Unit 4

Improvement in Link Performance

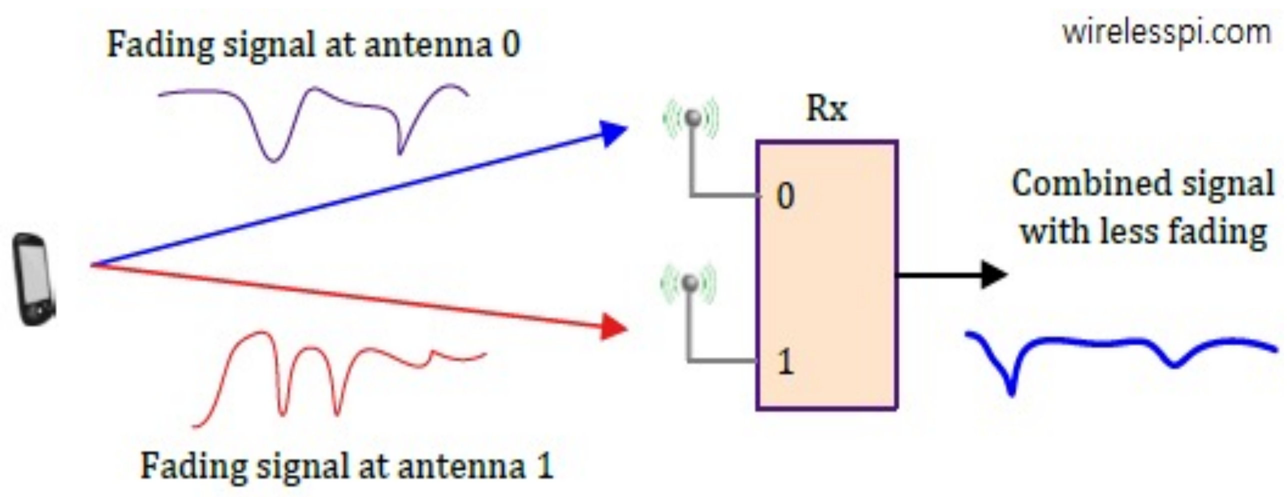
Introduction to Diversity, Equalization and Capacity

Diversity

Analogy

Most people on the planet are born with two kidneys and two lungs. If one of them fails, they can still live a healthy life with some precaution. This is the essence of diversity.

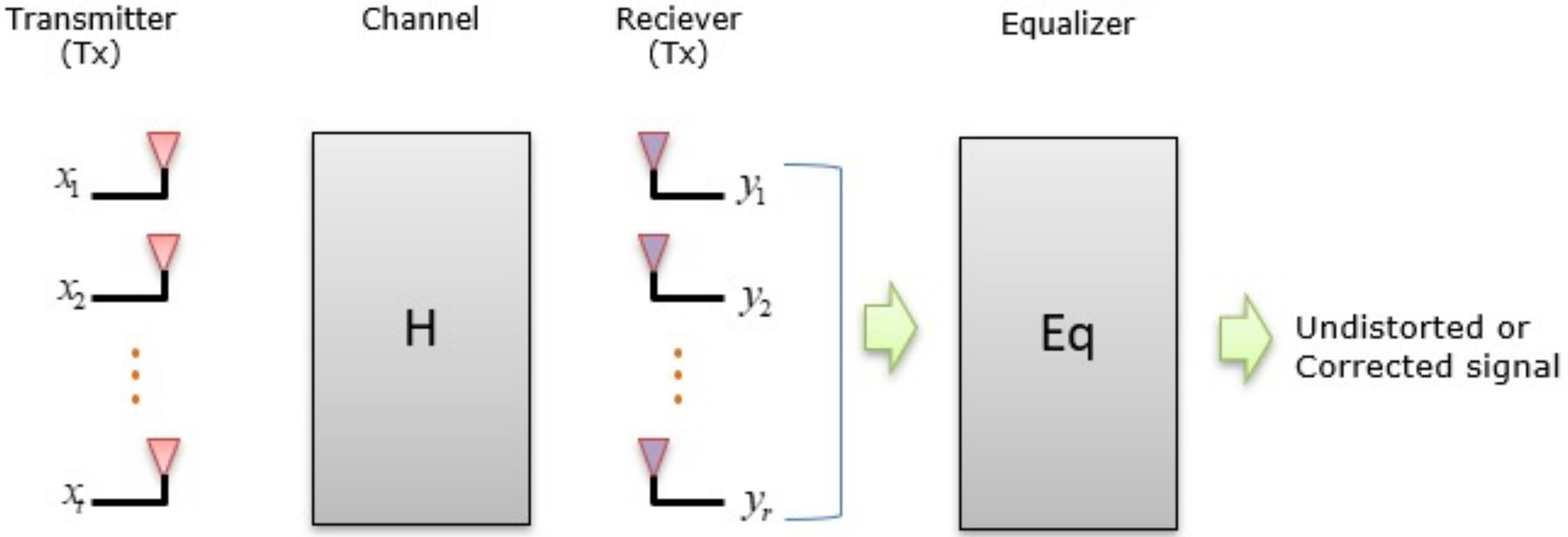
In the Context of Wireless Communication



Diversity is a technique used to compensate for fading channel impairments, and is usually implemented by using two or more receiving antennas.

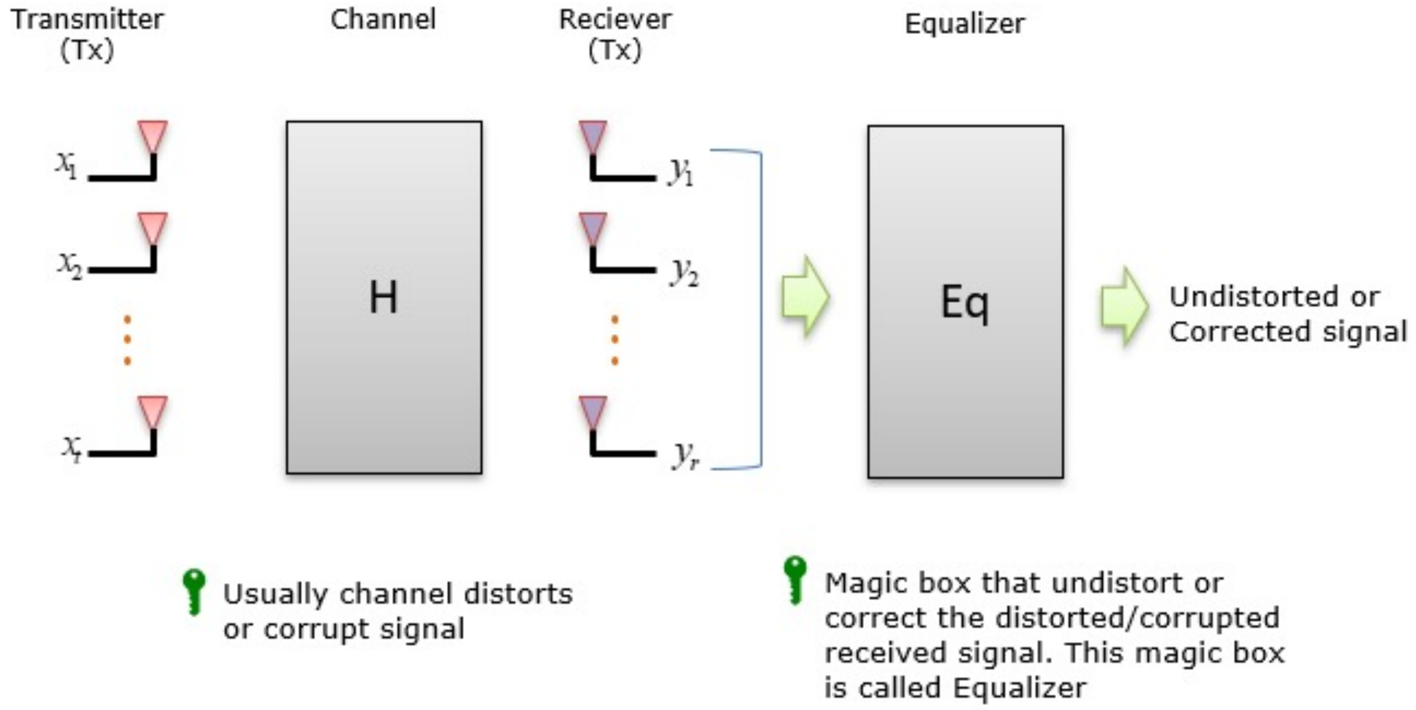
The most common diversity technique is called *spatial diversity,* whereby multiple antennas are strategically spaced and connected to a common receiving system. While one antenna sees a signal null, one of the other antennas may see a signal peak, and the receiver is able to select the antenna with the best signal at any time.

Equalization



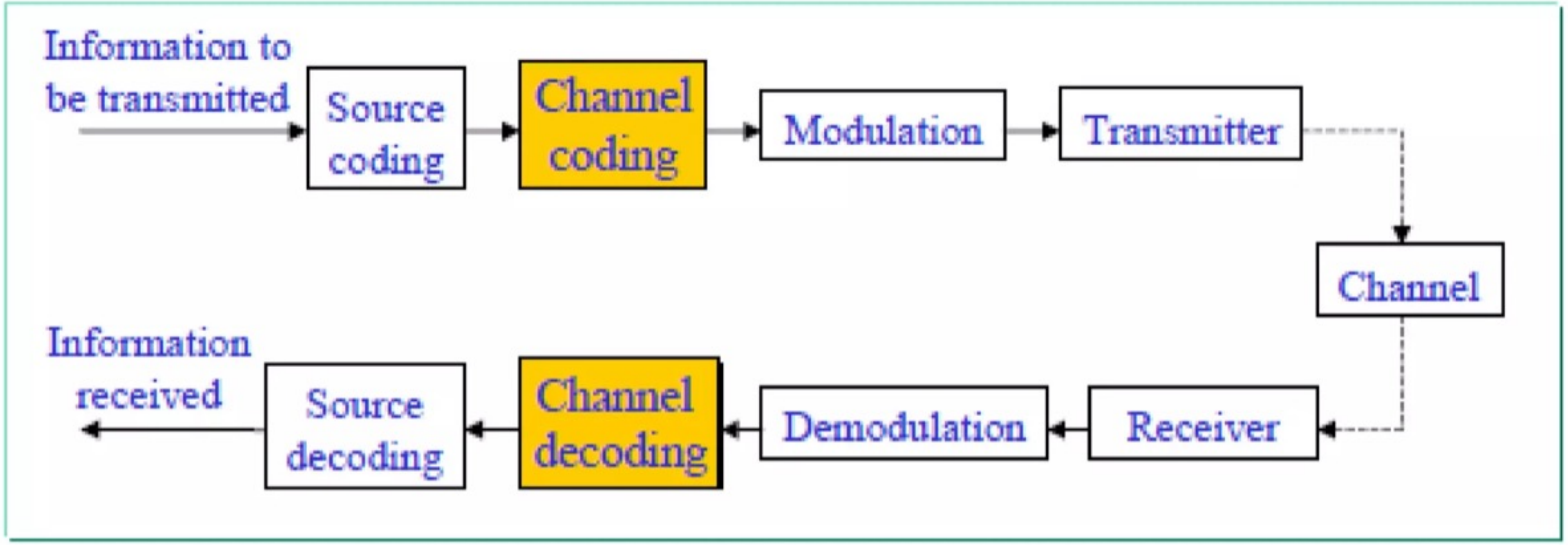
- Usually channel distorts or corrupt signal
- Magic box that undistort or correct the distorted/corrupted received signal. This magic box is called Equalizer

Equalization



Equalization compensates for *intersymbol interference* (ISI) created by multipath within time dispersive channels. If the modulation bandwidth exceeds the coherence bandwidth of the radio channel, ISI occurs and modulation pulses are spread in time into adjacent symbols. An equalizer within a receiver compensates for the average range of expected channel amplitude and delay characteristics. Equalizers must be adaptive since the channel is generally unknown and time varying.

Channel Coding



- Channel coding provides to the receiver the ability of error detection and correction
- Channel Encoder adds some redundant bits to the input bit sequence. Addition of these extra bits
  - Allows the receiver to perform error detection and correction
  - However, increases the bit rate and hence increase required bandwidth

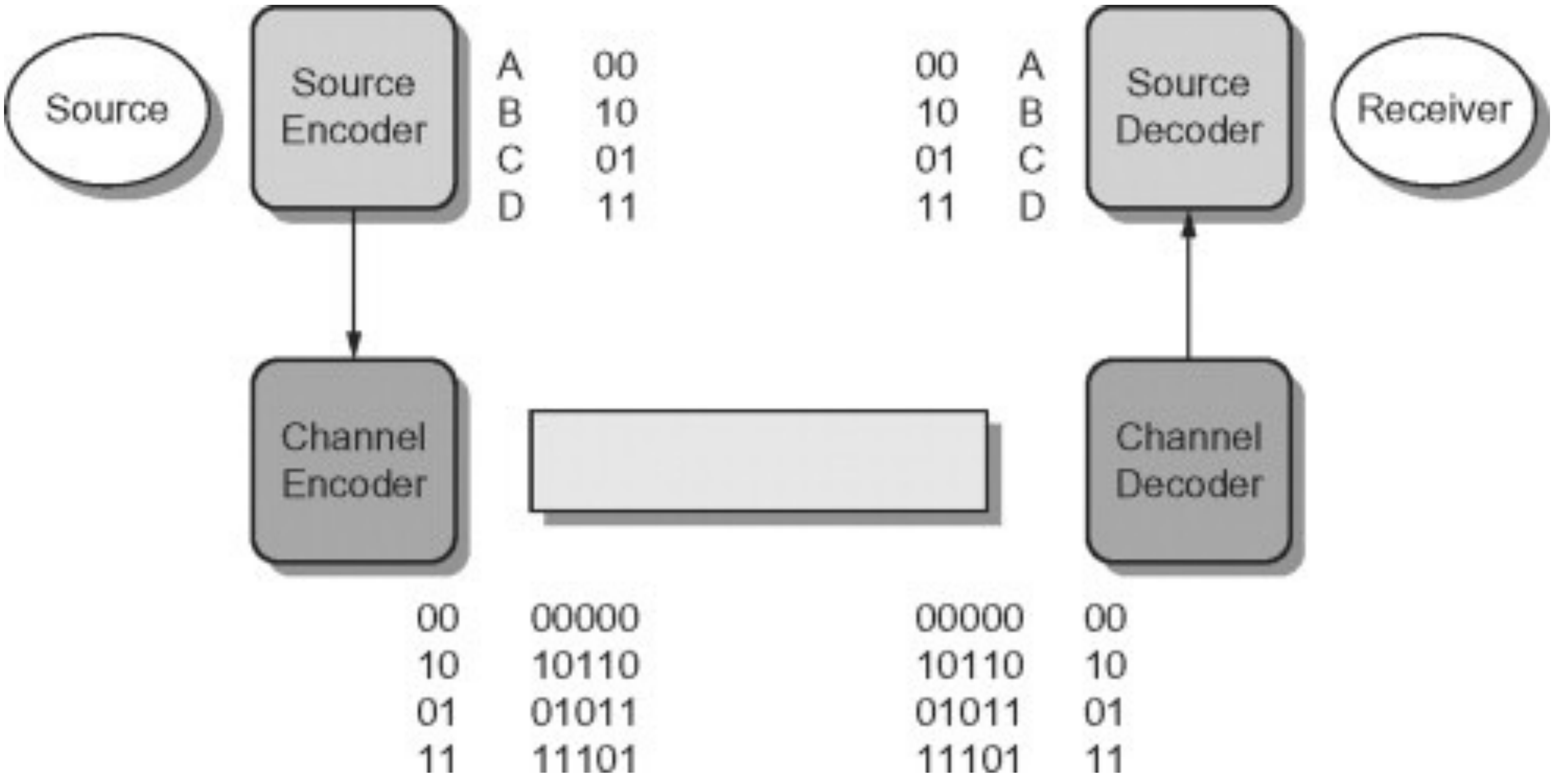
Channel Coding

Channel coding improves the small-scale link performance by adding redundant data bits in the transmitted message so that if an instantaneous fade occurs in the channel, the data may still be recovered at the receiver.

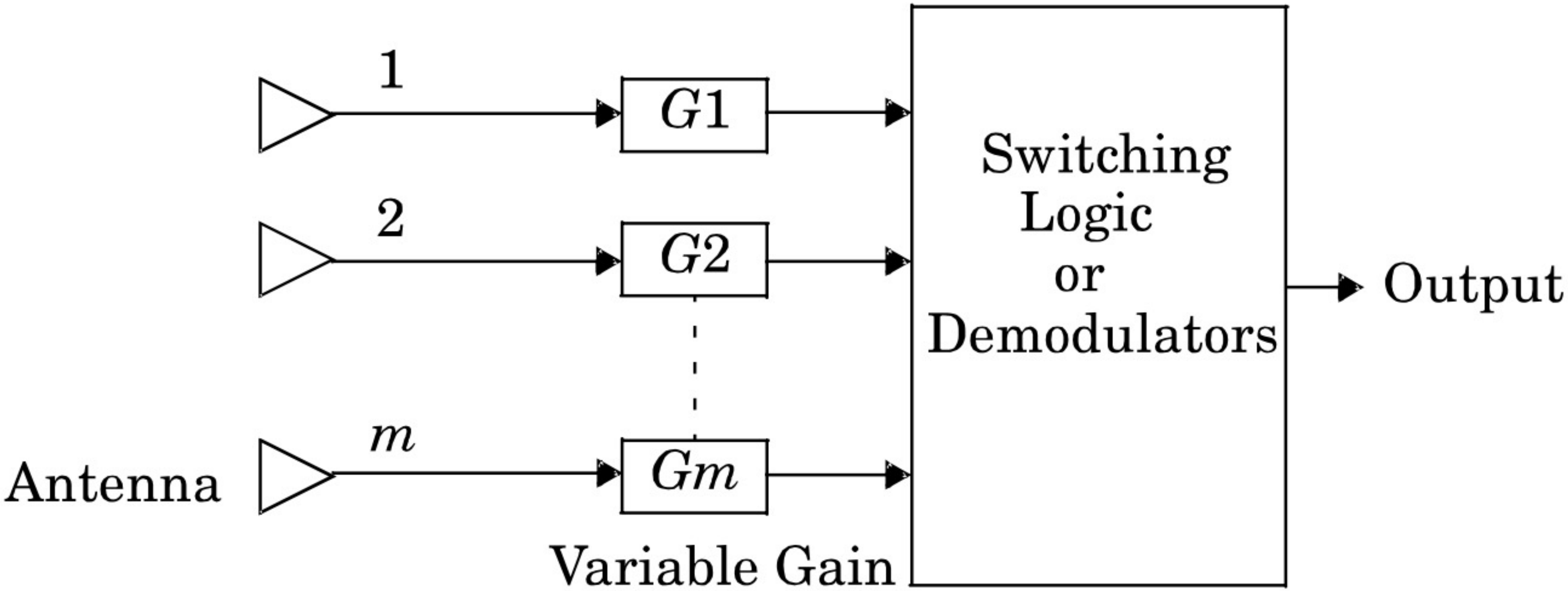
At the baseband portion of the transmitter, a channel coder maps the user's digital message sequence into another specific code sequence containing a greater number of bits than originally contained in the message.

The coded message is then modulated for transmission in the wireless channel.

Channel Coding



Space Diversity



Generalized block diagram for space diversity.

Space Diversity

- The concept of antenna space diversity is also used in base station design.

- At each cell site, multiple base station receiving antennas are used to provide diversity reception.

- However, since the important scatterers are generally on the ground in the vicinity of the mobile, the base station antennas must be spaced considerably far apart to achieve decorrelation.

- Separations on the order of several tens of wavelengths are required at the base station.

Space Diversity

Space diversity reception methods can be classified into four categories:

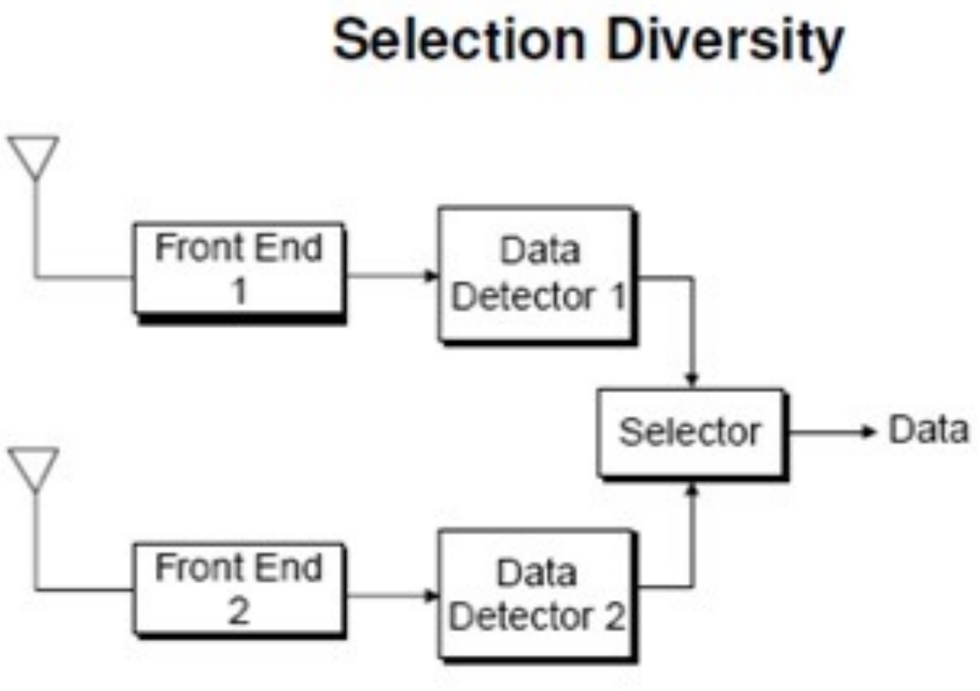
1.Selection diversity

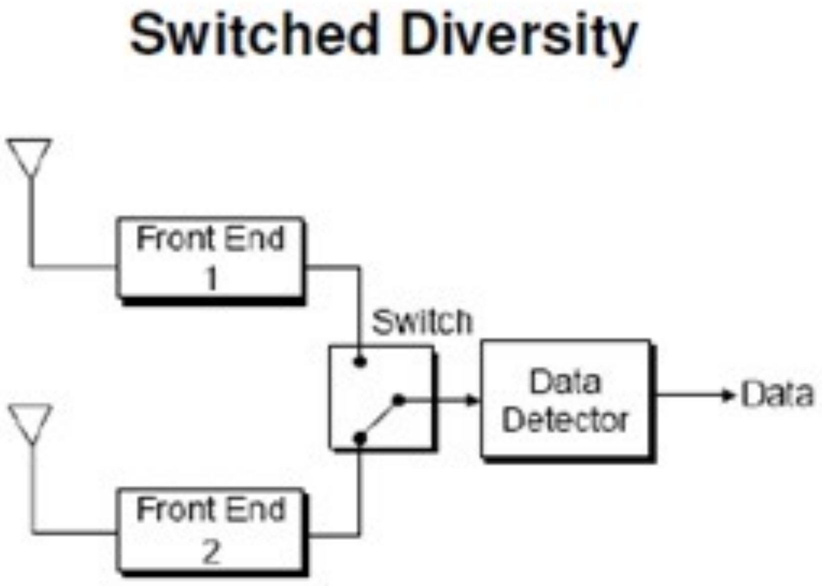
2.Feedback diversity

3.Maximal ratio combining

4. Equal gain diversity

Space Diversity: Selection Diversity





Space Diversity: Selection Diversity

- Selection diversity is the simplest diversity technique.
- A block diagram of this method is similar to that shown, where *m* demodulators are used to provide *m* diversity branches whose gains are adjusted to provide the same average SNR for each branch.
- The receiver branch having the highest instantaneous SNR is connected to the demodulator.
- The antenna signals themselves could be sampled and the best one sent to a single demodulator.
- In practice, the branch with the largest (S + *N)IN* is used, since it is difficult to measure SNR alone.
- A practical selection diversity system cannot function on a truly instantaneous basis, but must be designed so that the internal time constants of the selection circuitry are shorter than the reciprocal of the signal fading rate.

Space Diversity: Feedback or Scanning Diversity

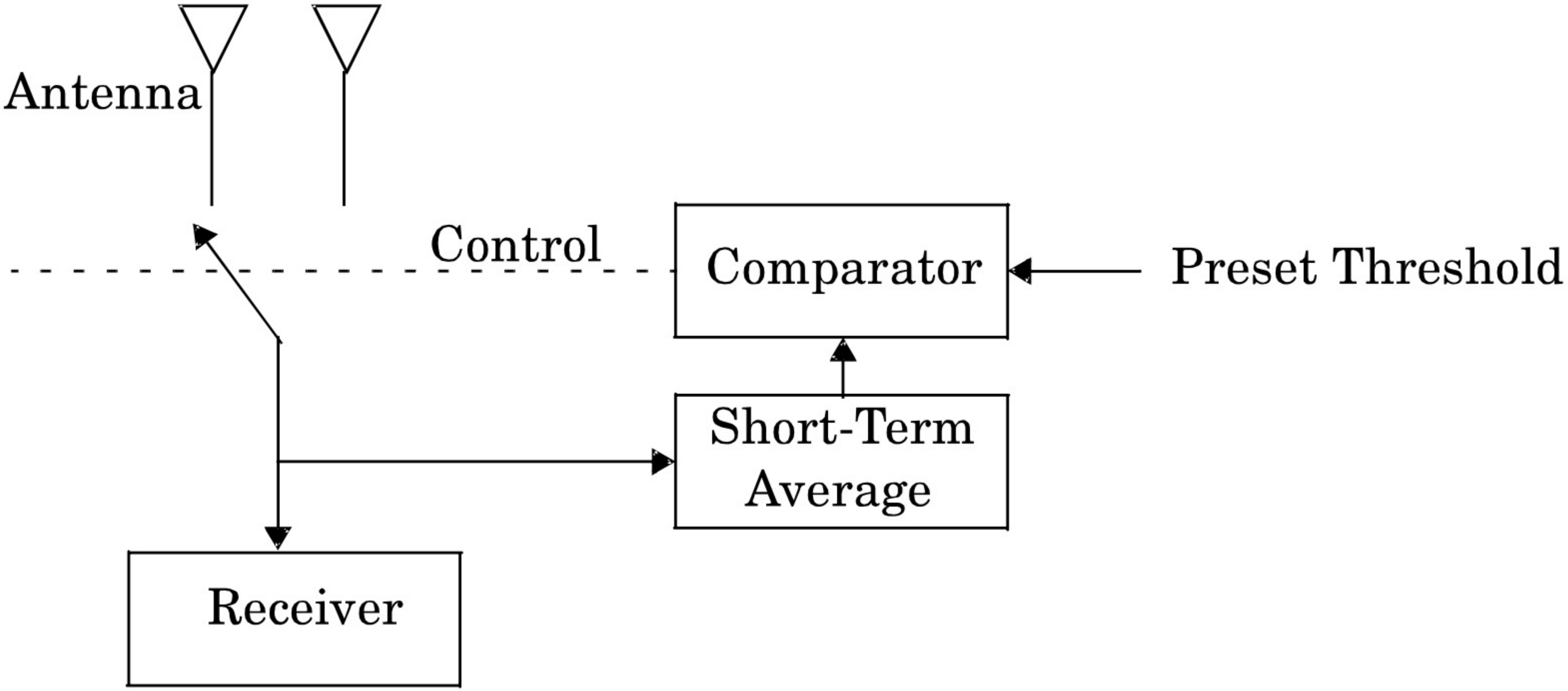


Figure 7.13 Basic form of scanning diversity.

Space Diversity: Feedback or Scanning Diversity

Scanning diversity is very similar to selection diversity except that instead of always using the best of M signals, the M signals are scanned in a fixed sequence until one is found to be above a predetermined threshold.

This signal is then received until it falls below threshold and the scanning process is again initiated.

The resulting fading statistics are somewhat inferior to those obtained by the other methods, but the advantage with this method is that it is very simple to implement-only one receiver is required.

Space Diversity: Maximal Ratio Combiner

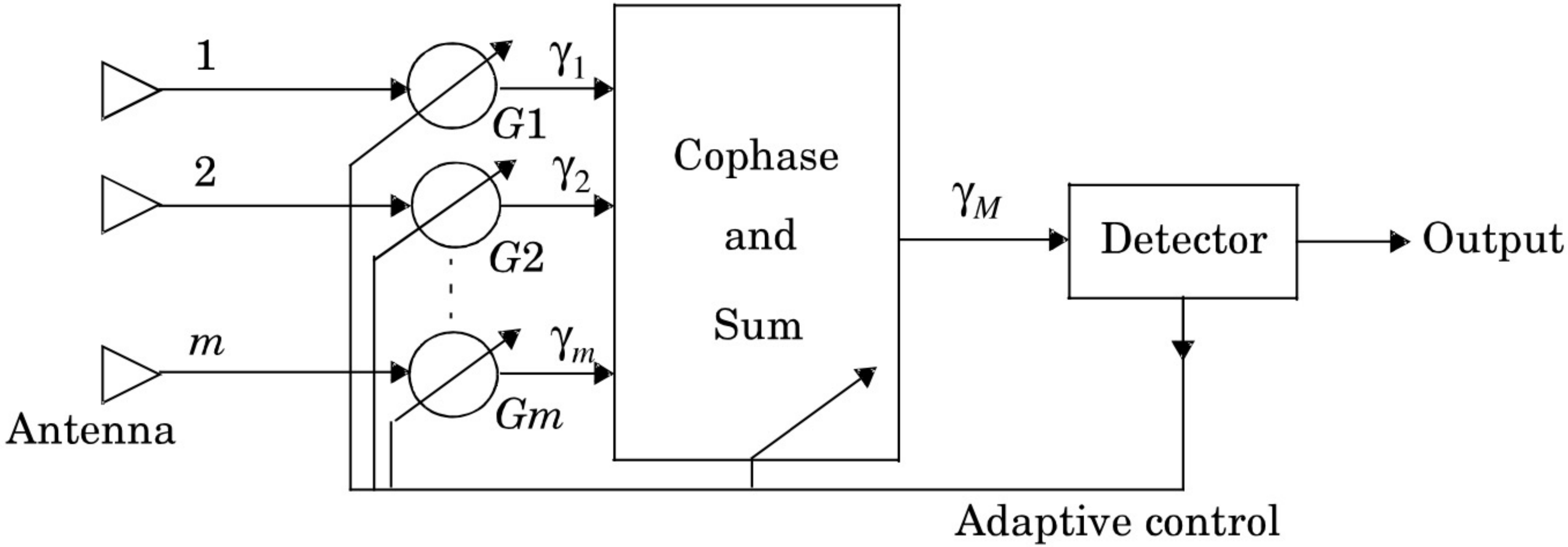


Figure 7.14 Maximal ratio combiner.

Space Diversity: Maximal Ratio Combiner

- In this method, the signals from all of the *M* branches are weighted according to their individual signal voltage to noise power ratios and then summed.

- Here, the individual signals must be co-phased before being summed (unlike selection diversity) which generally requires an individual receiver and phasing circuit for each antenna element.

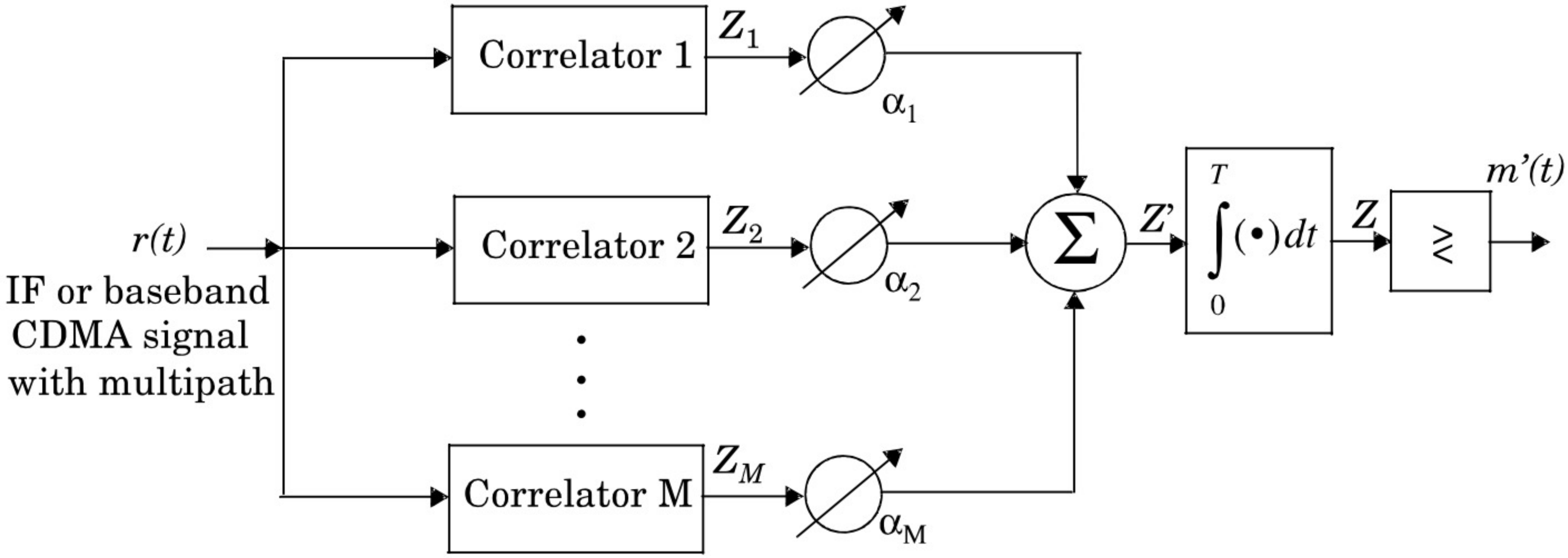
- Maximal ratio combining produces an output SNR equal to the sum of the individual SNRs.

- Thus, it has the advantage of producing an output *with an acceptable SNR even when none of the individual signals are themselves acceptable.*

- This technique gives the best statistical reduction of fading of any known linear diversity combiner.

- Modem DSP techniques and digital receivers are now making this optimal form of diversity practical.

Rake Receiver



Rake Receiver

In wireless communication, a **RAKE receiver** is a type of receiver used in systems like CDMA (Code Division Multiple Access) to efficiently handle multipath propagation. Below are key points about the RAKE receiver:

1. Purpose

- The RAKE receiver is designed to exploit multipath propagation rather than mitigate it. Multipath signals, which arrive at the receiver with different delays, are treated as separate signals.

2. Key Components

- **Fingers:** The RAKE receiver consists of several "fingers," each tuned to detect and process a specific multipath component of the received signal.

- **Combiner:** Combines the outputs of the fingers to maximize the signal-to-noise ratio (SNR).

- **Weighting System:** Each finger's output is weighted based on the signal strength or quality (e.g., using maximum ratio combining).

Rake Receiver

3. Working Principle

- The receiver identifies the strongest multipath components using a delay profile.
- Each finger of the RAKE receiver is synchronized to a particular delayed version of the original transmitted signal.
- The outputs of all fingers are combined coherently to reconstruct the original signal.

4. Multipath Exploitation

- Multipath propagation often results in constructive and destructive interference in traditional systems. RAKE receivers use delayed versions of the signal to achieve diversity gain.

5. Diversity Gain

- By processing multiple independent paths, the RAKE receiver improves the robustness and reliability of the communication link, reducing the impact of fading.

Rake Receiver

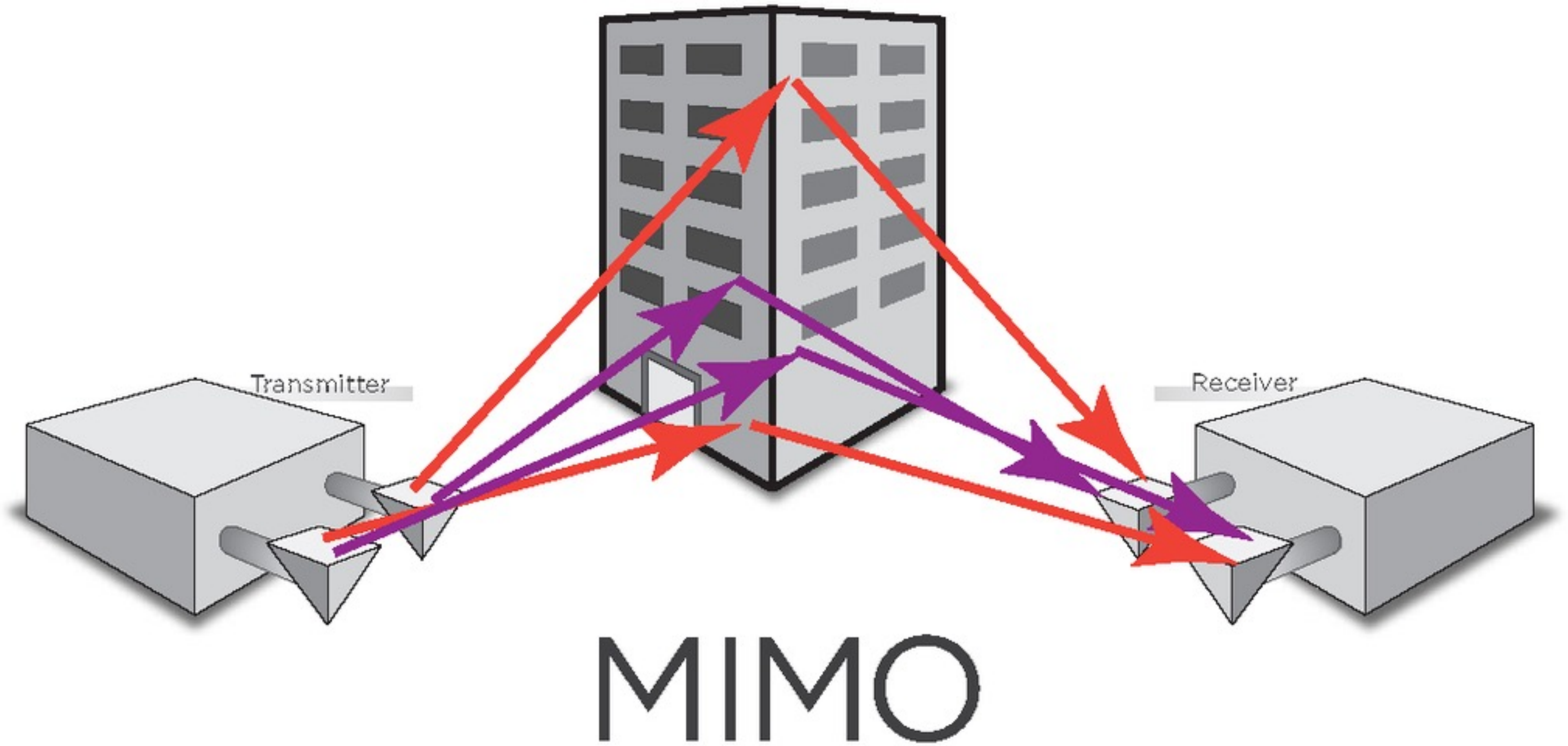
6. Applications

- Widely used in CDMA-based systems (e.g., 3G cellular networks).
- Applicable in systems like Ultra-Wideband (UWB) and other wireless standards.

7. Challenges

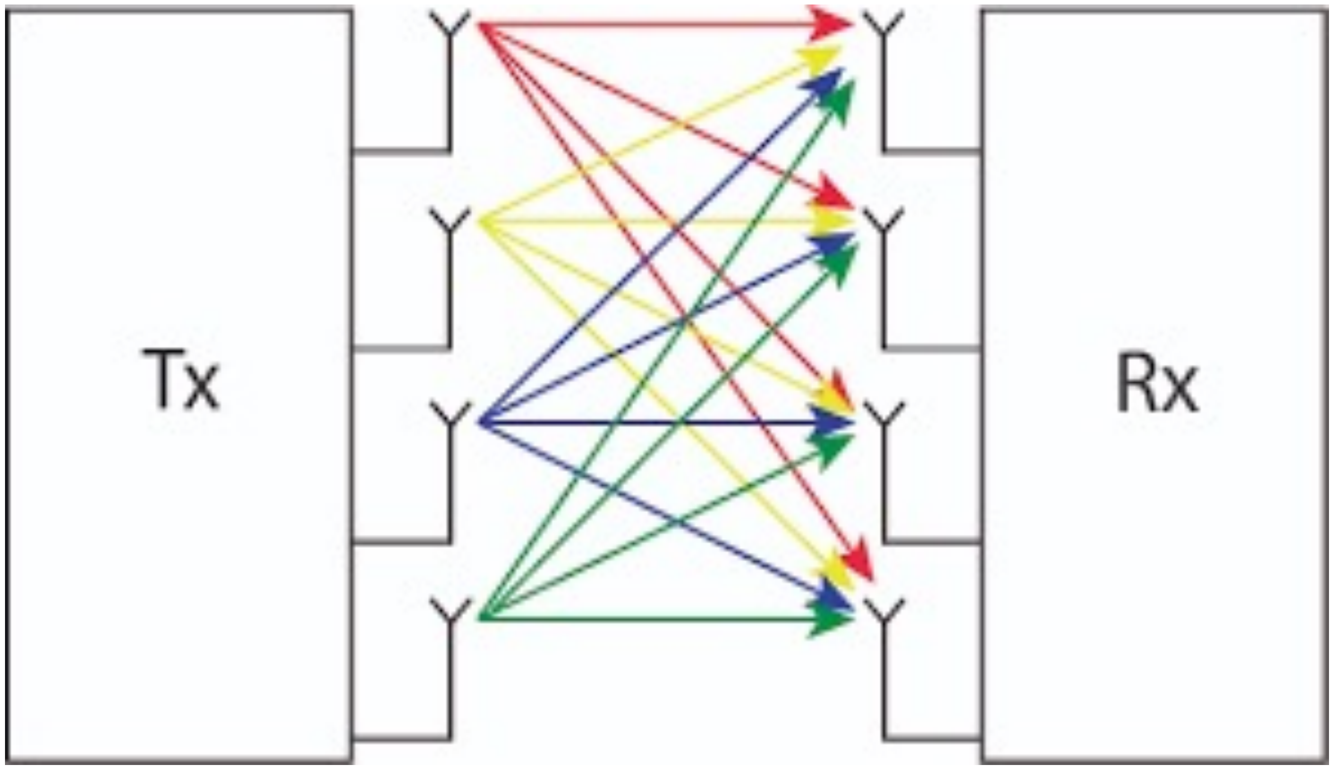
- **Complexity:** The implementation of multiple fingers increases computational and hardware complexity.
- **Path Selection:** Choosing the optimal number of paths (fingers) is critical to balance performance and complexity.
- **Interference Management:** Effectiveness may be reduced in environments with severe interference or noise.

MIMO (Multiple Input Multiple Output)



2 x 2 antenna elements

MIMO (Multiple Input Multiple Output)



4 x 4 antenna elements

MIMO Diversity

Purpose of MIMO Diversity

Mitigates Fading: Reduces the impact of deep fades by providing multiple signal paths, ensuring that at least one path has a strong signal.

Improves Reliability: Enhances link reliability by making the communication less susceptible to fluctuations in the wireless channel.

MIMO Diversity

Common MIMO Diversity Techniques

Transmit Diversity (Tx):

1. Multiple antennas at the transmitter send copies of the signal.
2. Example: **Alamouti Scheme** is a simple and widely used space-time block coding technique for 2 transmit antennas.

Receive Diversity (Rx):

1. Multiple antennas at the receiver independently receive the signal.
2. Example: **Maximal Ratio Combining (MRC):** Combines signals from multiple antennas to maximize the SNR.

Space-Time Coding:

1. Encodes data across multiple transmit antennas and time slots to provide diversity and coding gain.

Beamforming:

1. Combines signals from multiple antennas to focus energy toward a specific direction, improving diversity and signal strength.

MIMO Diversity

MIMO Diversity Gains

- **Diversity Gain:** Improves link reliability by reducing error rates.
- **Array Gain:** Boosts received signal power through coherent combination.
- **Multiplexing Gain (Tradeoff):** Can increase data rates by transmitting multiple streams, though often at the expense of diversity.

Applications

- **LTE/4G and 5G:** Uses MIMO diversity to enhance coverage and reliability.
- **Wi-Fi (802.11n/ac/ax):** Employs MIMO for both diversity and spatial multiplexing.
- **Massive MIMO:** Extends the concept by using a large number of antennas to achieve higher diversity and capacity.

MIMO versus Massive MIMO

	MIMO	Massive MIMO
Number of Antenna	≤ 8	≥ 16
Pilot Contamination	Low	High
Throughput	Low	High
Antenna Coupling	Low	High
Bit Error Rate	High	Low
Noise Resistance	Low	High
Diversity/Capacity Gain	Low	High
Energy Efficiency	Low	High
Cost	Low	High
Complexity	Low	High
Scalability	Low	High
Link Stability	Low	High
Antenna Correlation	Low	High

Massive MIMO

Massive MIMO: more than 10 x 10 antenna elements

Massive MIMO

Massive MIMO (Multiple Input Multiple Output) is an advanced wireless communication technology that employs a very large number of antennas (typically dozens or even hundreds) at the base station to serve multiple users simultaneously in the same frequency band. It is a key enabler for 5G and beyond due to its potential to significantly enhance system capacity, energy efficiency, and spectral efficiency.

Massive MIMO

Key Features of Massive MIMO

Large Number of Antennas:

- Uses tens to hundreds of antennas at the base station.
- Each antenna operates independently to form narrow, user-specific beams.

Simultaneous User Support:

- Can serve multiple users at the same time and frequency, leveraging spatial multiplexing.

Beamforming:

- Precisely focuses energy in the direction of intended users, improving signal strength and reducing interference.

Channel Hardening:

- Large antenna arrays average out the effects of small-scale fading, leading to more predictable channel behavior.

Massive MIMO

Benefits of Massive MIMO

1.Increased Spectral Efficiency:

1. Achieves higher data rates by serving multiple users in the same frequency band.

2.Improved Energy Efficiency:

1. Directs energy precisely toward users, reducing power wastage.

3.Enhanced Reliability and Coverage:

1. Overcomes signal degradation caused by fading, interference, and multipath effects.

4.Reduced Interference:

1. Beamforming minimizes interference to non-target users.

5.Scalability:

1. Supports a large number of simultaneous users in dense network scenarios