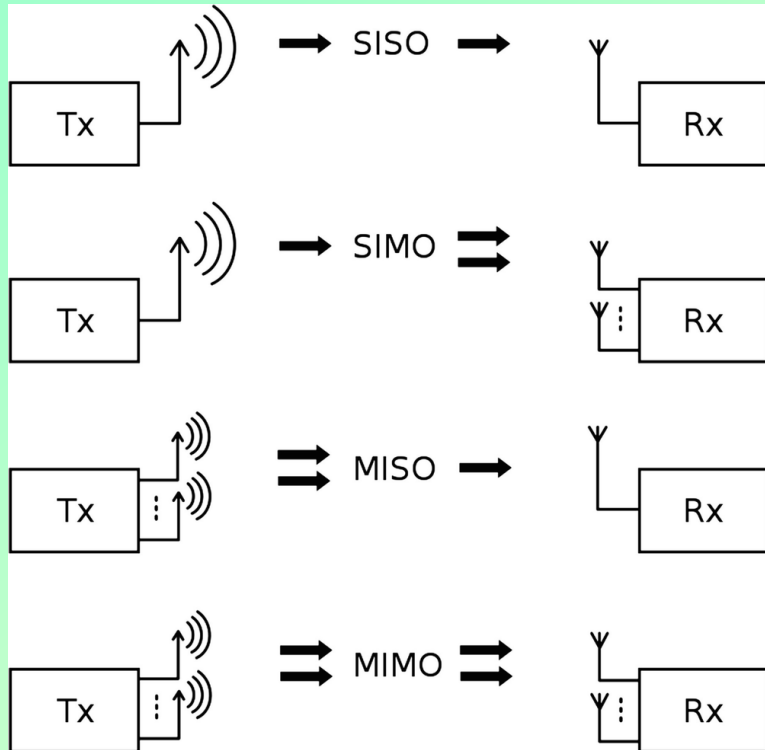
- At the receiver the known transmitted signal and the corresponding distorted waveform are used to estimate the expected channel characteristics
- Assume the channel is “constant” between transmissions of training signals
- Training signals add overhead and reduce efficiency
- But, the received signal may experience deep fading
 - Thus, diversity offer improved performance when one of the independent paths face deep fading.

▪ Orthogonal frequency division multiplexing (OFDM)

- Multicarrier modulation
- Uses a large number of parallel narrowband channels, each at a unique subcarrier
- Combats multipath and Narrow-band interference
- Problems
 - Sensitive of frequence and phase noise
 - Has large Peak-to-average ratio, thus resulting is inefficient use of power amplifiers.

▪ Channel coding

Space Diversity - Types



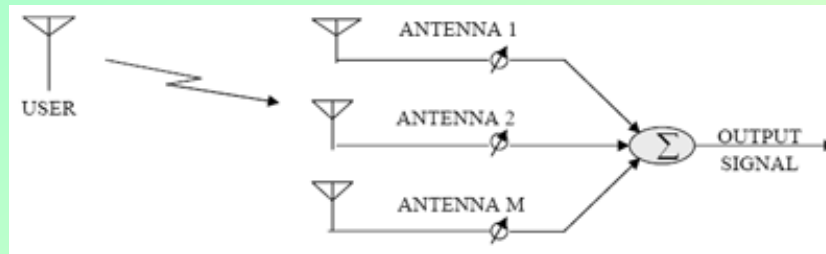
Separated on the order of $\frac{1}{2}$ wavelength

SISO – single input single output
SIMO – single input multiple output
MISO – multiple input single output
MIMO – multiple input multiple output

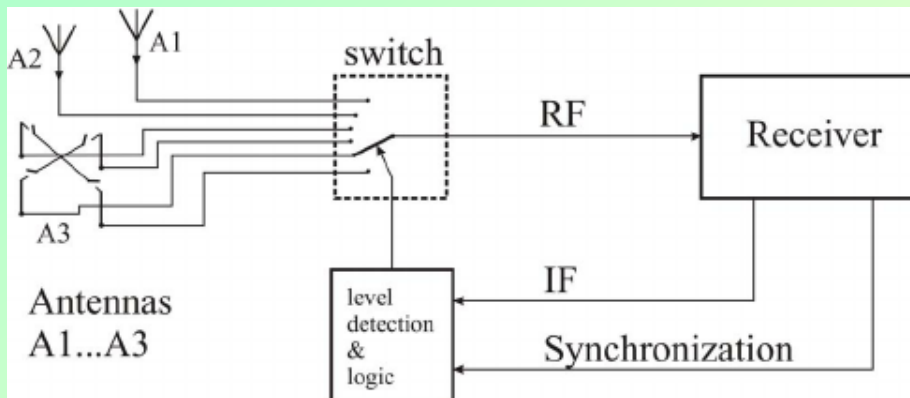
Categories of SD

- Selection diversity
- Feedback diversity
- Maximum ratio combining
- Equal gain diversity

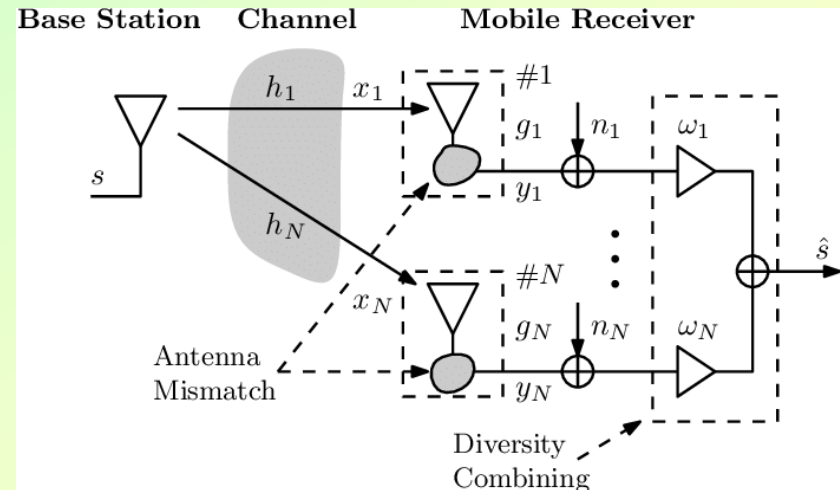
Space Diversity – With Selectivity



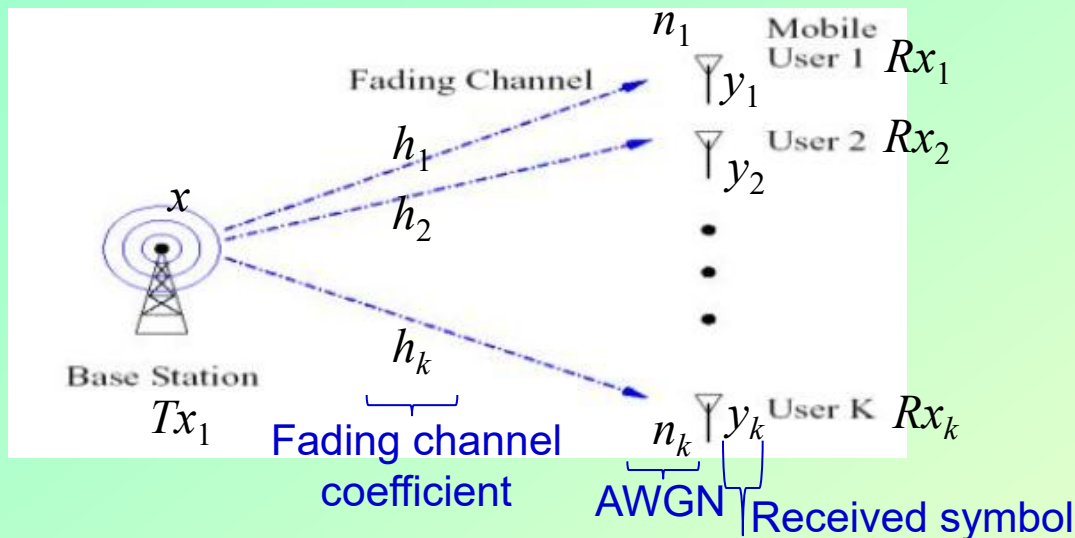
Combines with no selection



Selects the path with the highest SNR



Space Diversity – SIMO with Selection Diversity



$n_k = \{\text{zero mean and variance } \sigma_n^2\}$
 We assume that noise component are un-correlated, therefore independent. I.e.,
 $E\{n_1, n_2, n_k\} = 0$

Simple model:

$$y_1 = xh_1 + n_1$$

and

$$y_2 = xh_2 + n_2$$

$$y_k = xh_k + n_k$$

Vector model:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} x + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

$$\bar{y} = \bar{h}x + \bar{n}$$

Combined signal at the Rx:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} x + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

$$\tilde{y} = w_1 y_1 + w_2 y_2$$

Combining weights

Space Diversity - SIMO

Now

$$\tilde{y} = [w_1 \ w_2] \begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \bar{w}^T \bar{y}$$

$$\tilde{y} = \bar{w}^T \bar{h}x + \bar{w}^T \bar{n}$$

The signal to noise ratio is:

$$SNR = \frac{|\bar{w}^T \bar{h}|^2 P}{E\{|\bar{w}^T \bar{n}|^2\}}$$

P = Signal power

Let's look at the noise term

$$\bar{w}^T \bar{n} = [w_1 \ w_2] \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} = w_1 n_1 + w_2 n_2$$

$$\begin{aligned} E[(w_1 n_1 + w_2 n_2)^2] &= E(w_1^2 n_1^2 + w_2^2 n_2^2 + 2w_1 w_2 n_1 n_2) \\ &= \underbrace{w_1^2 E\{n_1^2\}}_{\sigma_n^2} + \underbrace{w_2^2 E\{n_2^2\}}_{\sigma_n^2} + \underbrace{2w_1 w_2 E\{n_1 n_2\}}_{= 0} \\ &\hspace{15em} \text{(since uncorrelated)} \end{aligned}$$

Thus

Space Diversity - SIMO

Thus

$$E \left\{ |\bar{w}^T \bar{n}|^2 \right\} = \sigma_n^2 (w_1^2 + w_2^2) = \sigma_n^2 \underbrace{\|\bar{w}\|^2}_{\text{Norm of } w}$$

And

$$\begin{aligned} \bar{w}^T \bar{h} &= [w_1 \quad w_2] \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} = w_1 h_1 + w_2 h_2 \\ &= \bar{w} \cdot \bar{h} \end{aligned} \quad \text{A dot product, use vector calculus}$$

$$|\bar{w} \cdot \bar{h}| = \|\bar{w}\| \cdot \|\bar{h}\| \cos \theta$$

$$\|\bar{w} \cdot \bar{h}\|^2 = \|\bar{w}\|^2 \cdot \|\bar{h}\|^2 \cos^2 \theta$$

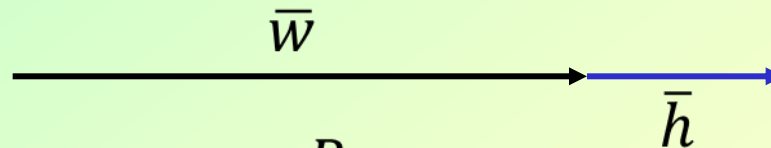
Space Diversity - SIMO

The signal to noise ratio is:

$$\begin{aligned} SNR &= \frac{|\bar{w}^T \bar{h}|^2 P}{\sigma_n^2 \|\bar{w}\|^2} \\ &= \frac{P \cdot \|\bar{w}\|^2 \cdot \|\bar{h}\|^2 \cos^2 \theta}{\sigma_n^2 \|\bar{w}\|^2} \\ &= \frac{P}{\sigma_n^2} \underbrace{\|\bar{h}\|^2}_{\cos^2 \theta} \end{aligned}$$

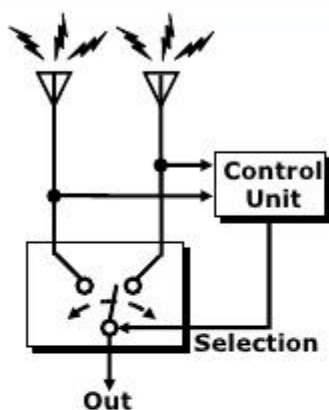
This is maximum when $\cos^2 \theta$ is maximum i.e., $\theta = 0$.

This means that both \bar{w} and \bar{h} must along the same line (path)



$$\begin{aligned} SNR &= \frac{P}{\sigma_n^2} \|\bar{h}\|^2 \\ &= \frac{P(|h_1|^2 + |h_2|^2)}{\sigma_n^2} \end{aligned}$$

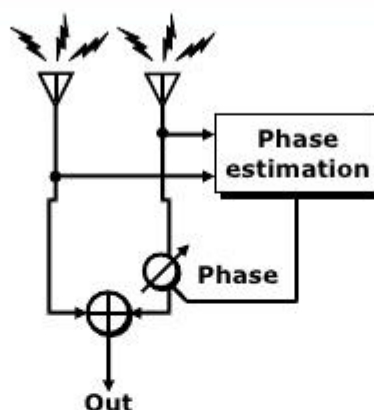
Diversity Combining



Selection Combining

$$Y_c = \begin{cases} Y_1 & ; Y_1 > Y_2 \\ Y_2 & ; Y_2 > Y_1 \end{cases}$$

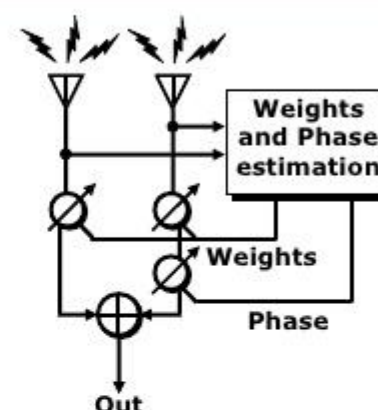
Choose the best



Equal Gain Combining

$$Y_c = \frac{Y_1 + Y_2}{2}$$

Simple average



Maximal Ratio Combining

$$Y_c = a_1 Y_1 + a_2 Y_2$$

Weighted average

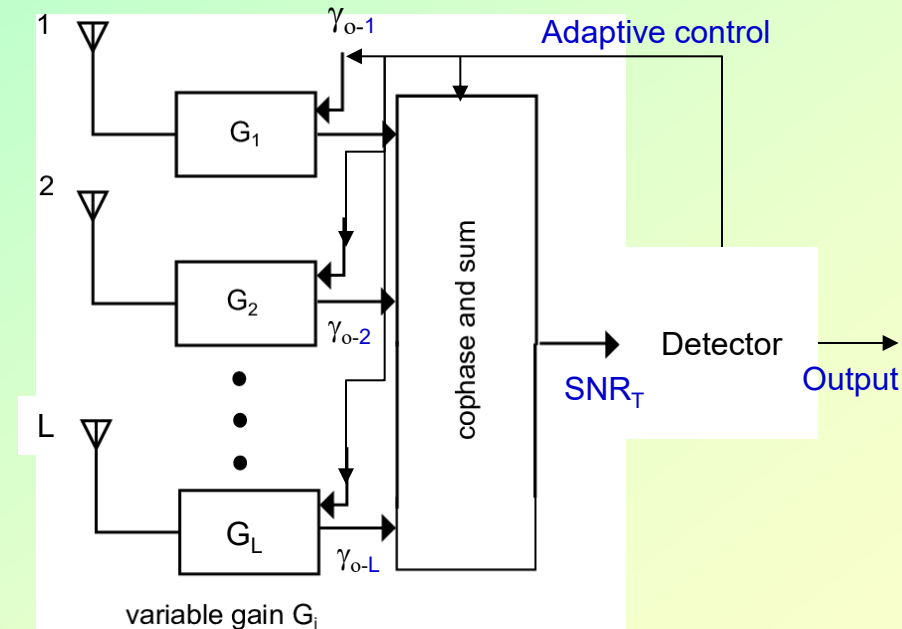
A sub-optimal version of selection combining is switch-and-stay combining in which alternate antenna are chosen if signal falls below a certain threshold

Space Diversity – Selection Diversity - MRC

- “L” paths are weighted based on the average SNR (γ_o) per path
- SNRs are added up to provide signals from all path the same co-phase condition
- A combined SNR is produced

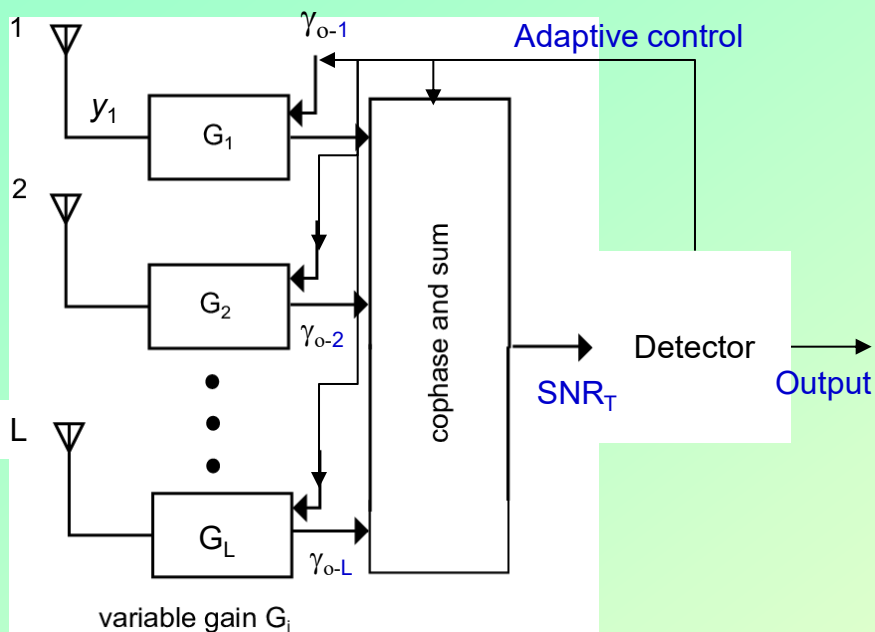
$$\text{SNR}_T = \sum_1^L \text{SNR}_l$$

- So even if one $\text{SNR} < \text{SNR}_{\text{threshold}}$, the SNR_T will be $> \text{SNR}_{\text{threshold}}$
- It offers the best statical reduction of fading of any linear diversity techniques



- If the gains are changing the overall SNR remains the same.
- If γ_{o-1} is high then G_1 should be low and vice versa. **So weak signals are boosted.**

Space Diversity – Selection Diversity - MRC



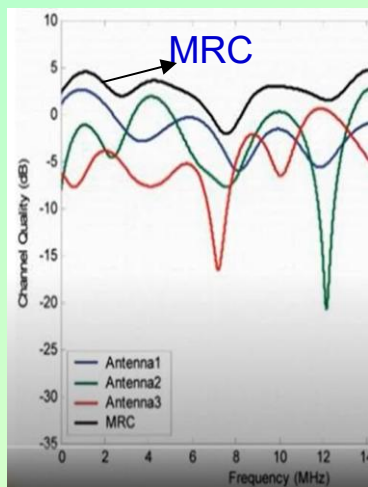
- At path i , we have

$$y_i = \alpha_i \sqrt{E_b} d + n_i$$

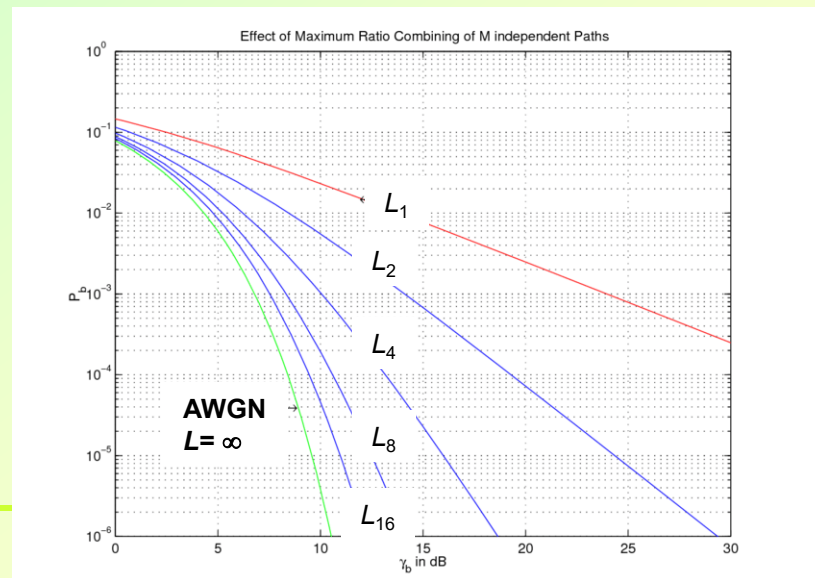
α_i : Fading complex envelop
 $\sqrt{E_b}$: Signal (bit) energy
 d : Data
 n_i : AWGN

- And at the input of cophase and sum we have

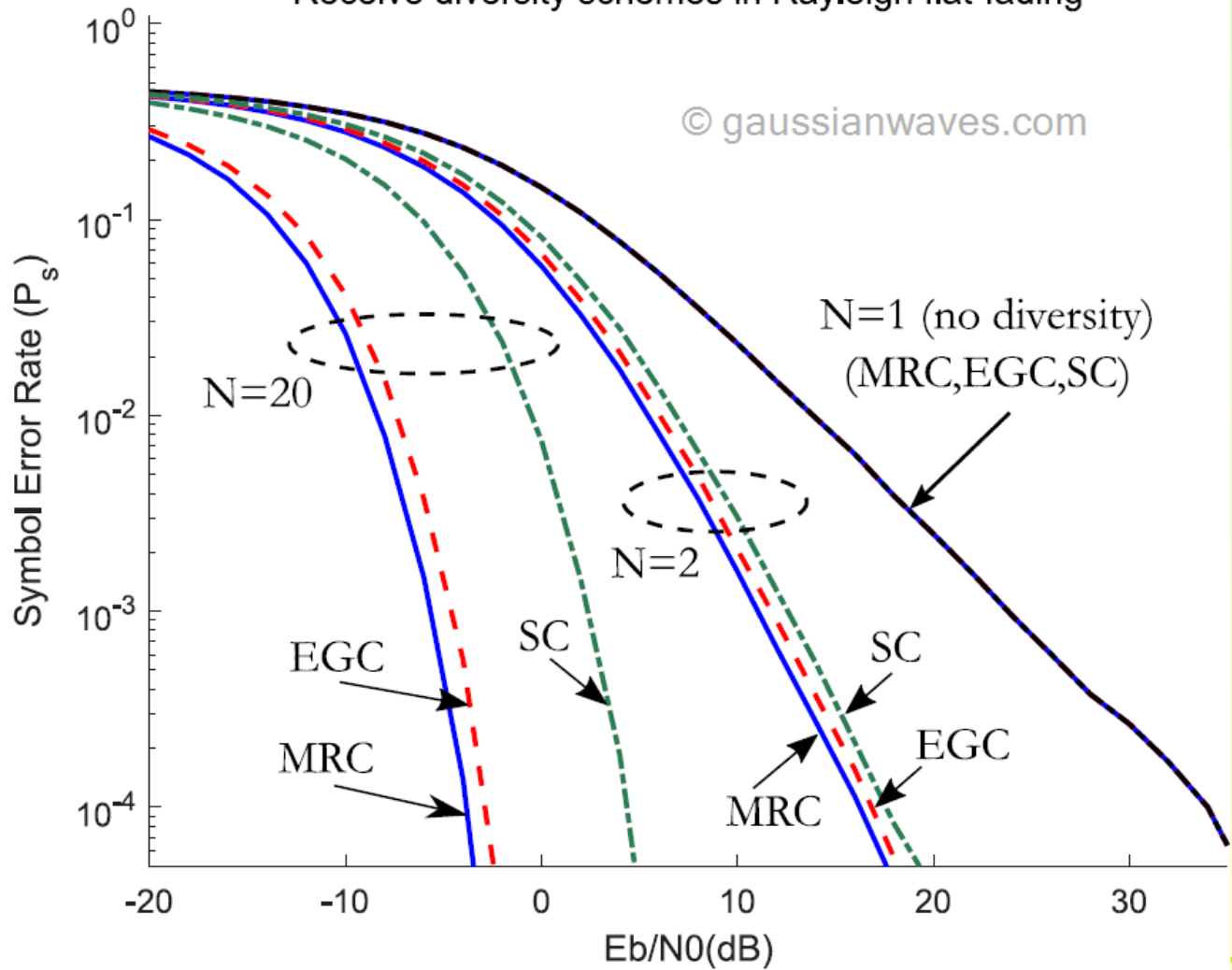
$$y'_i = y_i G_i$$



Note, MRC offers the best signal



Receive diversity schemes in Rayleigh flat-fading



System Design and Performance Prediction

- Base station placement dependent on
 - Propagation environment
 - Anticipated geographic distribution of users
 - Economic considerations (minimize number of base stations)
 - Political and public opinion considerations
 - Traffic types (3G)
- Performance figure of merit
 - Spectrum efficiency for voice: η_v voice circuits/MHz/base station
 - Spectrum efficiency for information: η_i bps/MHz/base station
 - Dropped call rate – fraction of calls ended prematurely

Summary

- The random fluctuations in the received power are due to fading.
 - If there is a relative motion between transmitter and receiver (mobile) the result is Doppler shift
 - If maximum Doppler shift is less than the data rate, there is “slow” fading channel.
 - If maximum Doppler shift is larger than the data rate, there is “fast” fading channel.
- Next lecture: Modulation Techniques**