ADVANCED WIRELESS TECHNOLOGIES

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MOOC on M4D 2013

Wireless Signal Fast Fading

- The wireless signal can reach the receiver via direct and scattered paths.
- As a result, the receiver sees the superposition of multiple copies of the transmitted signal.
  - Multipath Propogation
- These signal copies experience different attenuations, delays.

Wireless Signal Fast Fading

- Results in interference, amplifying or attenuating the signal power seen at the Rx.
  - This phenomenon is termed as **fading**.
- Strong destructive interference is referred to as a **deep fade.**

Techniques to Combat Fast Fading

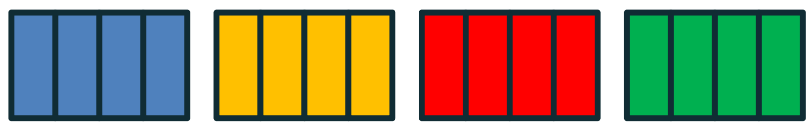
- Several techniques can be employed to improve performance in a wireless fading channel.
  - Forward Error Correction.
  - Interleaving.
  - Hybrid ARQ (HARQ).
  - **Diversity.**

Forward Error Correction (FEC)

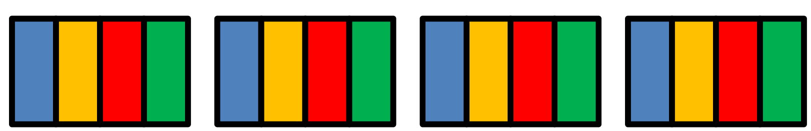
- System of error control for data transmission.
  - Coding the data stream to correct at receiver.
- Sender adds redundant data to its messages also known as ‘parity’ bits.
- Examples of forward error correction codes,
  - Block Codes.
  - Convolutional Codes.
  - Turbo Codes.
- FEC typically uses a large overhead.

Interleaving

- Symbol blocks to be transmitted.
  - Each symbol block is coded to protect against symbol errors (Ex. Convolutional Coding).

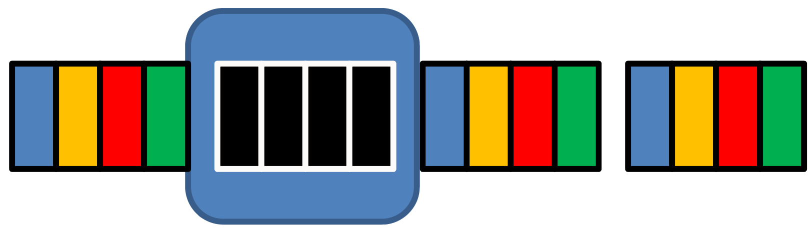


- Symbol blocks after **Interleaving.**
  - Interleaving arranges data in a non-contiguous fashion.

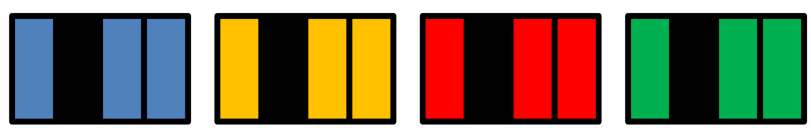


Interleaving

- Deep fade results in a ‘Burst Error’ in the symbol block affected by fading channel.



- Symbol blocks after **Deinterleaving.**
  - Erroneous symbols are spread across multiple blocks.



- This results in better error correction performance for the block code.
  - It can correct a fixed number of errors per block.

Hybrid Automatic Repeat reQuest

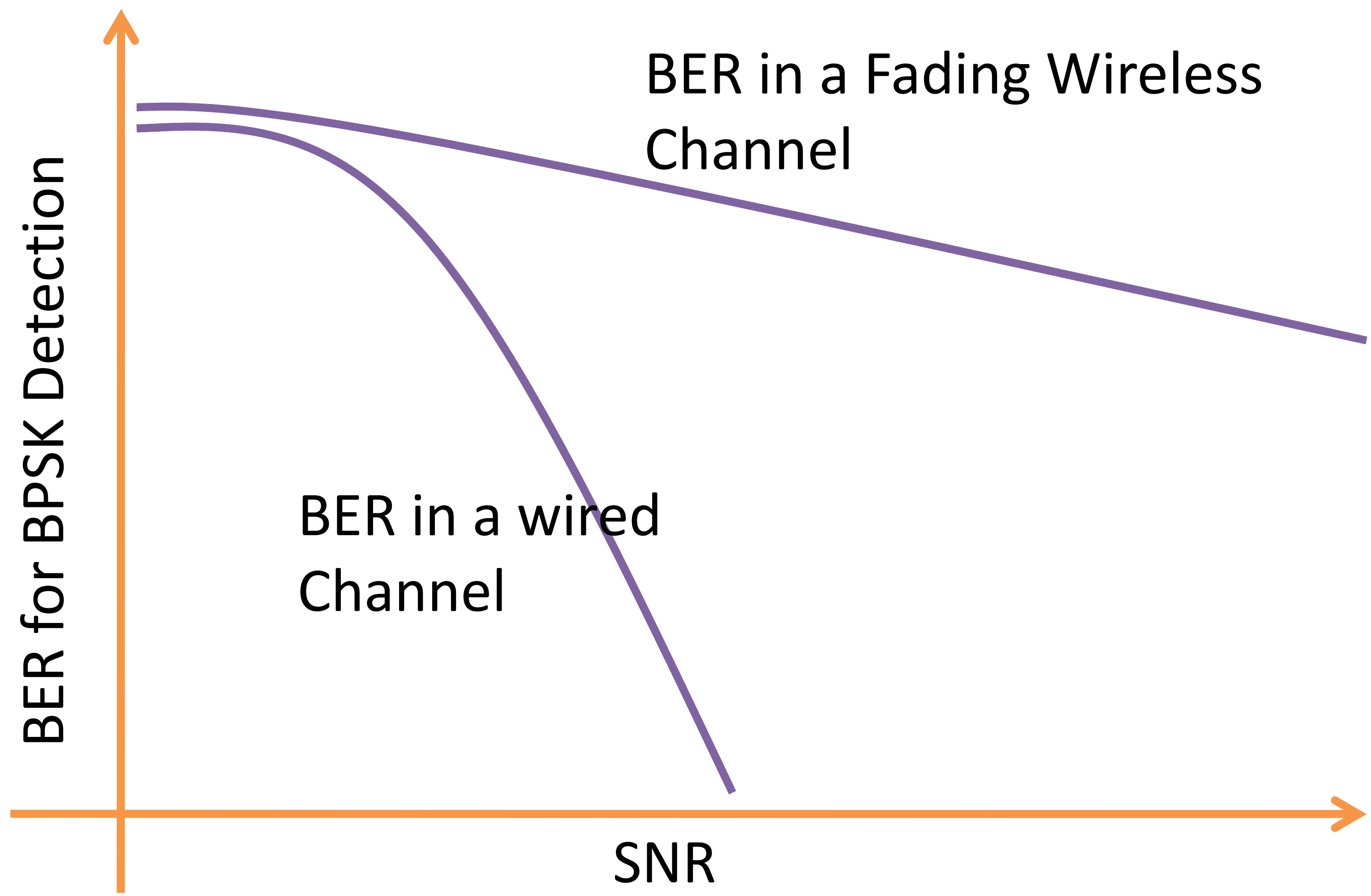
- It is an error-control method for packet data transmission.
- Uses ACKs/NACKs and timeouts to achieve reliable data transmission.
- An ACK is sent by the receiver to indicate that it has correctly received a data frame or packet.

Hybrid Automatic Repeat reQuest

- In case of a NACK, the receiver has two options in H-ARQ.
  - Send the complete packet (Chase Combining).
  - Send only the parity bits (Incremental Redundancy).
- It cannot be used for transmission of real-time information (Ex audio/ video).
- Suited for non real-time applications such as data, e-mail.

BER Performance of Fading Channels

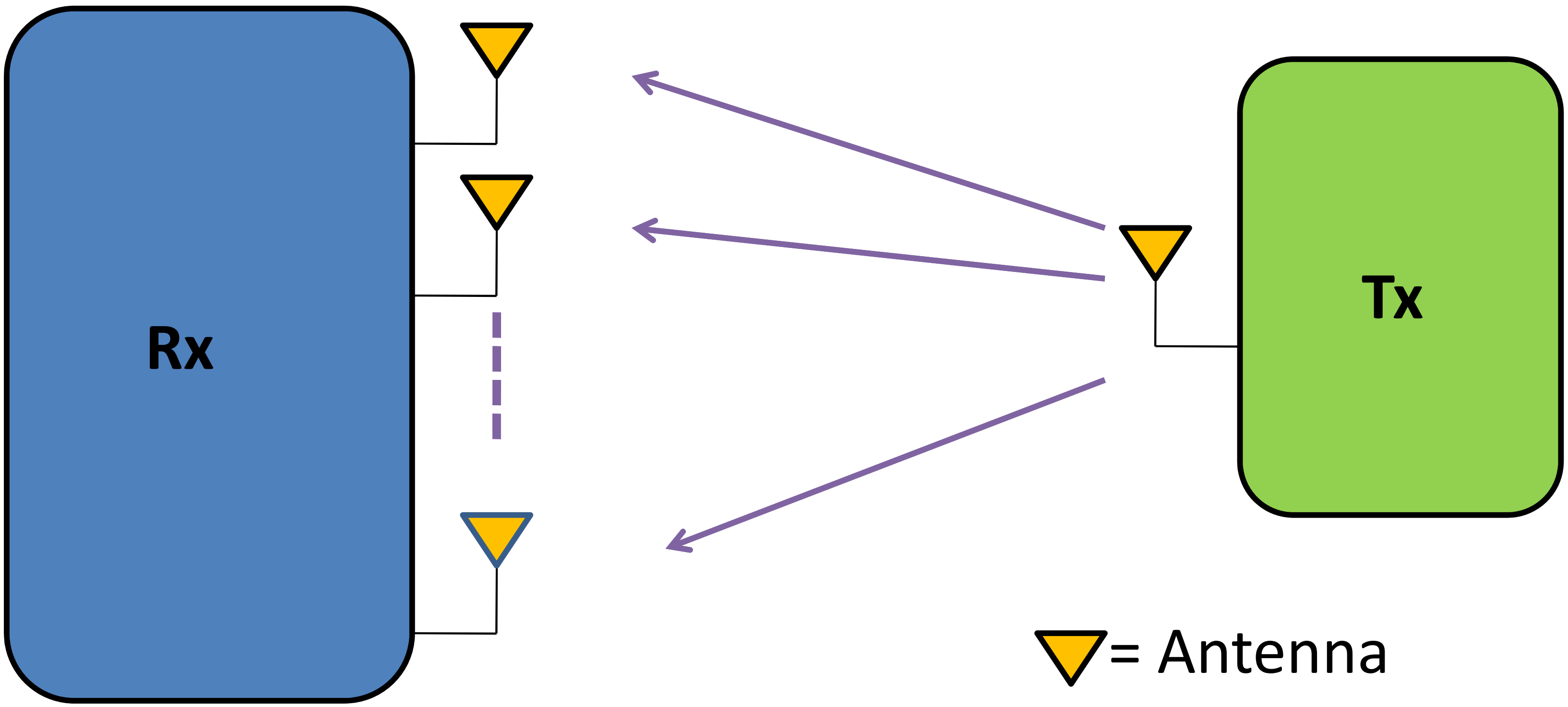
BER of a Rayleigh Fading Channel



Antenna Diversity

- Consider a wireless signal received using multiple antennas at the receiver (Rx) i.e. employing receive antenna diversity.
- Let the number of receive antennas be L.
- Hence, the receiver (Rx) sees L copies of the transmitted wireless signal, each traveling through an independent Rayleigh flat-fading channel.

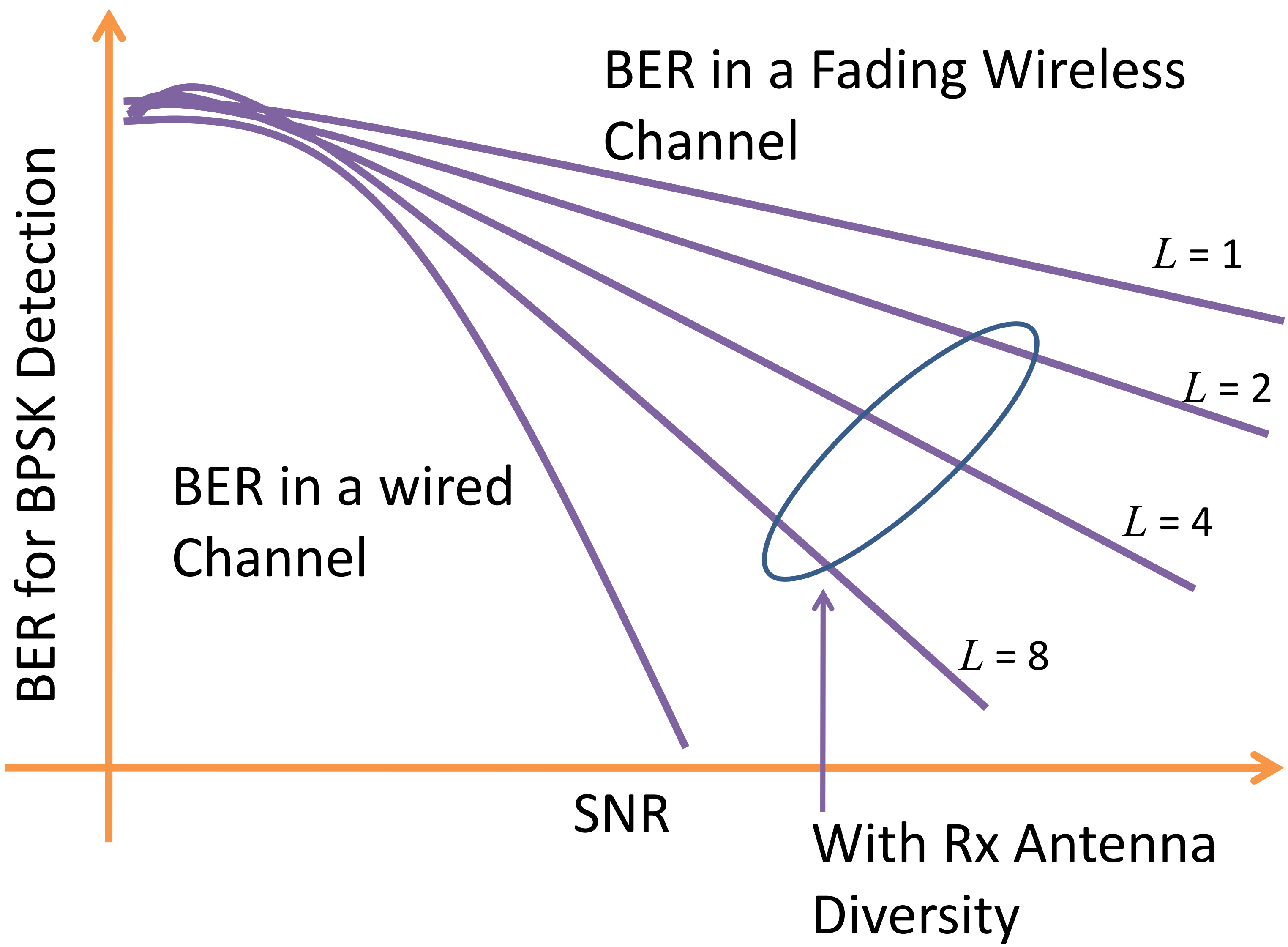
Schematic of a Rx Diversity System



Prerequisites for Diversity Gain

- Diversity implies the receiver is provided with multiple copies of the transmitted signal.
- The multiple signal copies should experience ***independent*** *levels of fading* in the wireless channel.
- This is because only in that case the probability that all signal copies fade simultaneously is reduced dramatically.
  - Leads to a significant reduction in the bit error rate.

BER of a Rayleigh Fading Channel



Types of Diversity

Diversity

- Examples of diversity techniques
  - Transmit/Receive Diversity.
  - Temporal Diversity.
  - Frequency Diversity.
  - Multipath Diversity.

Spatial Diversity

- As the name denotes, diversity can be obtained by transmitting the wireless signal across independently fading **spatial channels**.
- This implies there are several receiving and/or transmitting antennas that are spaced sufficiently far apart.
- Spatial separation should be sufficently large to reduce correlation between the different antennas or diversity branches.
- Spacing guideline is approximately $\lambda/2$. At 2 GHz, the spacing is roughly 5 cm.

Temporal Diversity

- Temporal diversity is achieved through transmission of same wireless signal at different times i.e. through **temporal** spacing.
- The time separation between the signal copies should be larger than the *coherence time* of the channel for the different copies to experience independent fading.
- For instance, at 2 GHz, 60 Km/Hr, the temporal spacing should at least be 2 ms.

Frequency Diversity

- Frequency diversity is achieved through transmission of same wireless signal in different independently fading frequency bands i.e. through **frequency spacing**.
- The frequency separation should be larger than the coherence bandwidth B_c of the channel.
- For cellular communications this is approximately 300 KHz, since the delay spread is of the order of 3μs.

Multipath Diversity

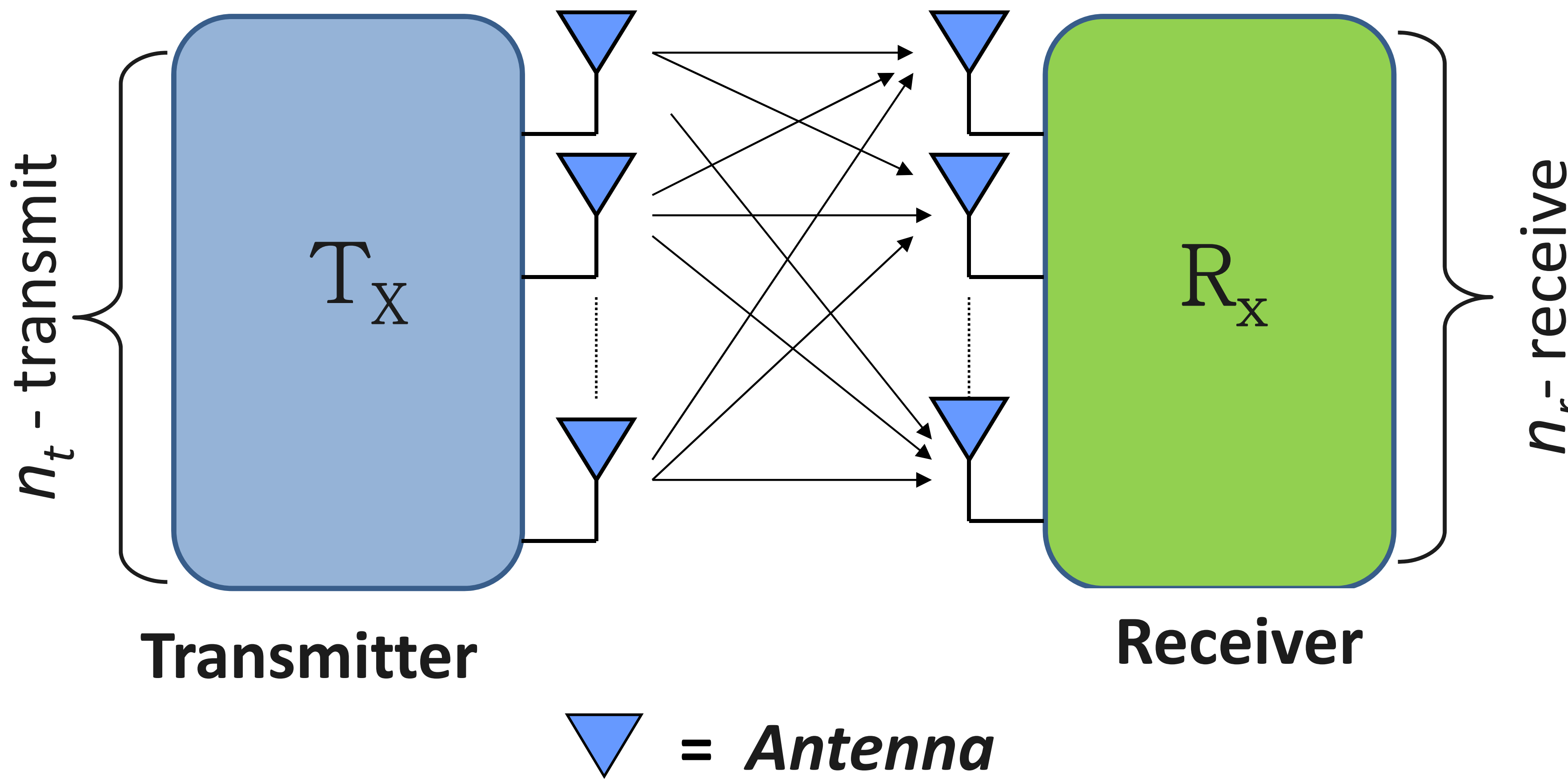
- Signal replicas received are received at different delays and phase factors at the receiver.
- If these different replicas are spaced sufficiently far apart so that they can be distinguished and they experience independent levels of fading, they can be used to exploit multipath diversity.
- Receiver structures such as RAKE receiver in CDMA and equalizers such as Maximum Likelihood Sequence Estimator (MLSE) in a TDM/TDMA system provide multipath diversity.

Multiple Input Multiple Output (MIMO) Systems

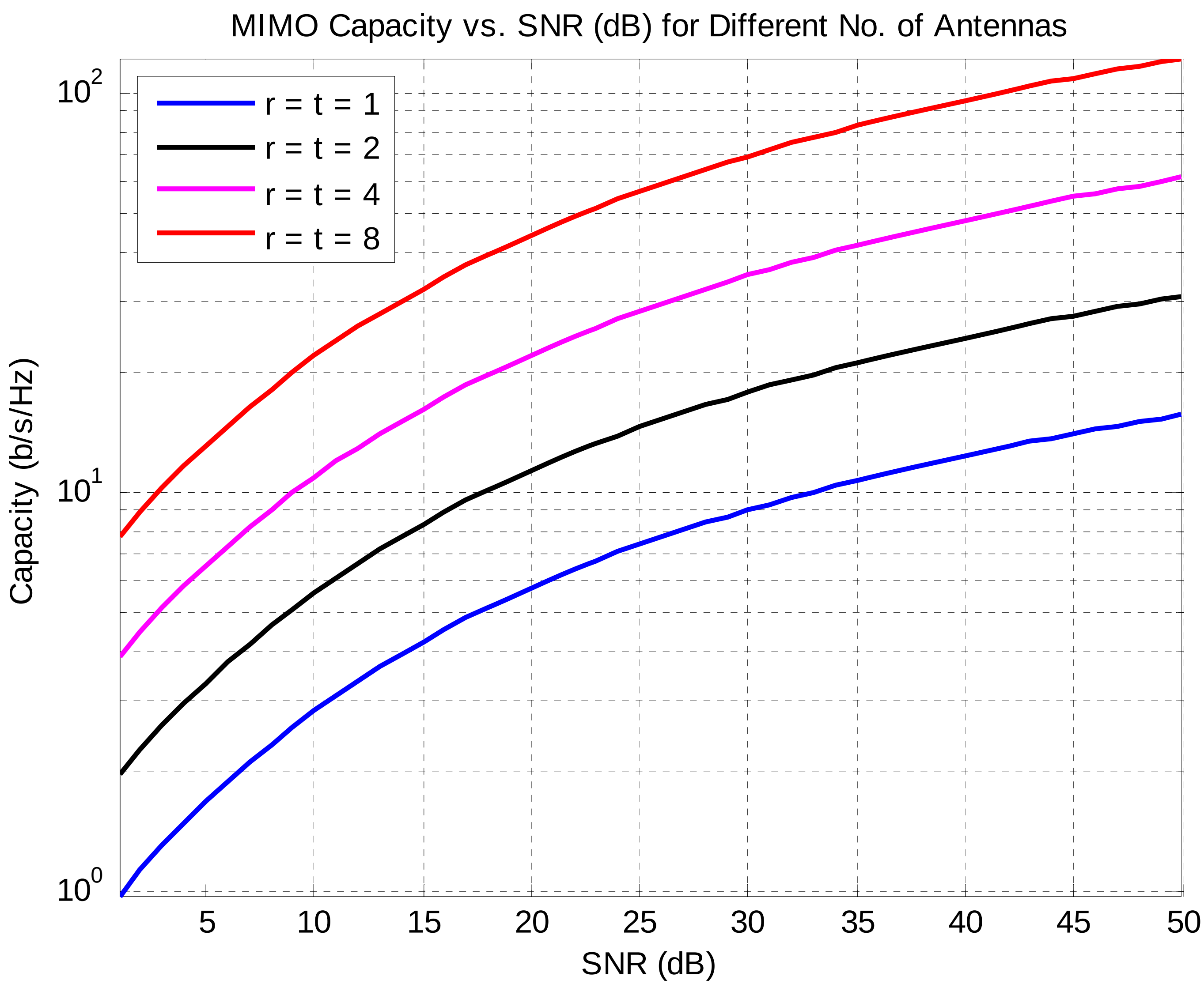
MIMO Communication Systems

- A MIMO system has multiple ($n_t > 1$) transmit and multiple ($n_r > 1$) receive antennas.
- MIMO wireless systems are a ***revolutionary breakthrough*** because they offer
  - **Linear** increase in throughput for the **same** transmit power
  - **Combats fading** through receive and transmit diversity.

MIMO System Schematic Diagram



MIMO Capacity vs. SNR, #Antennas



MIMO System Model

$$\mathbf{x} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{n_t} \end{bmatrix}$$

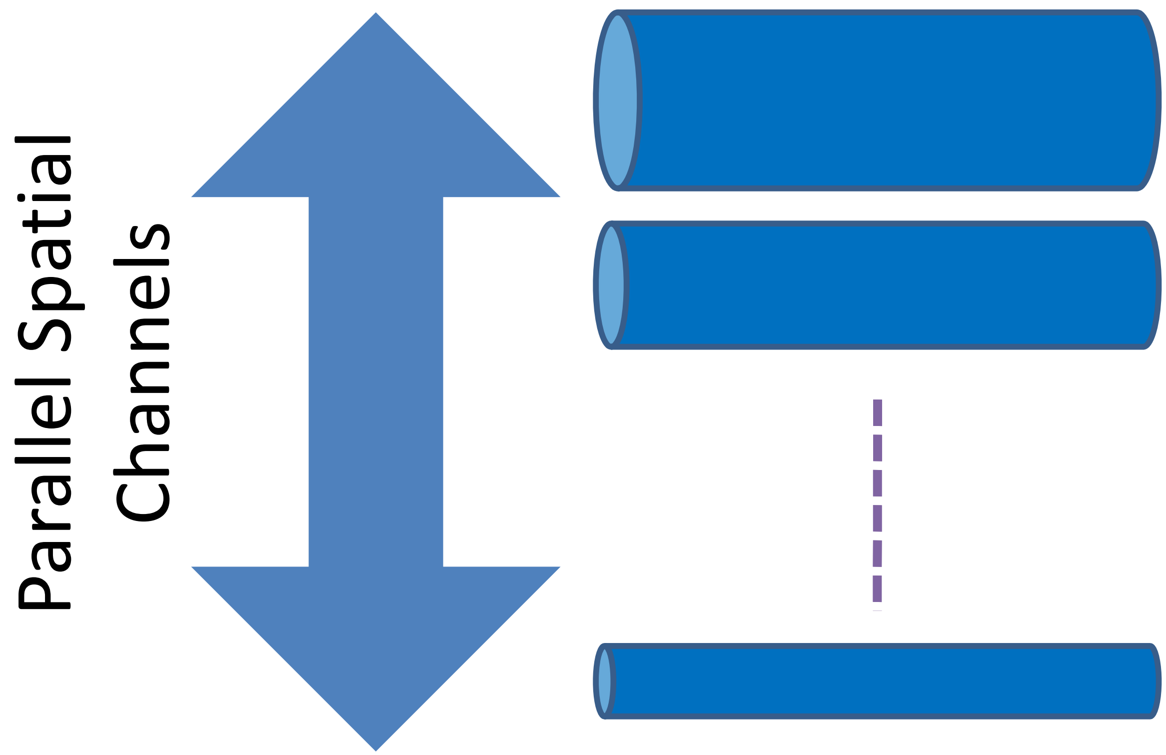
$$\mathbf{y} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_{n_r} \end{bmatrix}$$

- The MIMO system model can be represented as,

$$\mathbf{y}(k) = \mathbf{H}\mathbf{x}(k) + \mathbf{n}(k)\,.$$

MIMO Capacity Schematic

- The MIMO system can be schematically represented as having n_t ***parallel*** channels.
  - Spatial Multiplexing



SPACE-TIME BLOCK CODES

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Alamouti Code

- The **Alamouti Code** or the **Alamouti Scheme** can be employed to obtain transmit diversity in a 2 transmit antenna system.
- It was described by **Siavash Alamouti** in his pioneering 1998 work "*A simple transmit diversity technique for wireless communications*".
- This powerful scheme, has been included in all the 3G and 4G wireless cellular and LAN standards.

Alamouti Code

- Alamouti invented the first Orthogonal Space Time Block Code (OSTBC) in 1998.
- It was designed for a two-transmit antenna system and achieves second order diversity (L=2) using a very simplistic symbol transmit scheme.

Alamouti Code

- The Alamouti symbol transmit structure is given as,

$$[x(1), x(2)] \Rightarrow \begin{bmatrix} x(1) & -x^*(2) \\ x(2) & x^*(1) \end{bmatrix}$$

Time (→), Space (↑)