Diversity Techniques

Vasileios Papoutsis

Wireless Telecommunication Laboratory

Department of Electrical and Computer Engineering

University of Patras

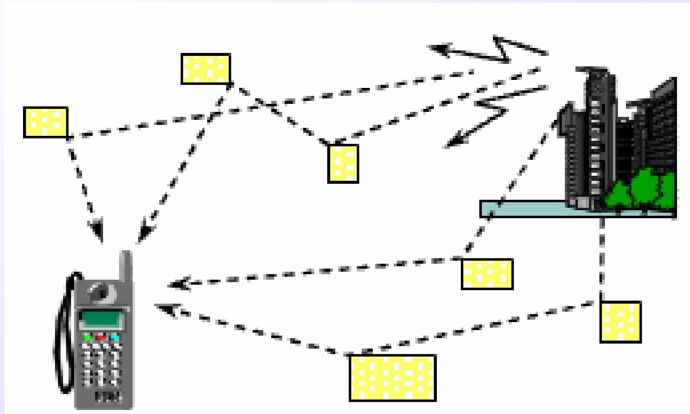
Patras, Greece

Outline

- Introduction
- Diversity Techniques
- Diversity Combining Techniques
- MISO / OFDMA scheme
- Conclusions

Challenges of Wireless Communication

- **High Data Rate, seamless and high mobility requirements**
- **Spectral efficiency challenge (2-10 b/s/Hz)**
- **Frequency selectivity due to large bandwidth requirements**
- **High System Capacity**
- **Seamless coverage and support across different networks, devices, and media forms**
- **Reliable Communications**
  - **Harsh wireless channel**
  - **Scarce radio spectrum**
  - **Energy constraint**



Fading (1)

- **Deviation or attenuation that a telecommunication signal experiences over certain propagation media**

- **May vary with time, geographical position and/or radio frequency, and is often modeled as a random process**

- **In wireless systems, fading may either be due to multipath propagation or due to shadowing from obstacles**

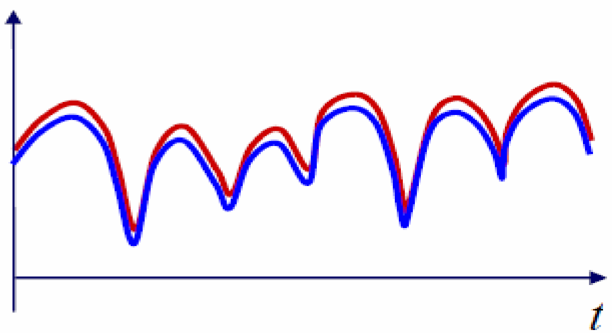
Fading (2)

- Reflectors in the environment surrounding a transmitter and receiver create multiple paths that a transmitted signal can traverse
- The receiver sees the superposition of multiple copies of the transmitted signal, each traversing a different path
- Each signal copy will experience differences in attenuation, delay and phase shift while travelling from the source to the receiver
- This can result in either constructive or destructive interference, amplifying or attenuating the signal power seen at the receiver
- Strong destructive interference is frequently referred to as a deep fade and may result in temporary failure of communication due to a severe drop in the channel signal-to-noise ratio

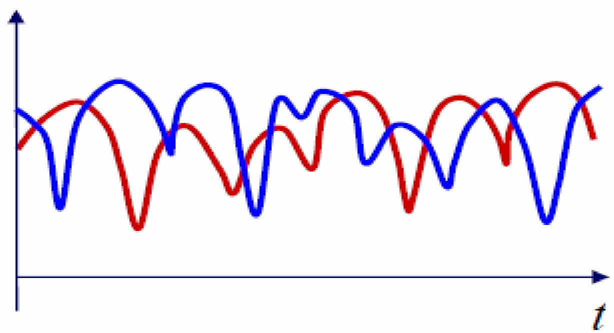
Fading (3)

Motivation of Diversity Techniques

- If a fading radio signal is received through only one channel, then in a deep fade, the signal could be lost, and there is nothing that can be done
- Diversity is a way to protect against deep fades, a choice to combat fading
- <u>The key</u>: create multiple channels or branches that have uncorrelated fading



The fading of two highly correlated channels



Two channels with uncorrelated fading

Basic Diversity Techniques

- **Diversity combats fading by providing the receiver with multiple uncorrelated replicas of the same information bearing signal**

- **There are several types of receiver diversity methods**

  - **Time Diversity**
  - **Frequency Diversity**
  - **Multiuser Diversity**
  - **Space Diversity**

Basic Diversity Combining Techniques

- Once you have created two or more channels or branches that have uncorrelated fading, what do you do with them?
- Techniques applied to combine the multiple received signals of a diversity reception device into a single improved signal
  - Selection Combining (SC)
  - Feedback or Scanning Combining (FC or SC)
  - Maximal Ratio Combining (MRC)
  - Equal Gain Combining (EGC)
  - Zero Forcing (ZF)
  - Minimum Mean Square Error (MMSE)

Outline

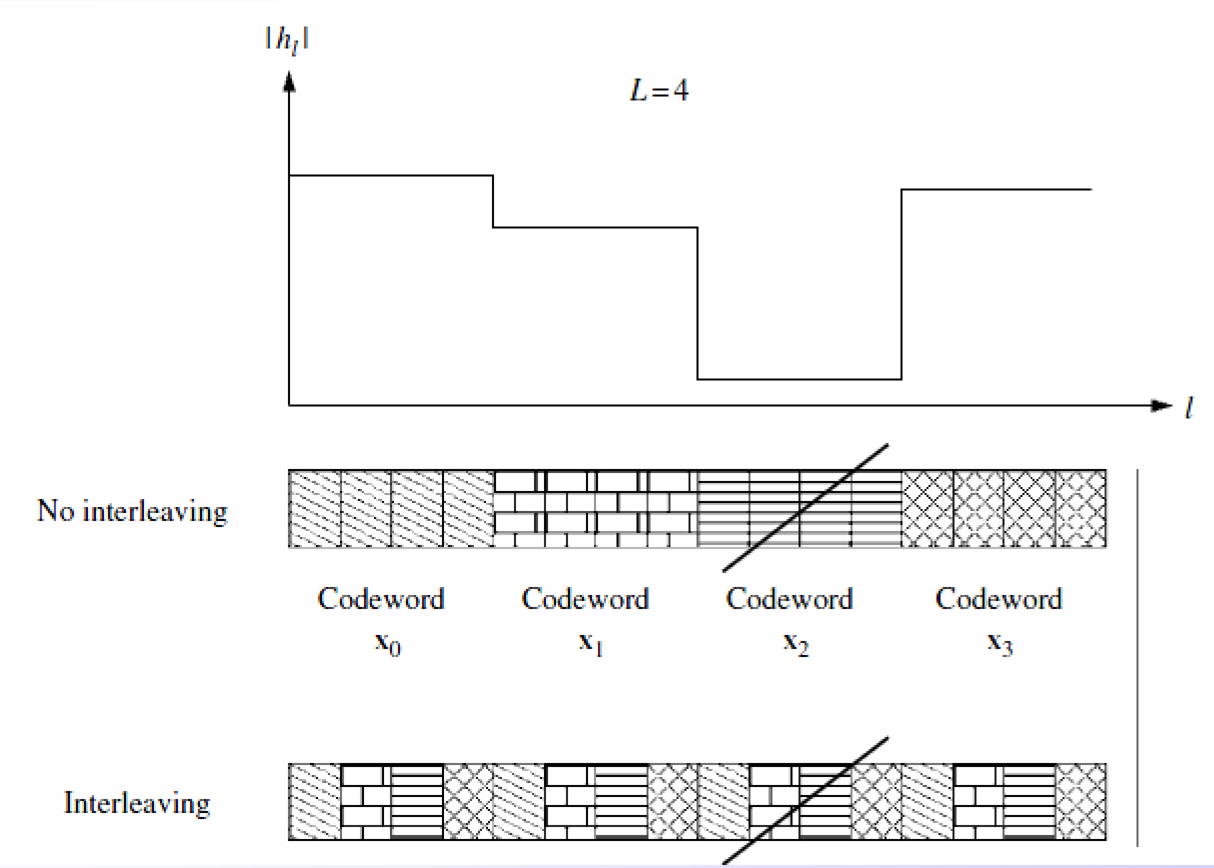
- Introduction
- Diversity Techniques
- Diversity Combining
- MISO / OFDMA scheme
- Conclusions

Time Diversity (1)

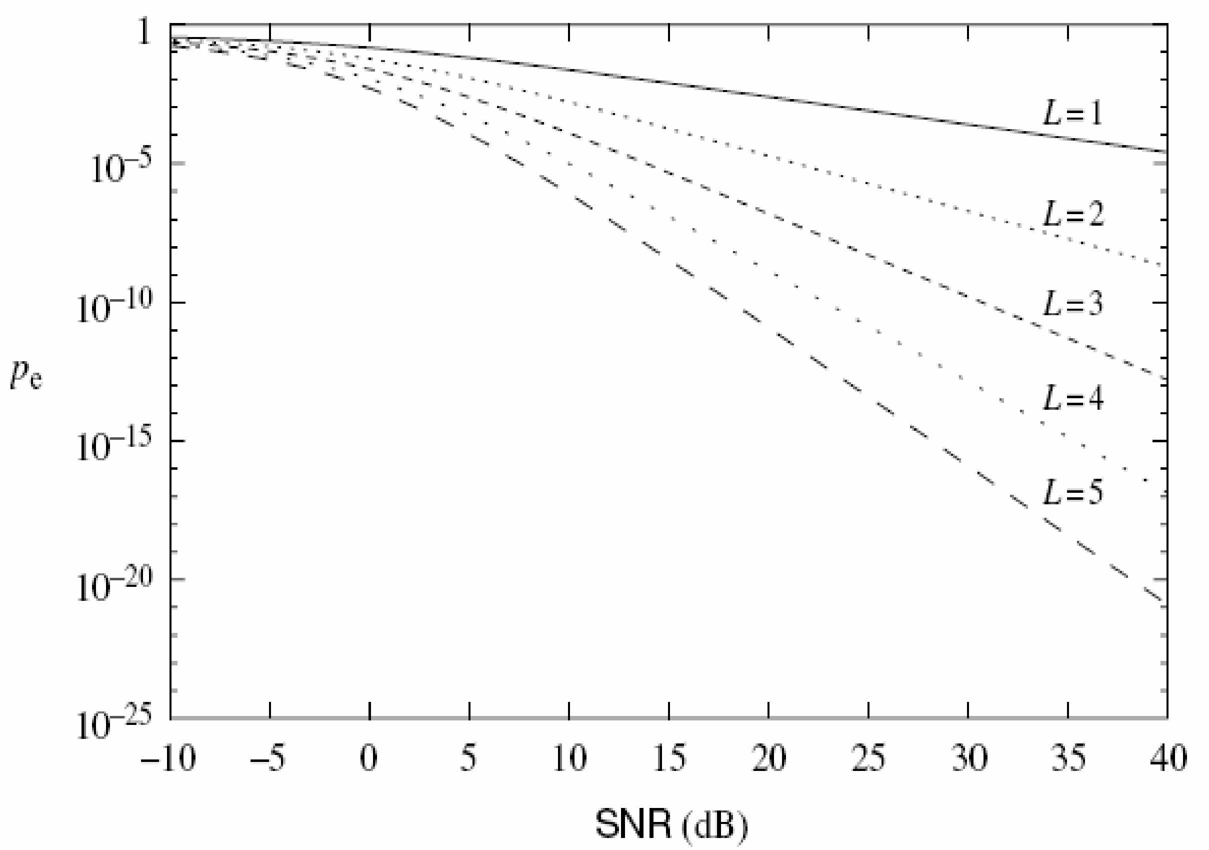
- Transmission in which signals representing the same information are sent over the same channel at different times
- The delay between replicas > coherence time → uncorrelated channels
- Use coding and interleaving (it breaks the memory of the channel, not all bits of the codeword are likely to fall into a deep fade)
- It consumes extra transmission time

Time Diversity (2)

- The codewords are transmitted over consecutive symbols (top) and interleaved (bottom)
- A deep fade will wipe out the entire codeword in the former case but only one coded symbol from each codeword in the latter
- In the latter case, each codeword can still be recovered from the other three unfaded symbols

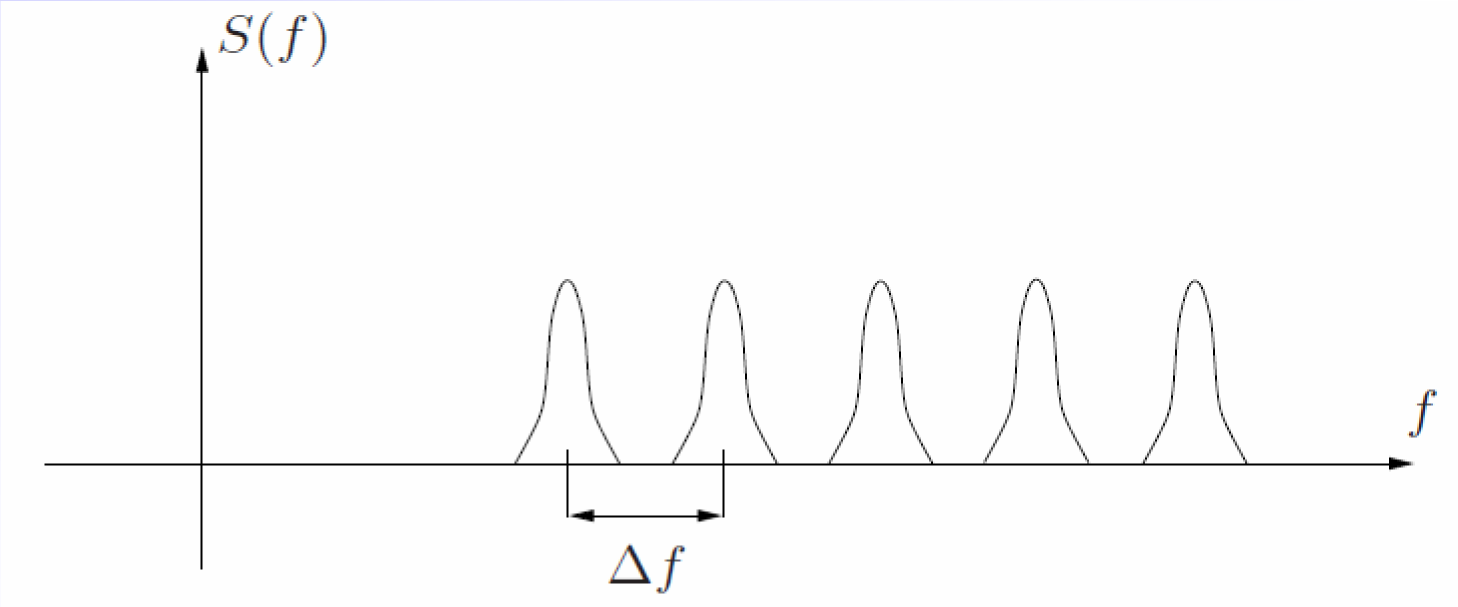


Time Diversity (3)



- Error probability as a function of SNR for different numbers of diversity branches L

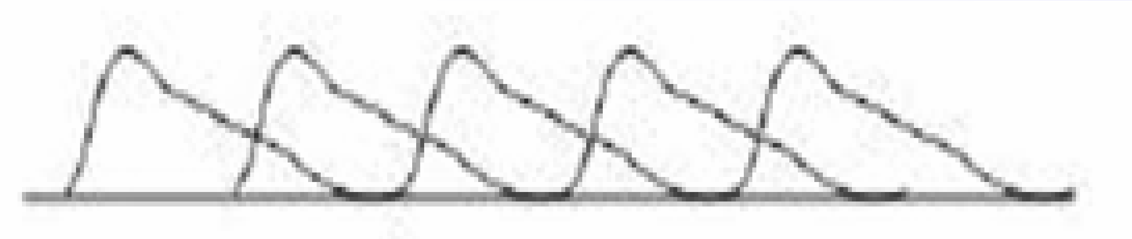
Frequency Diversity (1)



- Replicas sent in bands separated by at least the coherence bandwidth ➡ uncorrelated channels
- As two or more different frequencies experience different fading, at least one will have strong signal
- Frequency diversity consumes extra bandwidth

Frequency Diversity (2)

- Sending an information symbol every L symbol times
- Only one symbol can be transmitted every delay spread
- Once one tries to transmit symbols more frequently than the coherence bandwidth, inter-symbol interference (ISI) occurs



Multiuser Diversity

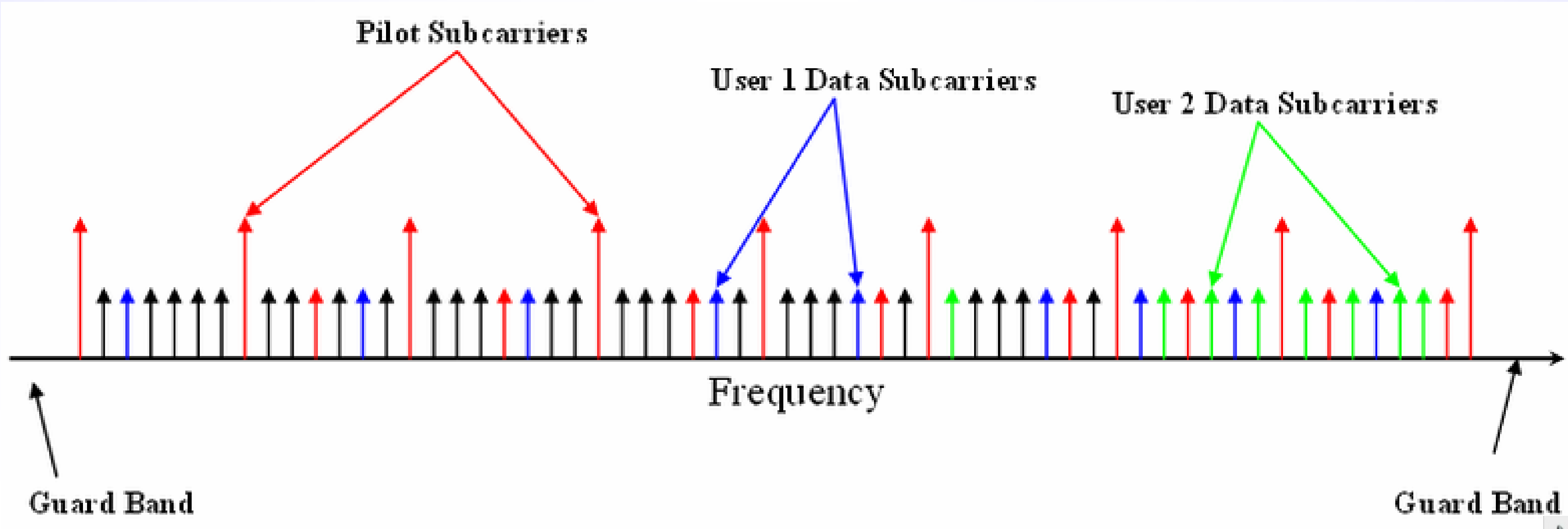
- Opportunistic user scheduling at either the transmitter or the receiver
- In a large system with users fading independently, there is likely to be a user with a very good channel at any time
- Transmitter selects the best user among candidate receivers according to the qualities of each channel between the transmitter and each receiver

OFDMA (1)

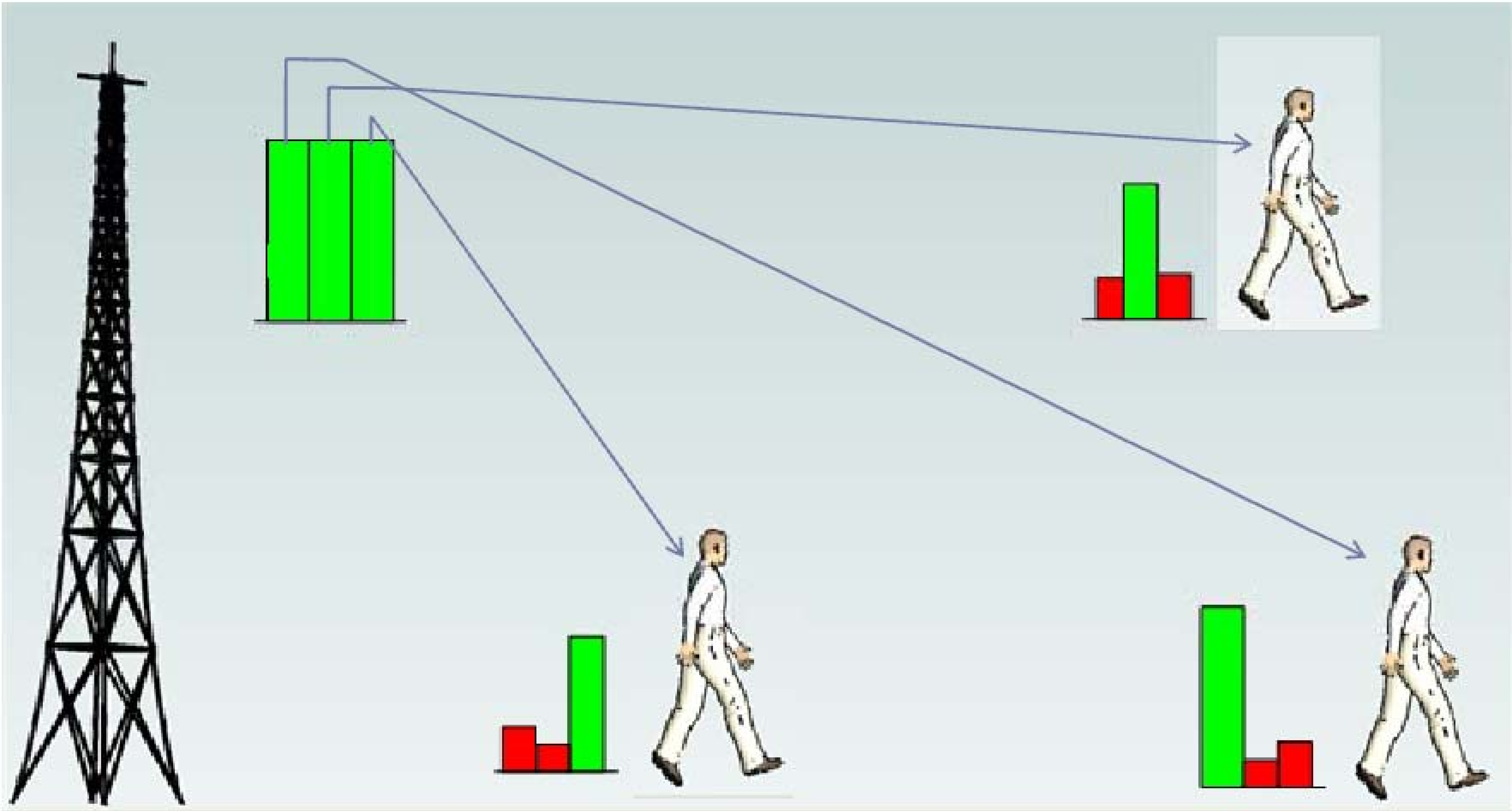
- Orthogonal Frequency Division Multiple Access (OFDMA) exploits multiuser diversity.
- Multiuser version of the popular Orthogonal Frequency Division Multiplexing (OFDM) digital modulation scheme which combats ISI
- Superior performance in frequency-selective fading wireless channels
- Modulation and multiple access scheme used in latest wireless systems such as IEEE 802.16e (Mobile WiMAX)

OFDMA (2)

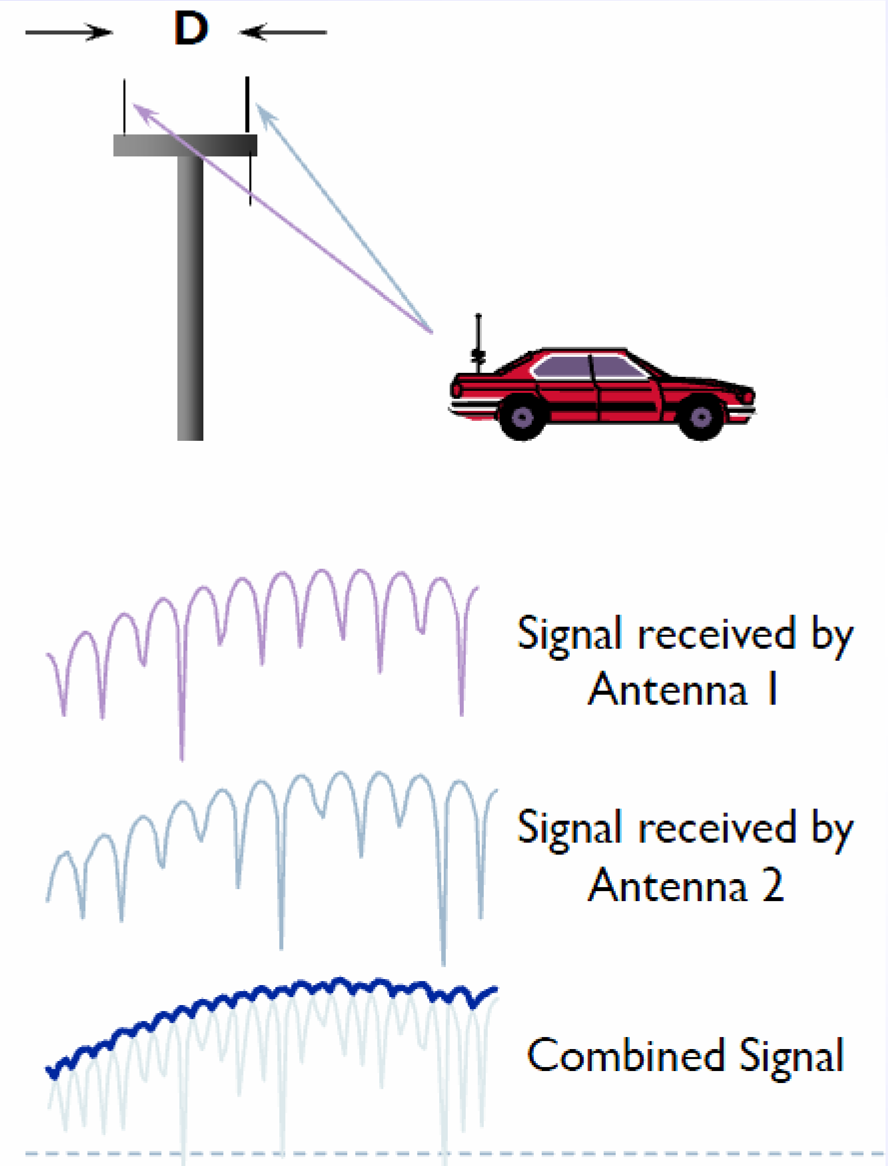
- Total bandwidth is divided into subcarriers.
- Multiple access is achieved by assigning subsets of subcarriers to individual users
- A subcarrier is exclusively assigned to a user
- Dynamic subcarrier assignment



OFDMA (3)

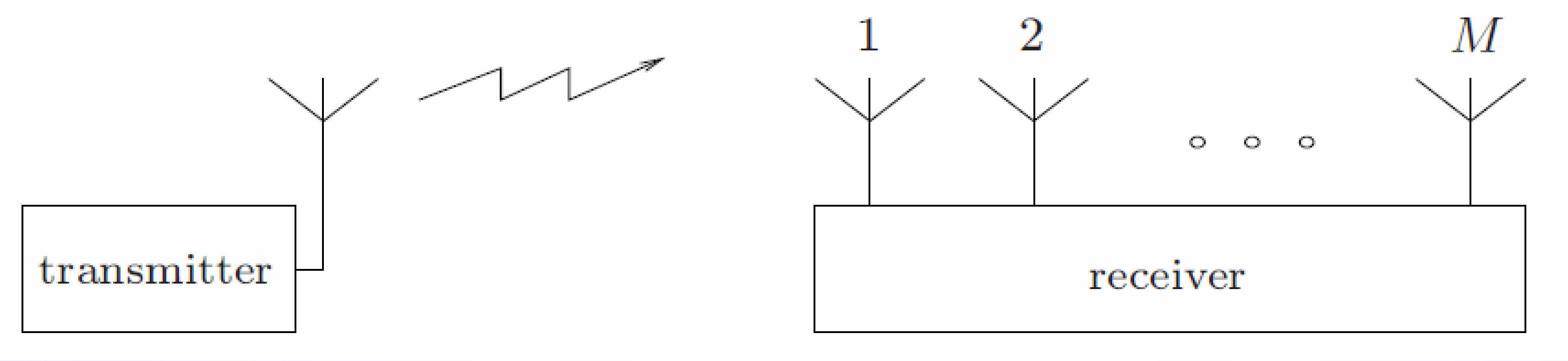


Space Diversity (1)



- **Two antennas separated by several wavelengths will not generally experience fades at the same time**
- **Space Diversity can be obtained by using two receiving antennas and switching instant-by-instant to whichever is best**

Space Diversity (2)



- **Several (receive) antennas (M)**
- **Uncorrelated branches → Distance between antennas ≈ λ/2, where λ is the wavelength**
- **In GSM, λ ≈ 30 cm**

Space Diversity (3)

- **Single-input, single-output (SISO) channel**

  No spatial diversity

- **Single-input, multiple-output (SIMO) channel**

  Receive diversity

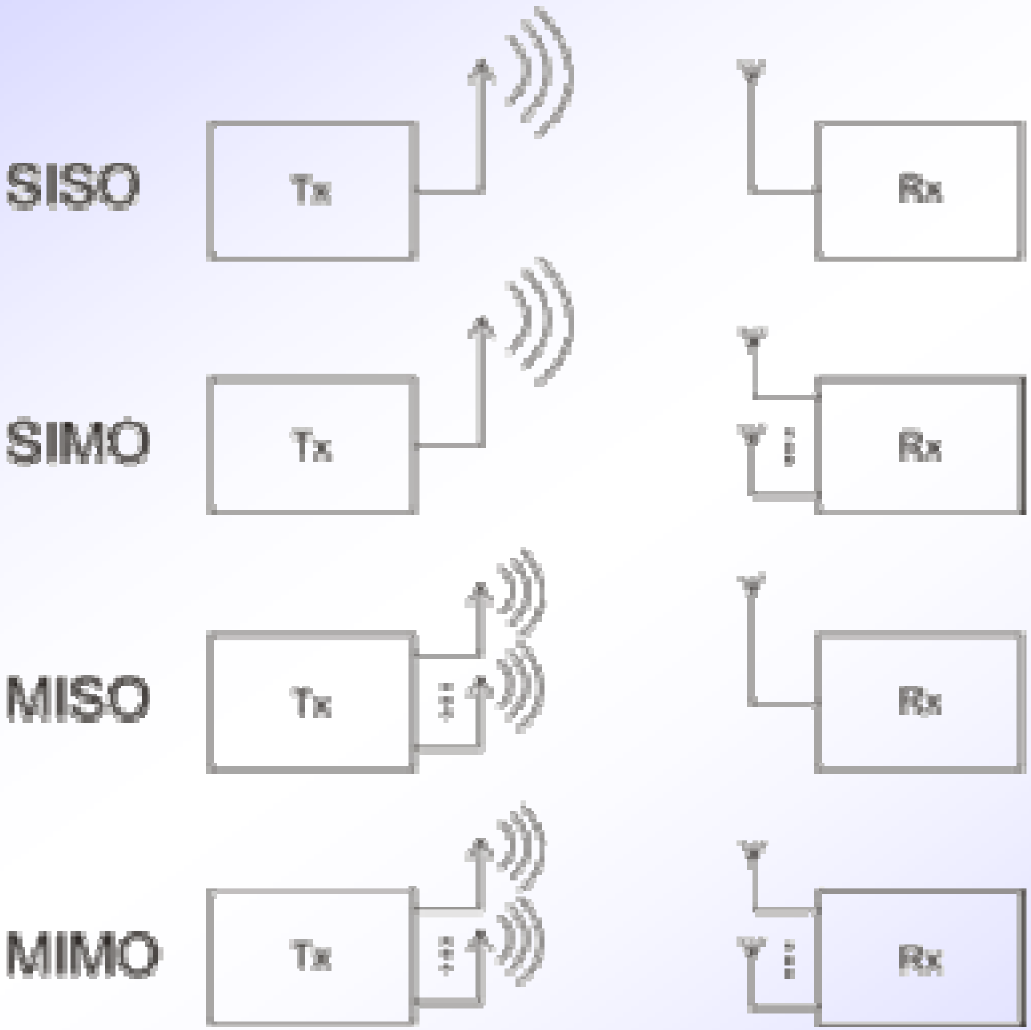
- **Multiple-input, single-output (MISO) channel**

  Transmit diversity

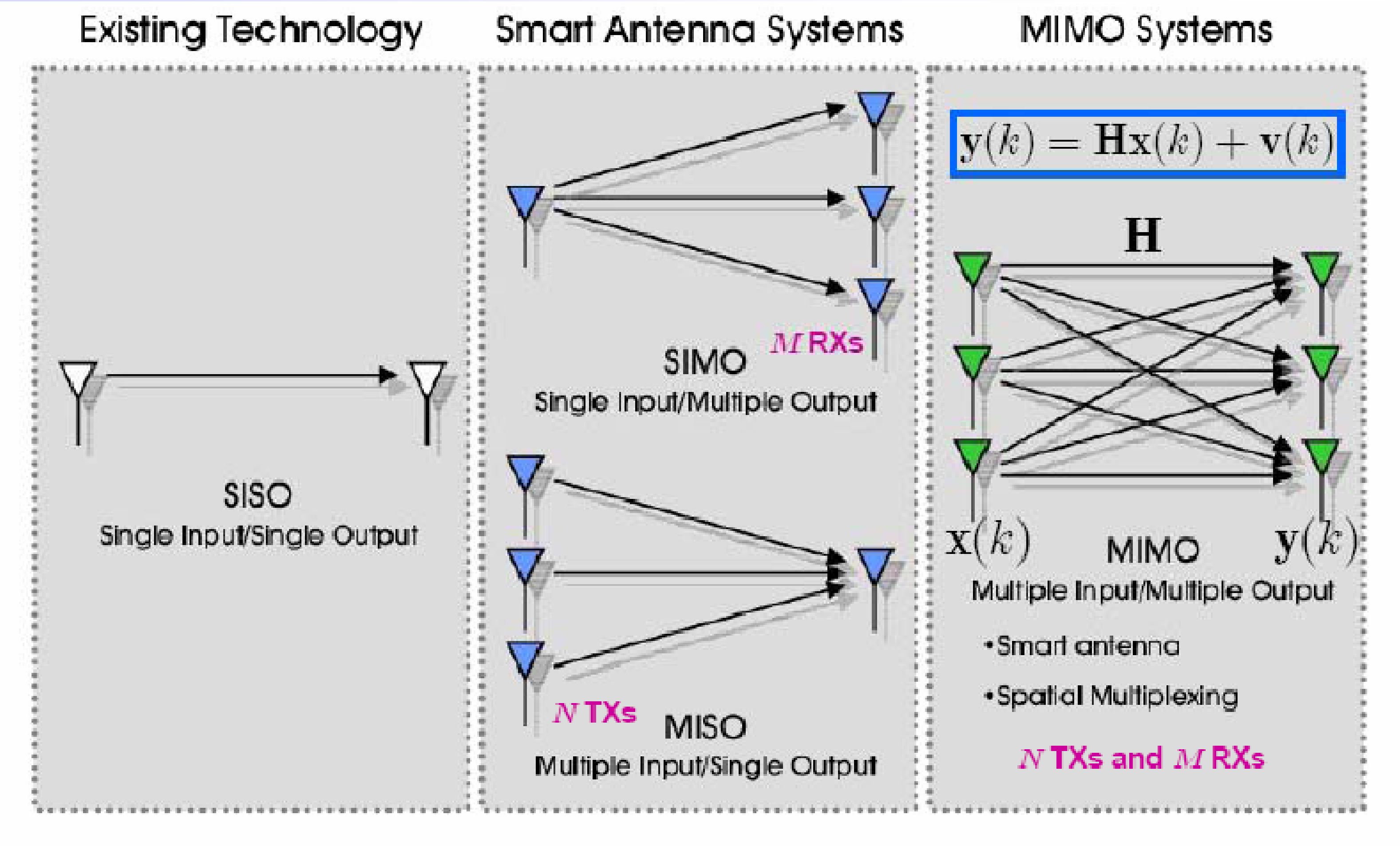
- **Multiple-input, multiple-output (MIMO) channel**

  Combined transmit and receive diversity

Space Diversity (4)

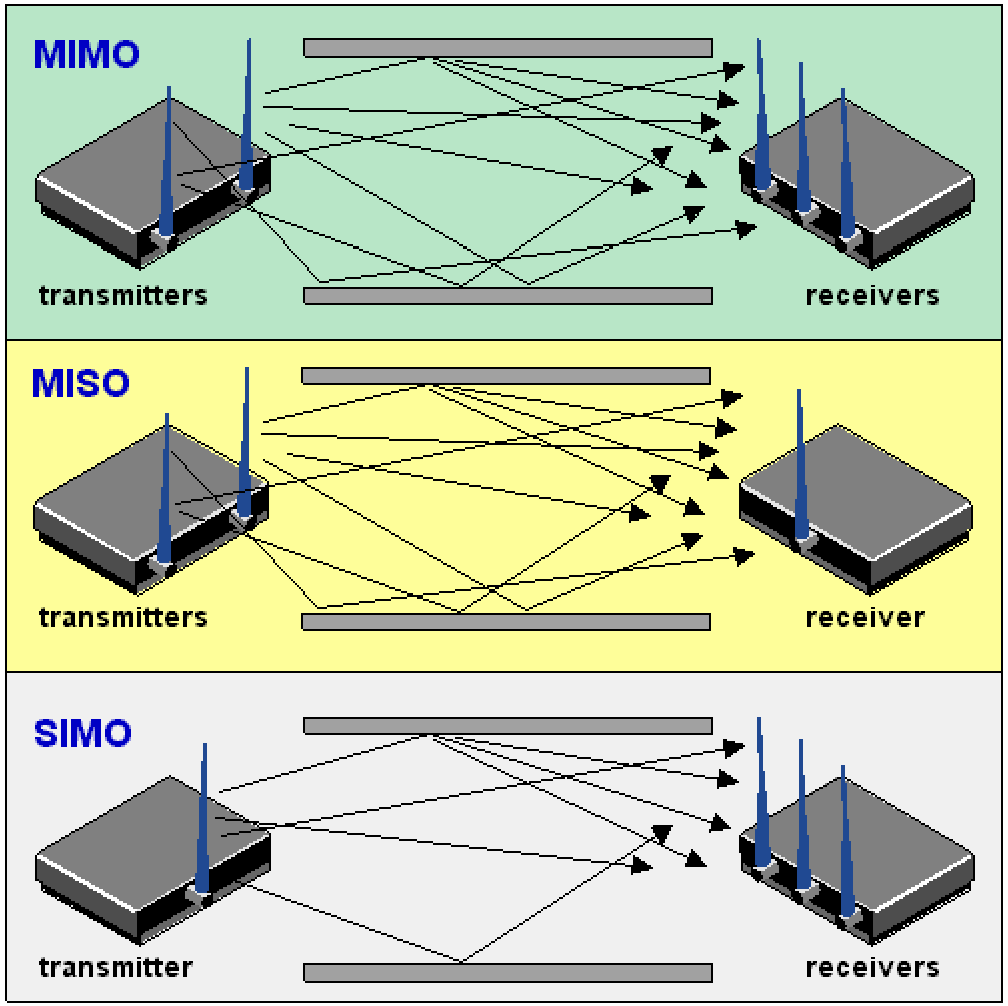


Space Diversity (5)



Multiple Input Multiple Output (1)

- **MIMO uses independent channel fading due to multipath propagation to increase capacity**
- **No extra bandwidth required**
- **Multiple independent samples of the same signal at the receiver give rise to diversity**



Multiple Input Multiple Output (2)

- **MIMO system with N_T transmit and N_R receive antennas**

$$\begin{bmatrix} r_1(k) \\ \vdots \\ r_{N_R}(k) \end{bmatrix} = \begin{bmatrix} h_{11} & \cdots & h_{N_T 1} \\ \vdots & \ddots & \vdots \\ h_{1N_R} & \cdots & h_{N_T N_R} \end{bmatrix} \begin{bmatrix} x_1(k) \\ \vdots \\ x_{N_T}(k) \end{bmatrix} + \begin{bmatrix} n_1(k) \\ \vdots \\ n_{N_R}(k) \end{bmatrix}$$

$$\mathbf{r}(k) = \mathbf{H} \cdot \mathbf{x}(k) + \mathbf{n}(k)$$

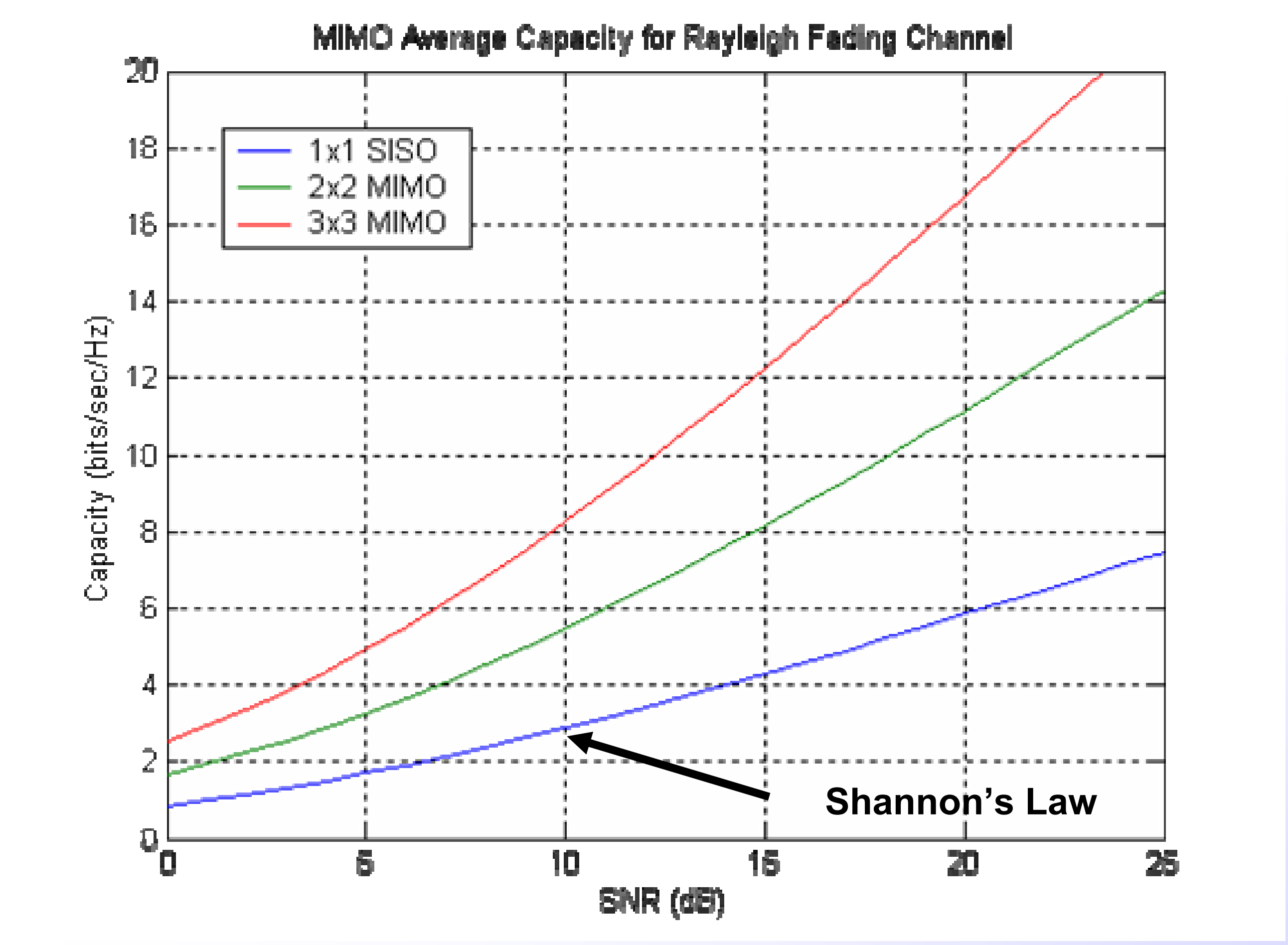
$\mathbf{r}(k)$: received vector

$\mathbf{H}$: quasi-static channel matrix

$\mathbf{x}(k)$: transmitted vector

$\mathbf{n}(k)$: white Gaussian noise vector

Multiple Input Multiple Output (3)

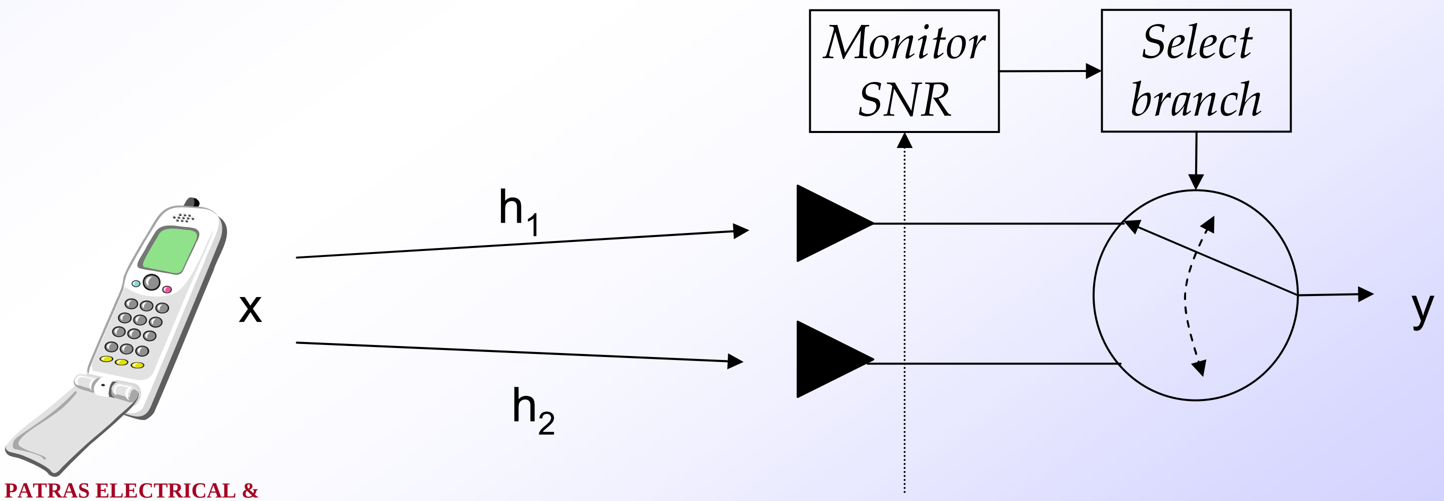


Outline

- Introduction
- Diversity Techniques
- <u>Diversity Combining Techniques</u>
- MISO / OFDMA scheme
- Conclusions

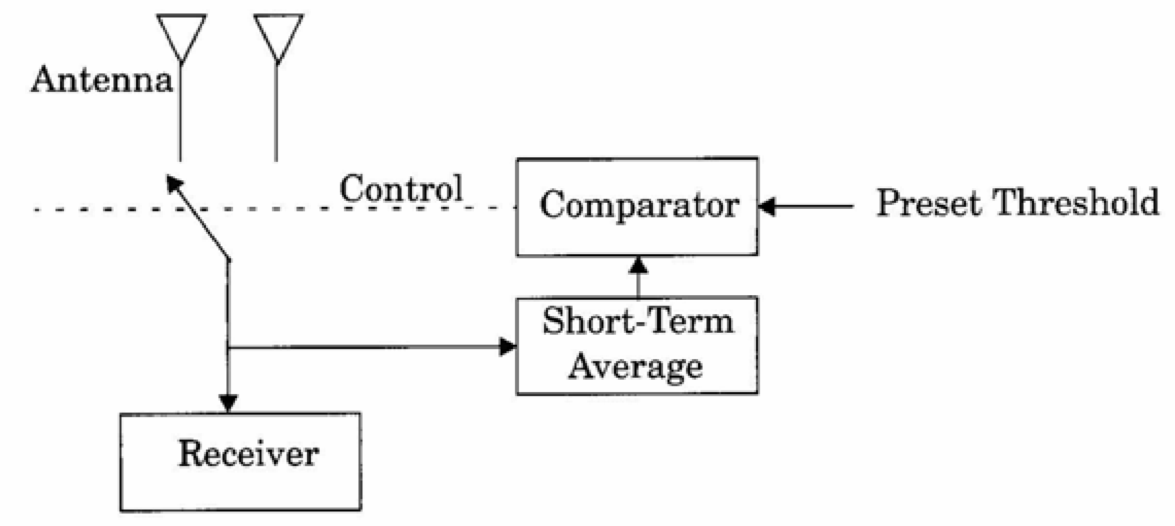
Selection Combining

- Simple and cheap
- Receiver selects branch with highest instantaneous SNR
- New selection made at a time that is the reciprocal of the fading rate
- This will cause the system to stay with the current signal until it is likely the signal has faded



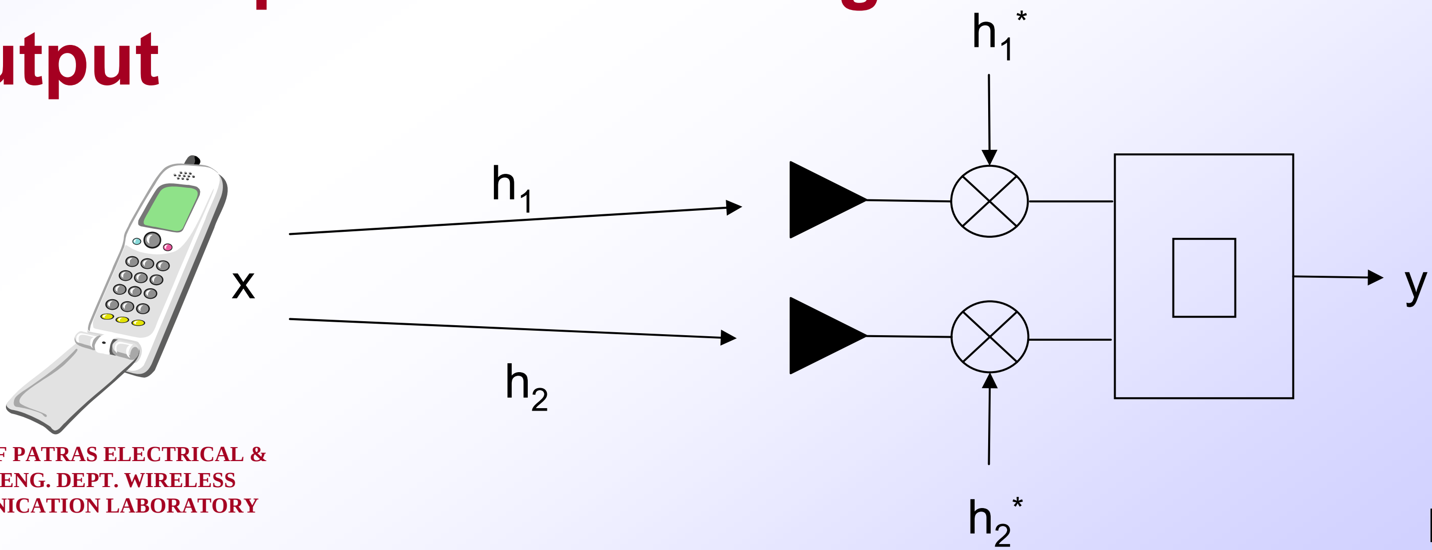
Feedback or Scanning Combining

- Scan each antenna until a signal is found that is above predetermined threshold
- If signal drops below threshold → rescan
- Only one receiver is required (since only receiving one signal at a time), so less costly → still need multiple antennas



Maximal Ratio Combining

- All paths cophased and summed with optimal weighting to maximize combiner output SNR
- Optimal technique to maximize output SNR
- A means of combining the signals from all receiver branches, so that signals with a higher received power have a larger influence on the final output



Equal Gain Combining

- Simplified method of Maximal Ratio Combining
- Combine multiple signals into one
- The phase is adjusted for each receive signal so that
  - The signal from each branch are co-phased
  - Vectors add in-phase
- Better performance than selection diversity

ZF / MMSE

- **MIMO system**

$$\mathbf{r}(k) = \mathbf{H} \cdot \mathbf{x}(k) + \mathbf{n}(k)$$

- **ZF: Pseudo inverse of the channel, simplest**

$$\hat{\mathbf{x}} = (\mathbf{H}^{*}\mathbf{H})^{-1}\mathbf{H}\mathbf{r} = \mathbf{H}^{+}\mathbf{r}$$

- **MMSE: Intermediate complexity and performance**

$$\hat{\mathbf{x}} = (\frac{1}{SNR}\mathbf{I}_{N_R} + \mathbf{H}^{H}\mathbf{H})^{-1}\mathbf{H}^{H} \cdot \mathbf{r}$$

Outline

- Introduction
- Diversity Techniques
- Diversity Combining Techniques
- MISO / OFDMA scheme
- Conclusions

System Model

- Base Station uses many antennas
- A single antenna is available to each user
- ZF beamforming inverts the channel matrix at the transmitter in order to create orthogonal channels between the transmitter and the receiver. It is then possible to encode users individually
- Sum capacity is maximized while maintaining proportional fairness among users
- Proportional rate constraints are used
- User selection procedure takes fairness into account

Problem Formulation (1)

$$\max_{\rho_{k,i,n},p_{k,i,n}} \sum_{k=1}^{K} R_k$$

s. t.

$$\sum_{k=1}^{K} p_{k,i,n} \leqslant \frac{P_T}{N_c}; \quad \forall n,i$$

$$\sum_{k=1}^{K} \rho_{k,i,n} \leqslant N_t; \quad \forall n,i$$

$$p_{k,i,n} \geqslant 0,\ \rho_{k,i,n} \in \{0,1\}; \quad \forall n,i,k$$

$R_1:R_2:\ldots:R_K=\gamma_1:\gamma_2:\ldots:\gamma_K$

- **Where $R_k = \sum_{n=1}^{N_c}\sum_{i=1}^{I} \rho_{k,i,n} \log_2\left(1+p_{k,i,n}\gamma_{k,i,n}\right)$ is the data rate of user k per Hertz**
- **$\rho_{k,i,n}=1$ if user k in the set A_i is selected in the subcarrier n, otherwise $\rho_{k,i,n}=0$**

Problem Formulation (2)

- $\gamma_{k,n} = \left| \boldsymbol{h}_{k,n} \boldsymbol{\omega}_{k,n} \right|^2 / \left(\sigma_n^2 \Gamma \right)$ is the equivalent signal to noise ratio
- $\Gamma = -\ln\left(5B_k\right)/1.5$ and B_k is the BER requirement of user k
- $\omega_{k,n}$ is the N_t x 1beamforming vector for user k
- P_T is the total transmitted power
- N_c is the total number of subcarriers
- There are I possible combinations of users transmitting on the same subcarrier, denoted as $\mathcal{A}_i$
- $p_{k,i,n}$ is the allocated power to user k in the set A_i in subcarrier n

Outline

- **Introduction**
- **Diversity Techniques**
- **Diversity Combining Techniques**
- **MISO / OFDMA scheme**
- **<u>Conclusions</u>**

Conclusions (1)

- Multipath fading is not an enemy but ally
- Diversity is used to provide the receiver with several replicas of the same signal
- Diversity techniques are used to improve the performance of the radio channel without any increase in the transmitted power
- As higher as the received signal replicas are decorrelated, as much as the diversity gain

Conclusions (2)

- MRC outperforms the Selection Combining
- Equal gain combining (EGC) performs very close to the MRC
- Unlike the MRC, the estimate of the channel gain is not required in EGC
- Among different combining techniques MRC has the best performance and the highest complexity, SC has the lowest performance and the least complexity

Thank You!!!