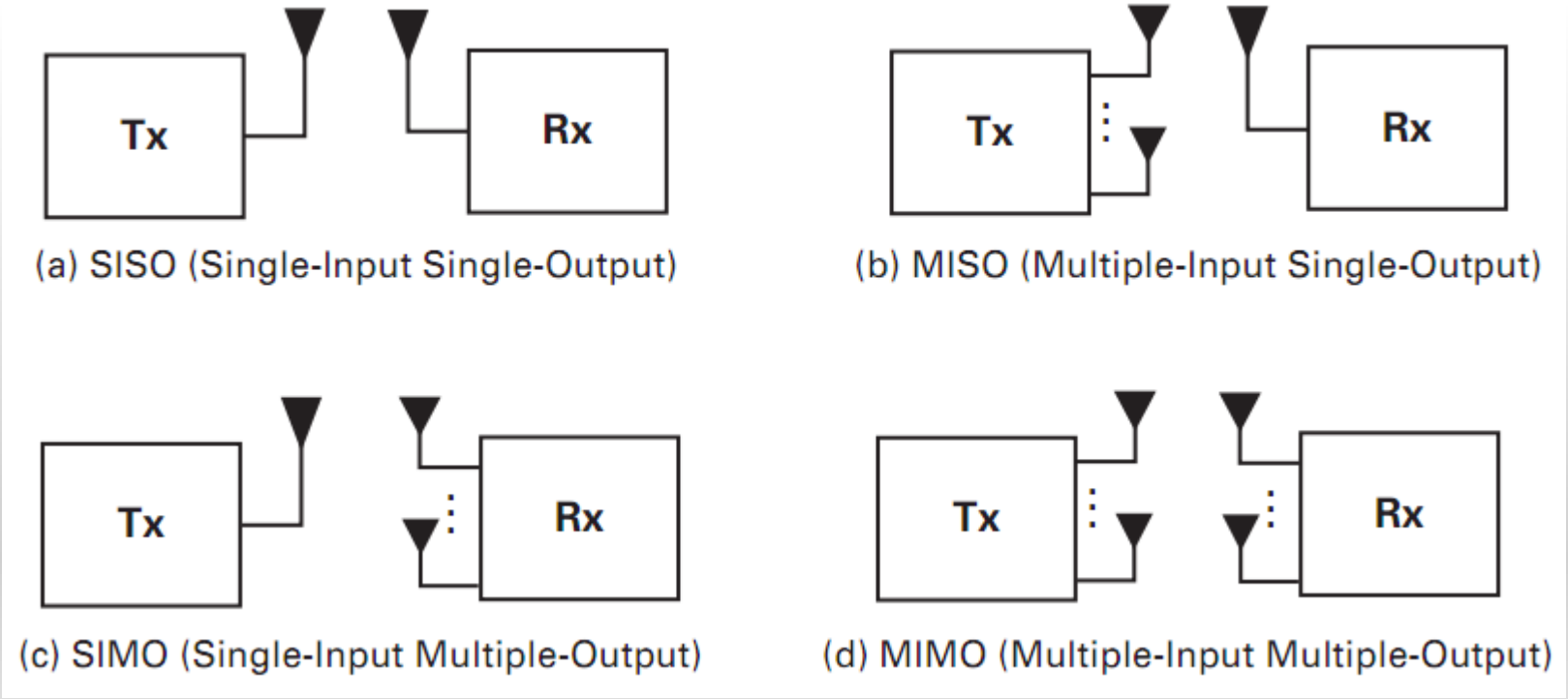
# KOMUNIKASI NIRKABEL BROADBAND

## MULTIPLE INPUT MULTIPLE OUTPUT (MIMO)

By : Dwi Andi Nurmantris

# Multiple Antenna Configuration



# Why Multiple Antenna ?

Our Resource :

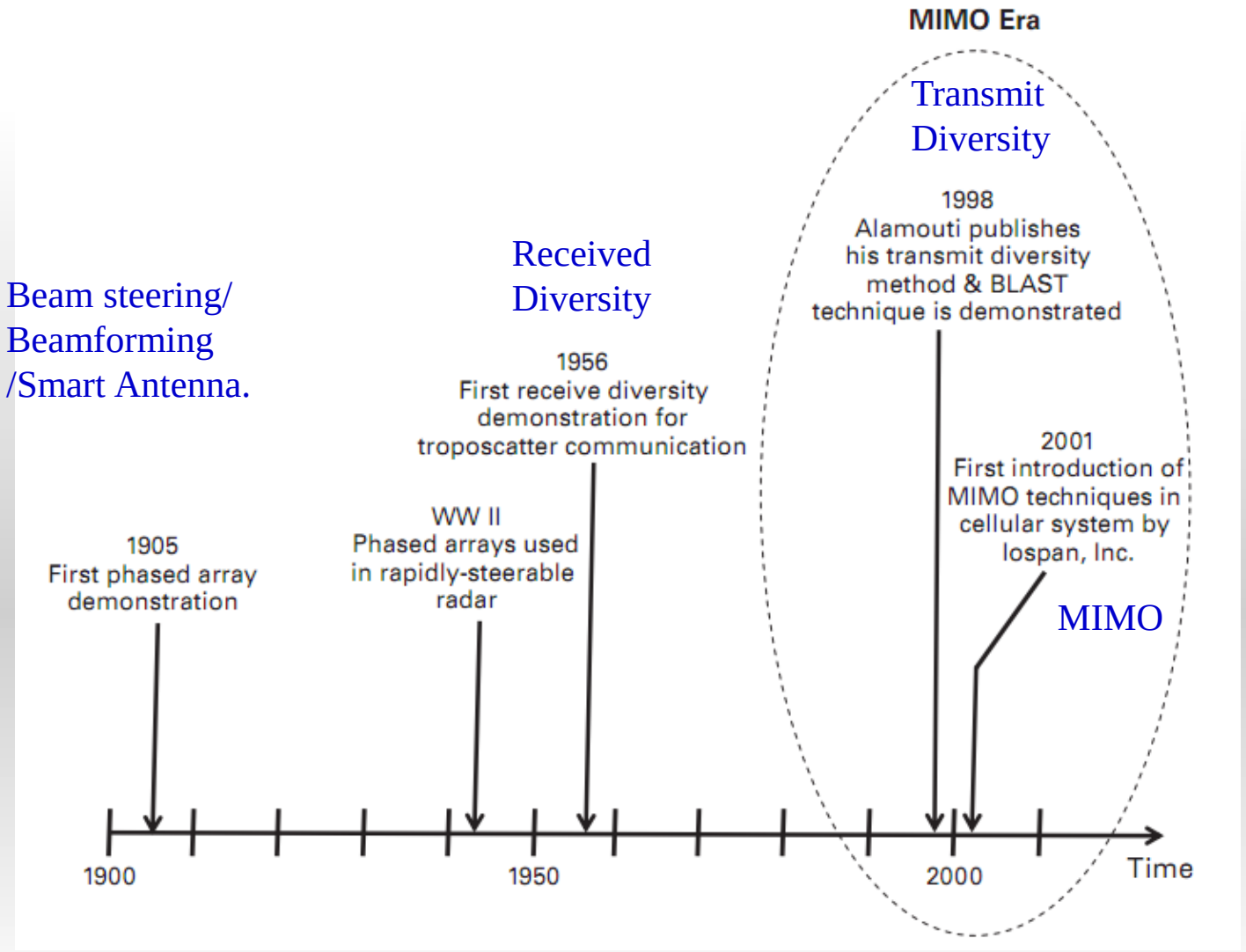
Frequency → Limited
Time → Limited
Power → Limited

An Alternative :
**Space → Multiple Antenna Technique**

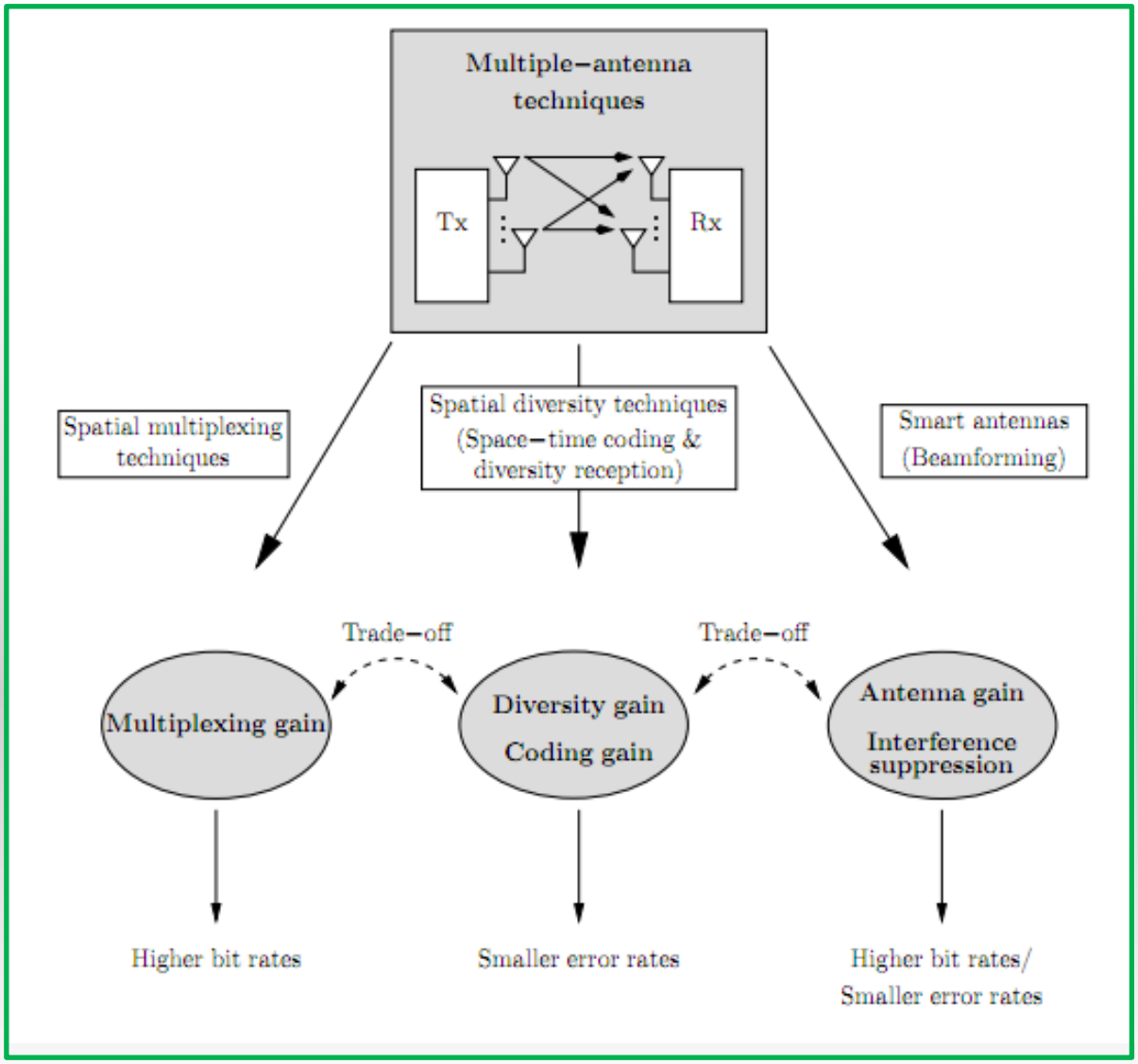
Our Goal :

High Capacity
High Datarate
Small Error

# Multiple Antenna Hystory



# Multiple Antenna Technique



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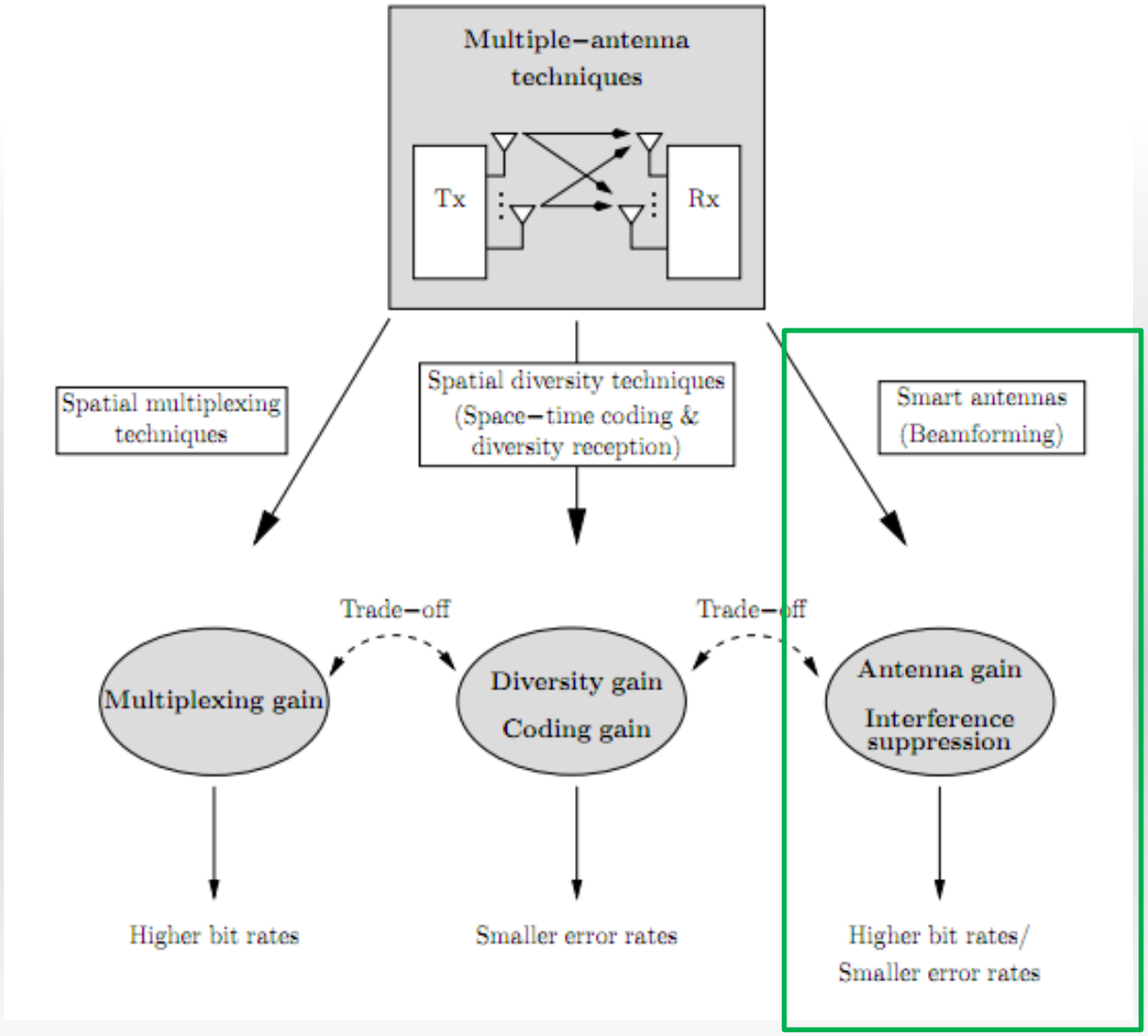
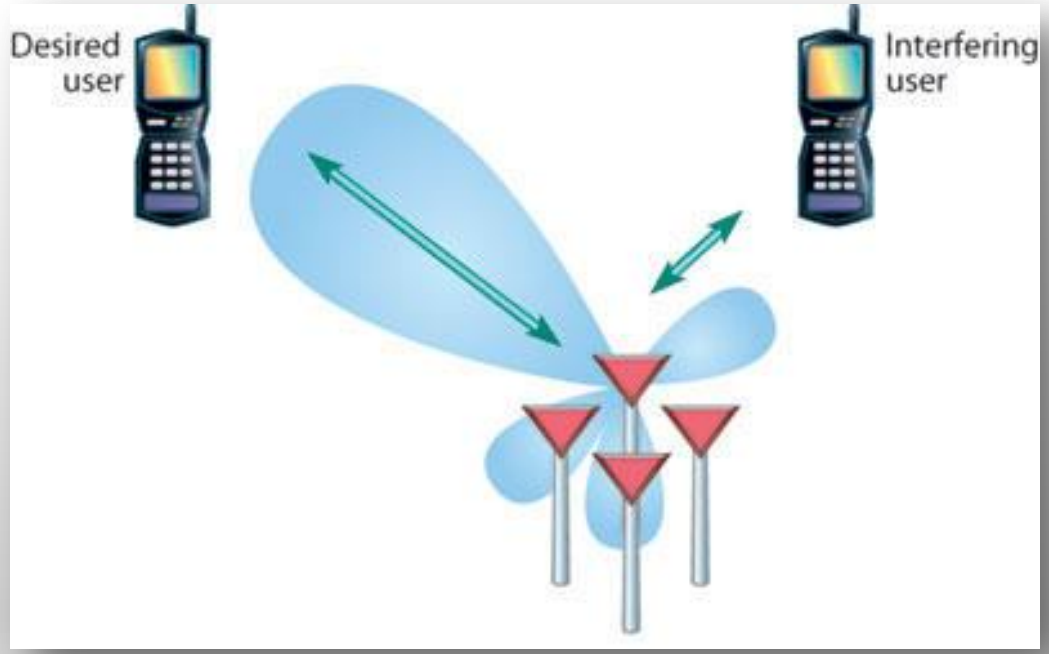


# Multiple Antenna Technique

## Beamforming



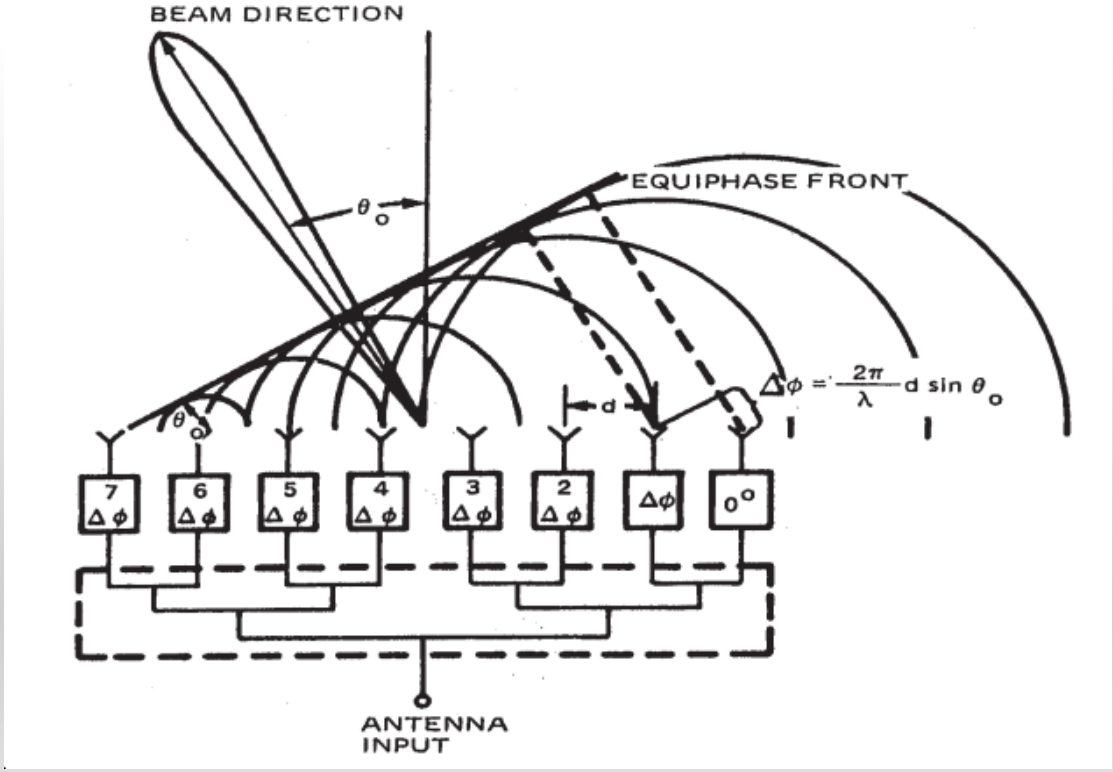

Smart antennas focus on :

- Beamforming – directing energy in a desired physical direction;
- Adaptive nulling – creating nulls in desired directions to reduce interference.

**Beamforming** is Using antenna array to focus the energy in the direction of a client device. By using the same power but focusing it towards the receiver, it is possible to increase the signal to noise ratio at the receiver. Higher signal to noise ratio enables use of more aggressive coding, and therefore, higher speed

# Multiple Antenna Technique

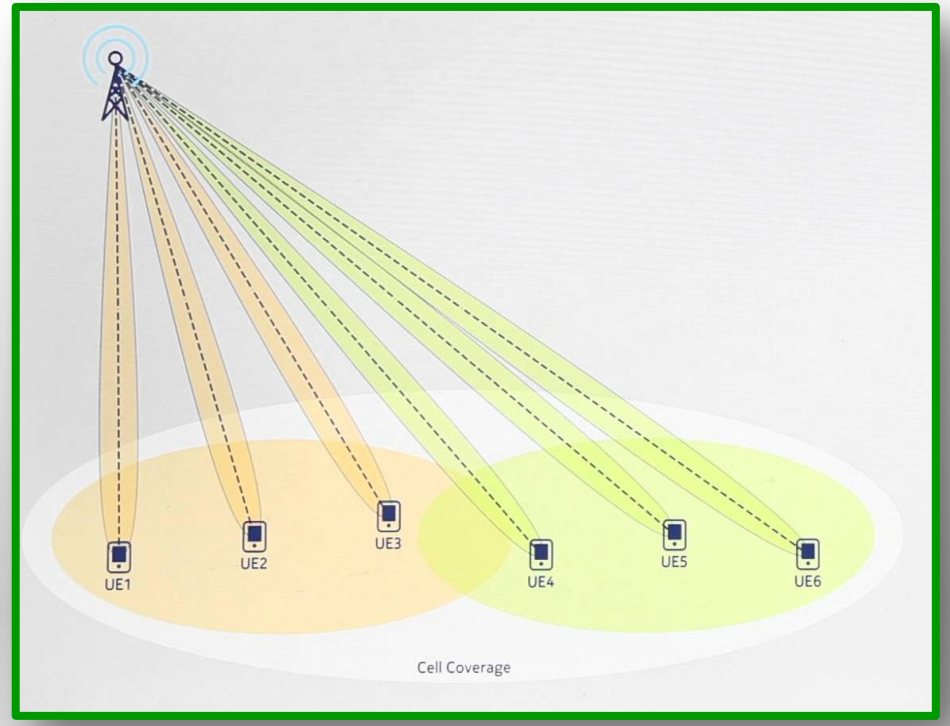
## Beamforming




Pembentukan diagram arah dari suatu susunan antena di medan jauh tergantung dari MAGNITUDA dan FASA dari medan-medan yang dihasilkan masing-masing elemen antena.

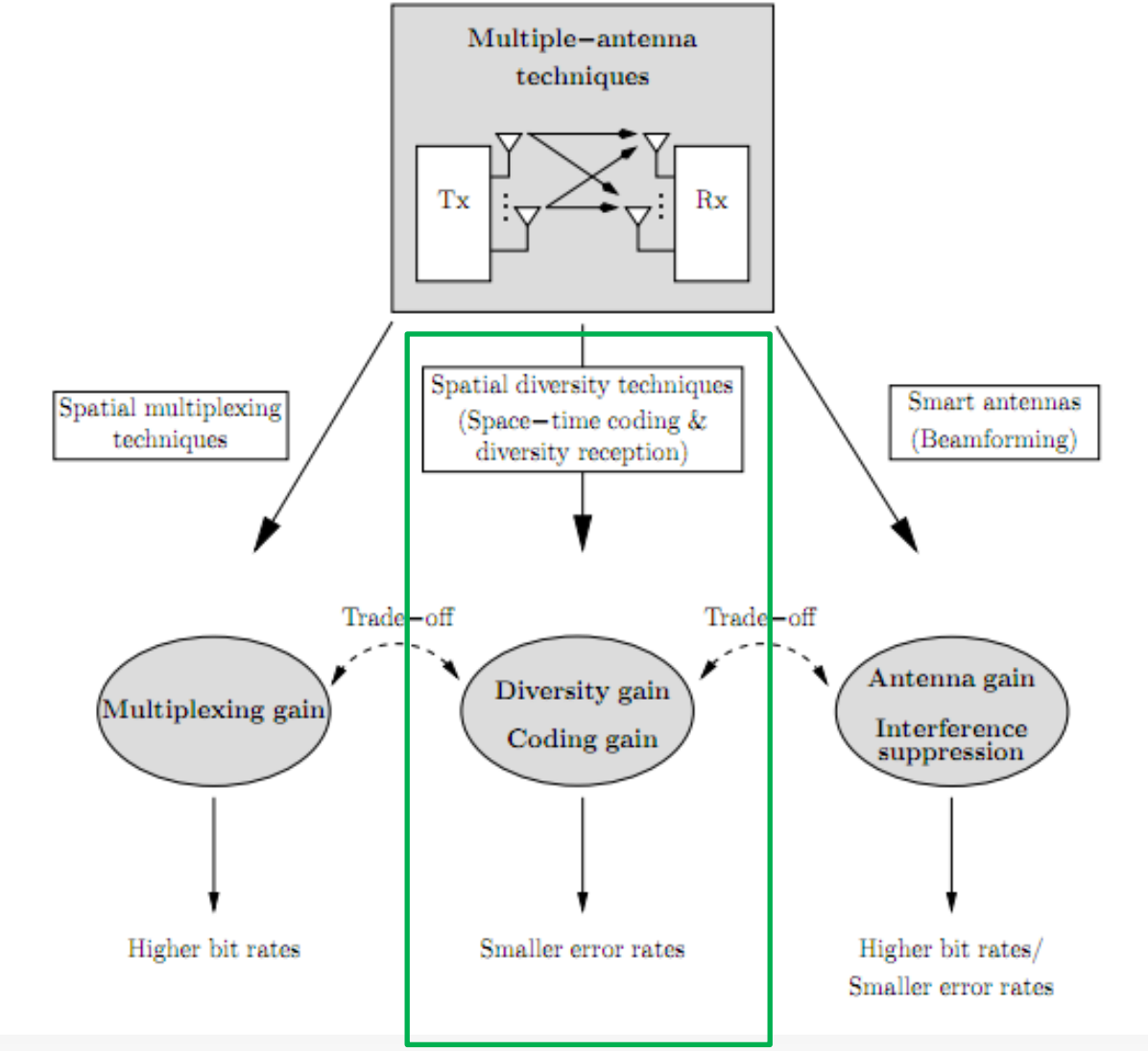
# Multiple Antenna Technique

## Space/Spatial Division Multiple Access




(**SDMA**) is a channel access method based on spatial location of mobile devices by focusing the signal into narrow transmission beams. Through the use of smart antennas with beams pointed at the direction of the mobile station, SDMA serves different users within the same region.

# Multiple Antenna Technique



# Multiple Antenna Technique

## Konsep Diversity

- In order to reduce the impact of fading, the concept of **diversity** is often employed. Diversity refers to transmitting replicas of the same signal over a fading channel in such a way that each replica fades independently of the others.
- By combining the replicas, however, the depths of the fades, and, so too, their adverse effects, can be significantly reduced because the fades do not tend to occur at the same time
- Diversity involves two steps:
  a) creating independent replicas of the signal; and
  b) combining the replicas.

# Multiple Antenna Technique

## Konsep Diversity

Macam teknik diversity :

- Frequency Diversity
- Time Diversity
- Polarization Diversity
- Space Diversity

# Multiple Antenna Technique

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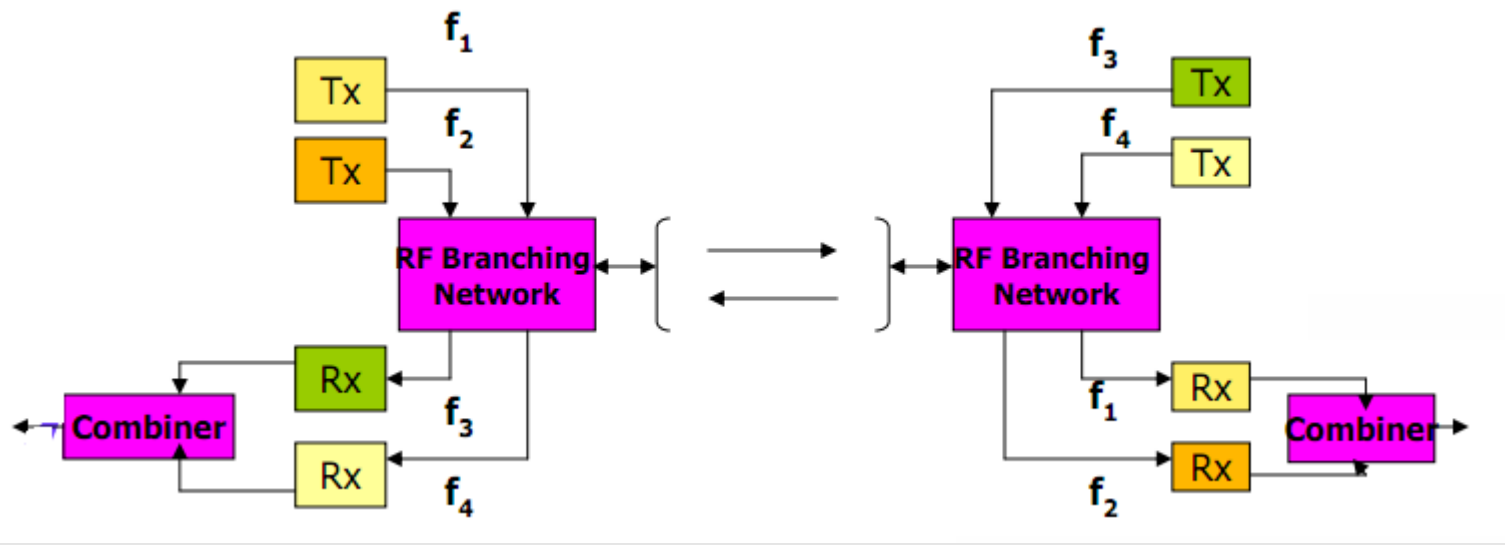
Transmit the signal on different RF frequencies that are spaced far enough apart that the fading occurs independently on each carrier. This is called **frequency diversity**



# Multiple Antenna Technique

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Macam teknik diversity :

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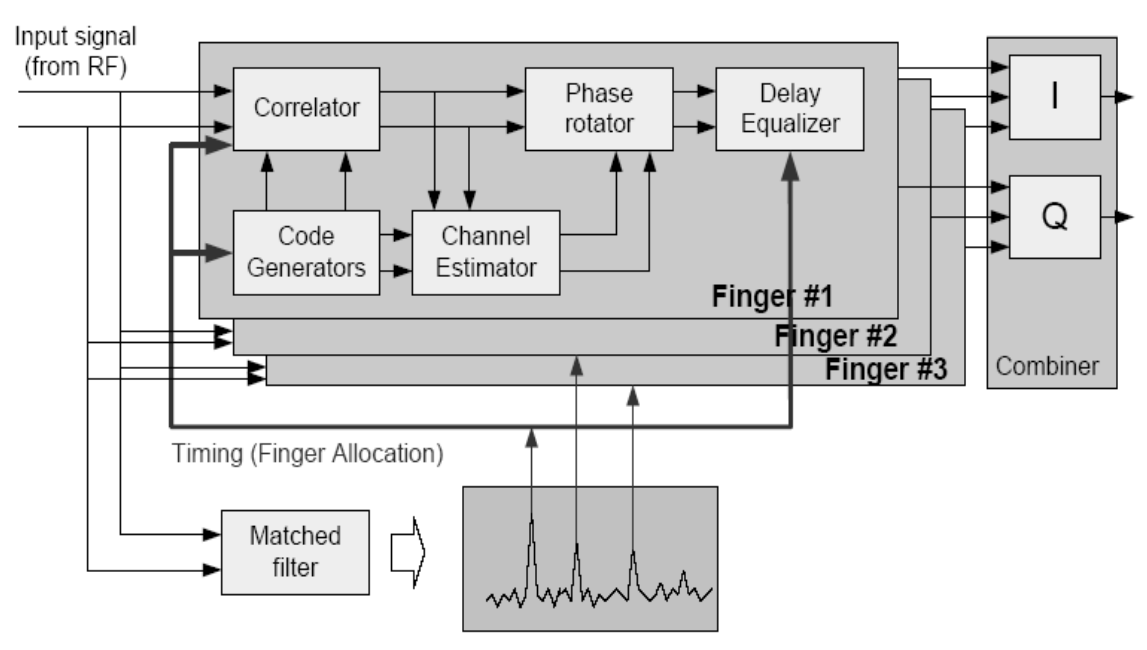
**Time diversity**, involves transmitting the same signal at different times. In a multipath environment, this occurs naturally because the same signal arrives at the receiver by traveling over multiple physical paths, which tend to experience independent fading. Rake receivers are used to process such signals




Rake Receiver is essentially a set of several receivers. One of the receivers (fingers) constantly searches for different multipaths

# Multiple Antenna Technique

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**Polarization diversity**, transmit the same information on signals having different polarizations, called polarization diversity. Normally, fading is independent of signals having different polarizations.

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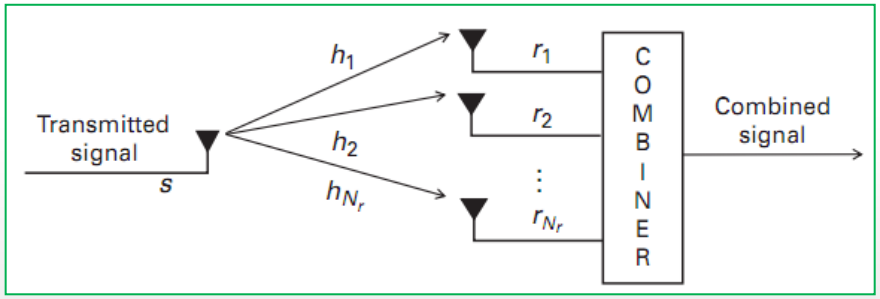


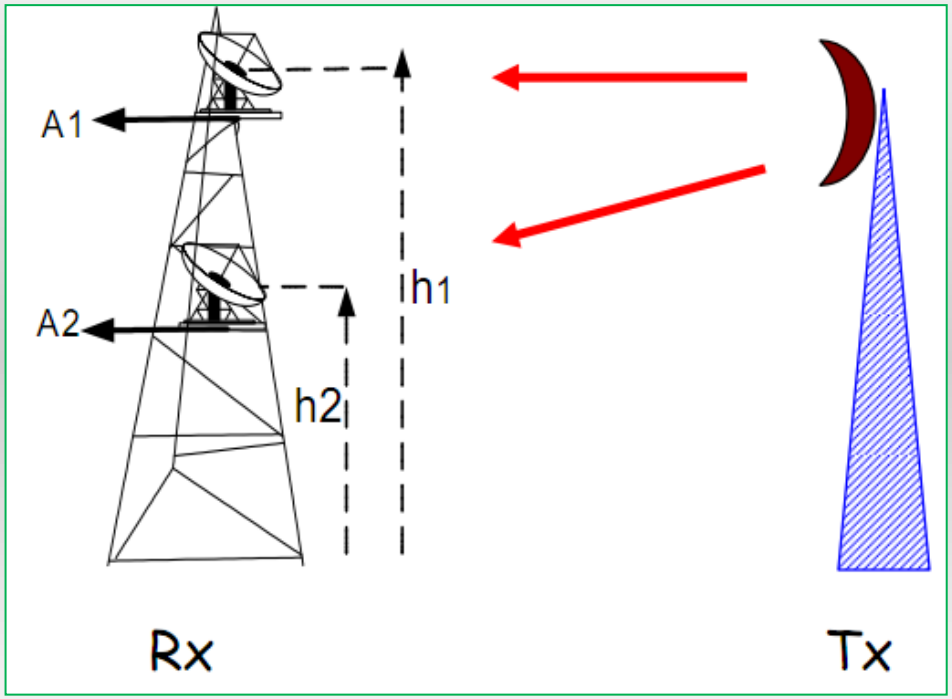


**Space/Spatial diversity**, transmitting the same information over different physical paths between the transmitter and receiver. One way to create spatial diversity is to transmit a signal from one transmit antenna and receive it using multiple receive antennas → Receiver Spatial Diversity

# Multiple Antenna Technique

## Konsep Diversity

Macam teknik diversity :

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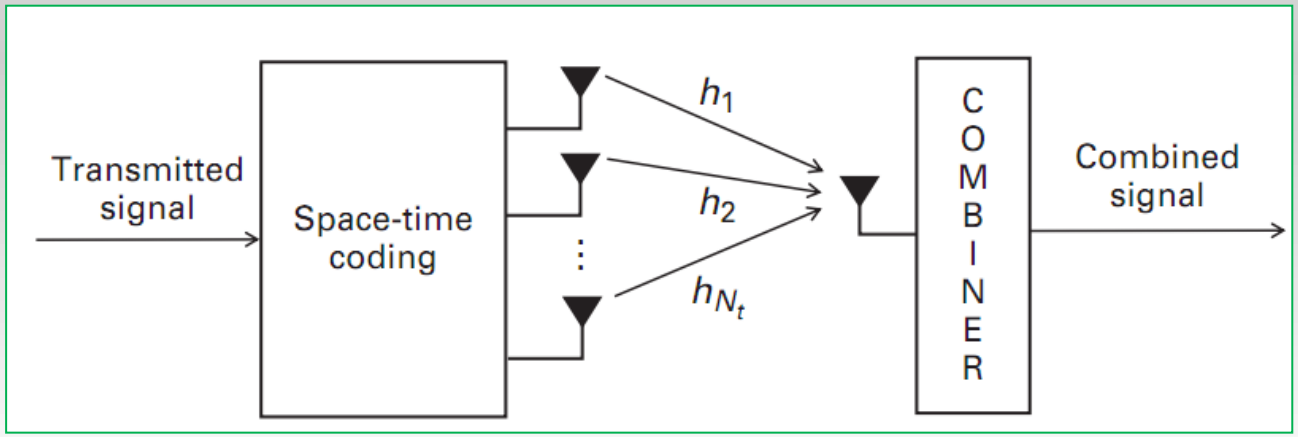
- The growing use of cellular communications, a desire for a different type of diversity architecture arose, called **transmit diversity.**
- The motivation for developing transmit diversity was the fact that the mobile unit in most cellular systems is small and, as a result, is often not capable of having multiple antennas. As a result, receive diversity on the forward link of cellular systems may not be possible.



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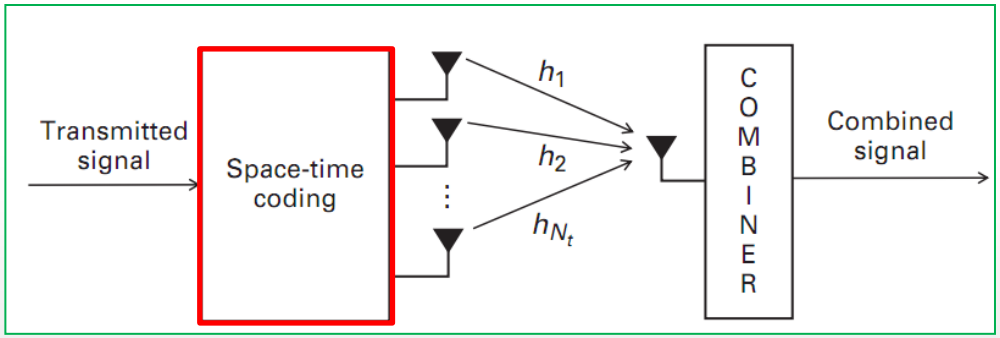


**Alamouti coding**

- ❑ Alamouti coding was one of the first space-time codes to be developed, and it is now included in the definition of all modern wireless standards that employ MIMO techniques
- ❑ Alamouti's technique has the following advantages over alternative schemes: a) it requires CSIR only (as opposed to requiring both CSIT and CSIR); b) it does not involve any bandwidth expansion, which some of the competing techniques do; and c) Alamouti coding has relatively low computational complexity due to the fact that its decoding rules are quite simple.
- ❑ Alamouti coding works with any number of receive antennas, it is restricted to cases where there are only two transmit antennas.

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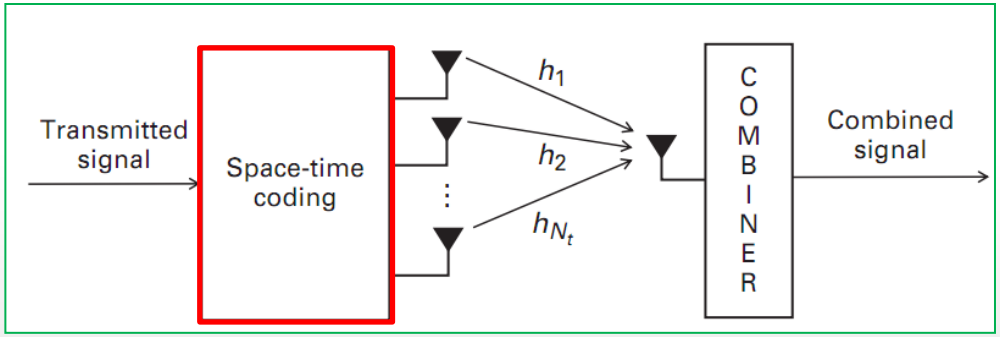
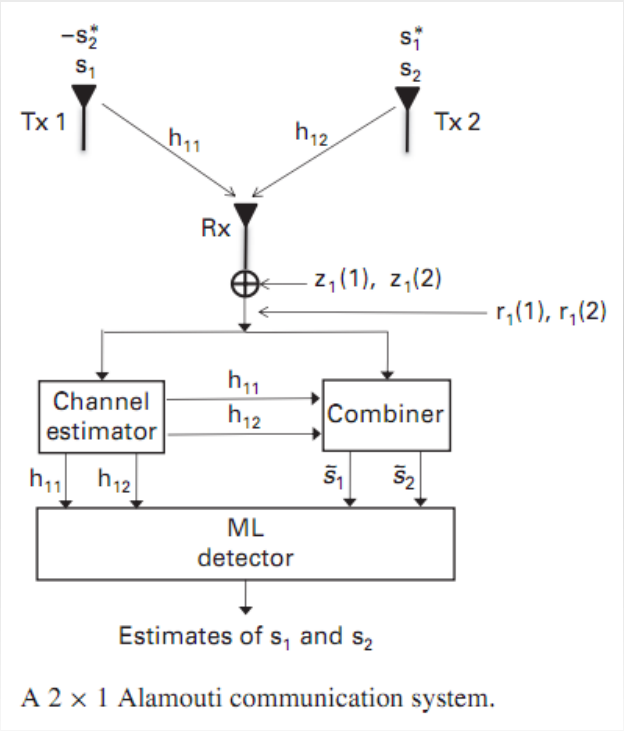



## Alamouti coding




A 2 × 1 Alamouti communication system.

**Table 6.1** Alamouti space-time coding.

| Transmit time | Antenna 1 | Antenna 2 |
|---|---|---|
| $t$ | $s_1$ | $s_2$ |
| $t + T_s$ | $-s_2^*$ | $s_1^*$ |

At some instant of time, t, symbol s1 is transmitted from transmit antenna 1 and symbol s2 is transmitted from the second transmit antenna. During the next symbol interval period at time t+Ts, the symbols −s*2 and s*1 are transmitted from antennas 1 and 2, respectively. This demonstrateshow Alamouti coding involves coding in both the spatial and time dimensions; hence, itis an example of a space-time code.

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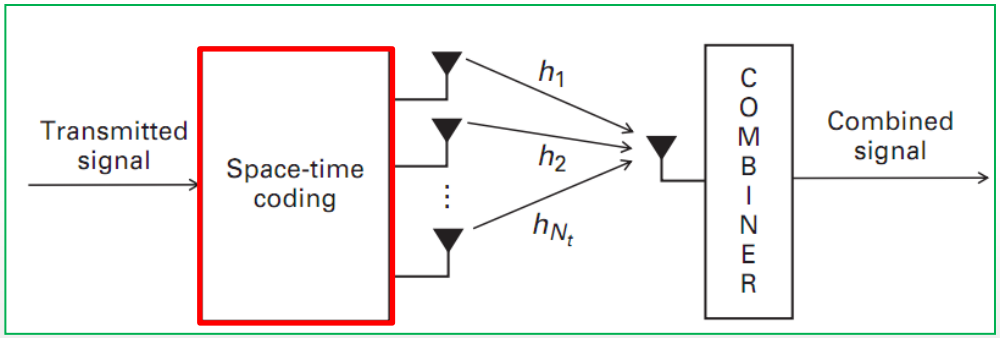


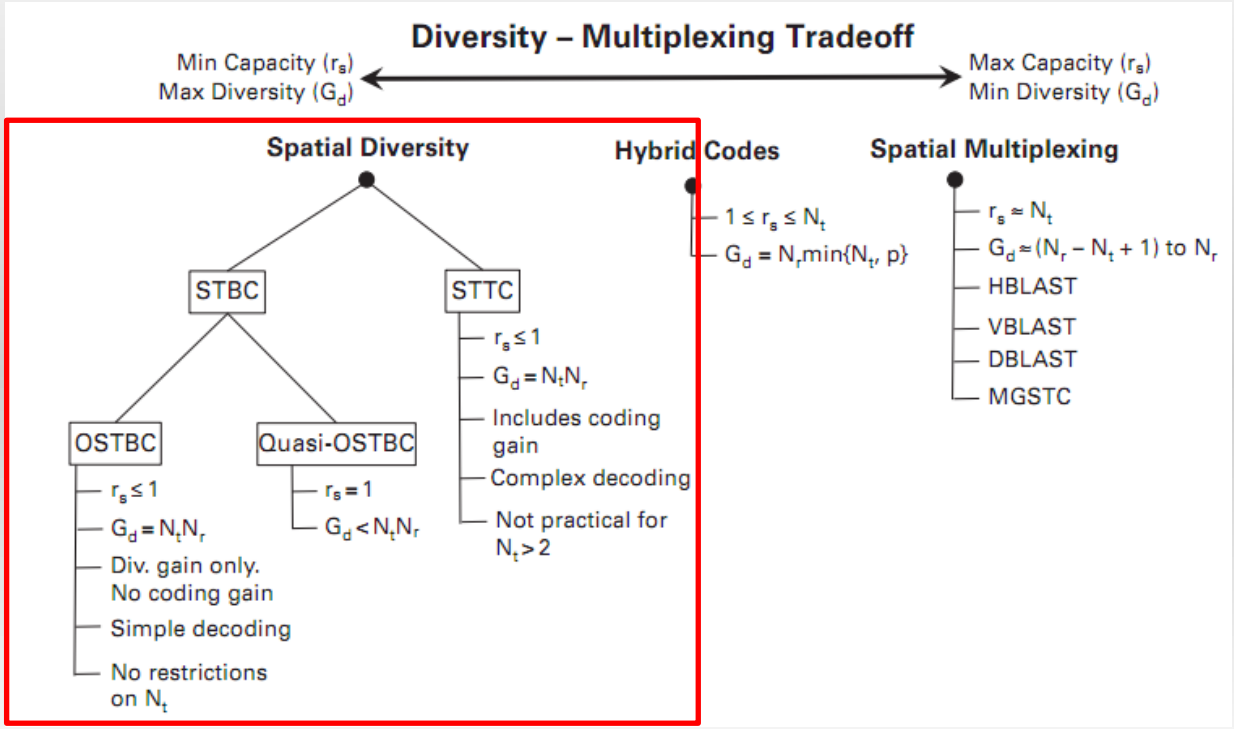

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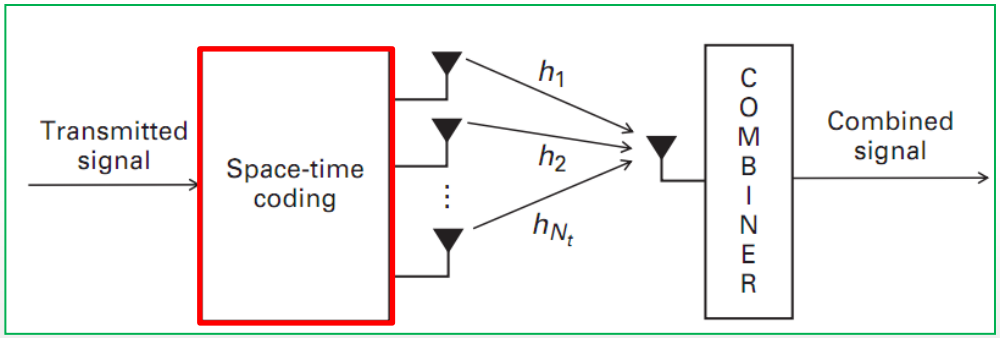
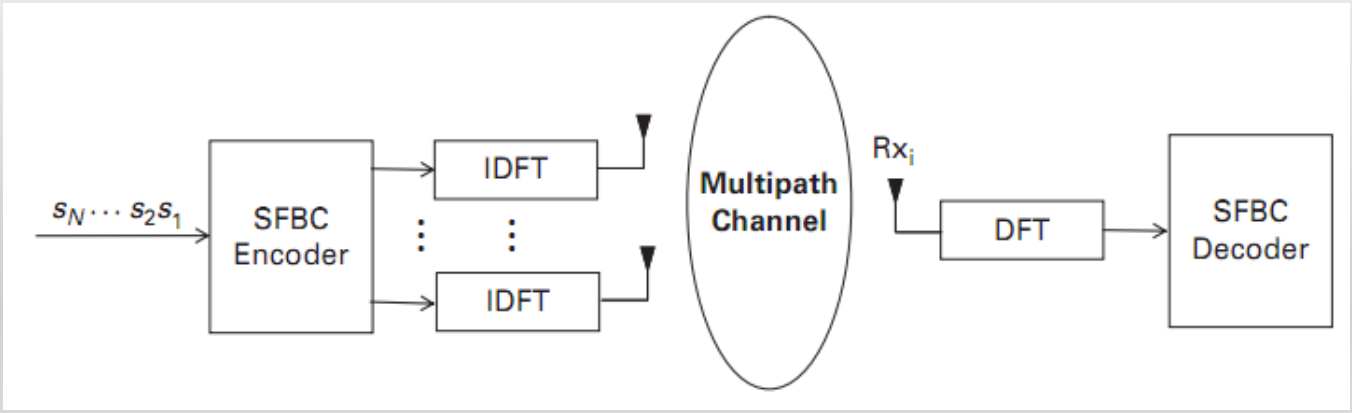



## Space Frequency block Coding (SFBC)




- ❑ Space frequency block coding (SFBC) is a technique that is used to achieve spatial diversity in OFDM MIMO systems, including LTE and WiMAX. As its name suggests, SFBC is similar to STBC, except that in SFBC data symbols are encoded across space and frequency rather than across space and time.

# Multiple Antenna Technique

## Konsep Diversity

there are different ways to combine the replicas at the receiver :

- selective combining
- equal gain combining
- maximal ratio combining

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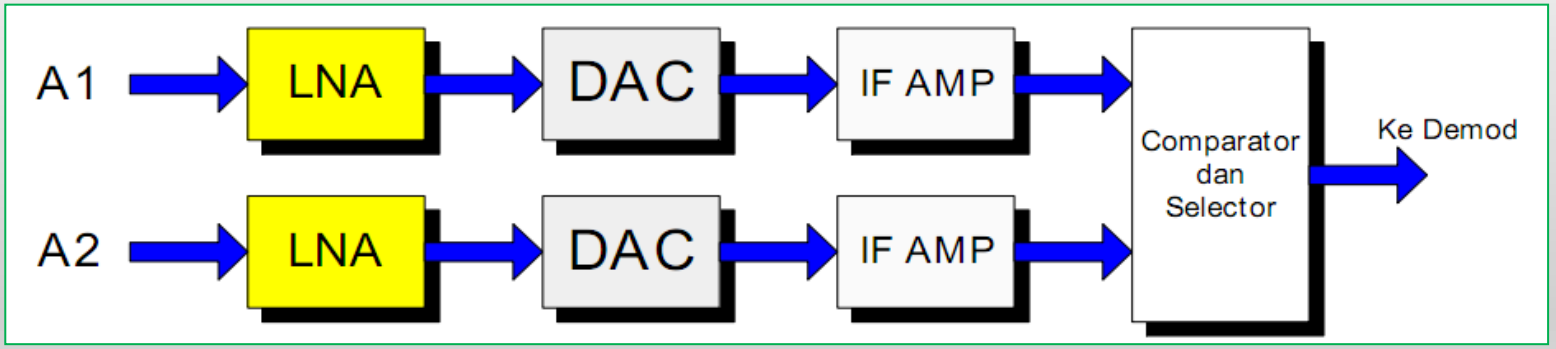


**selective combining**, which involves comparing the replicas at each sample time and choosing the largest value for the output of the combiner

# Multiple Antenna Technique

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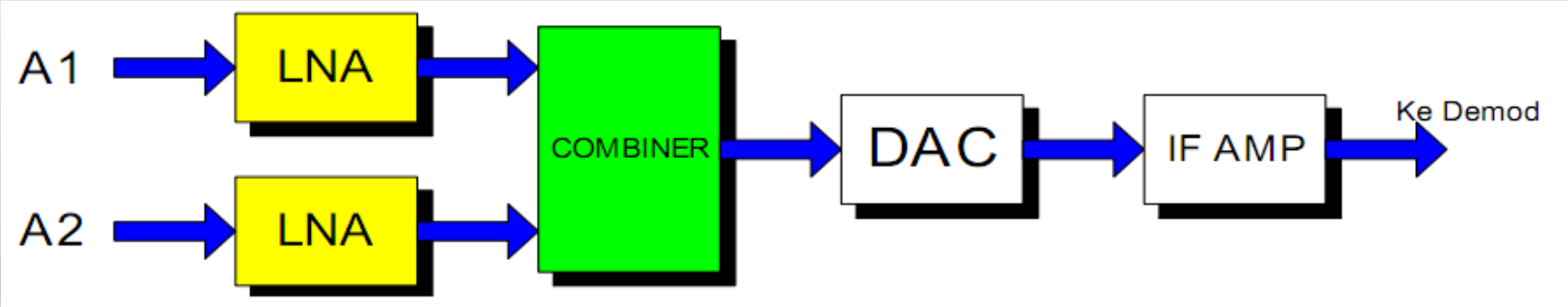


**equal gain combining,** involves adding the replicas together.

# Multiple Antenna Technique

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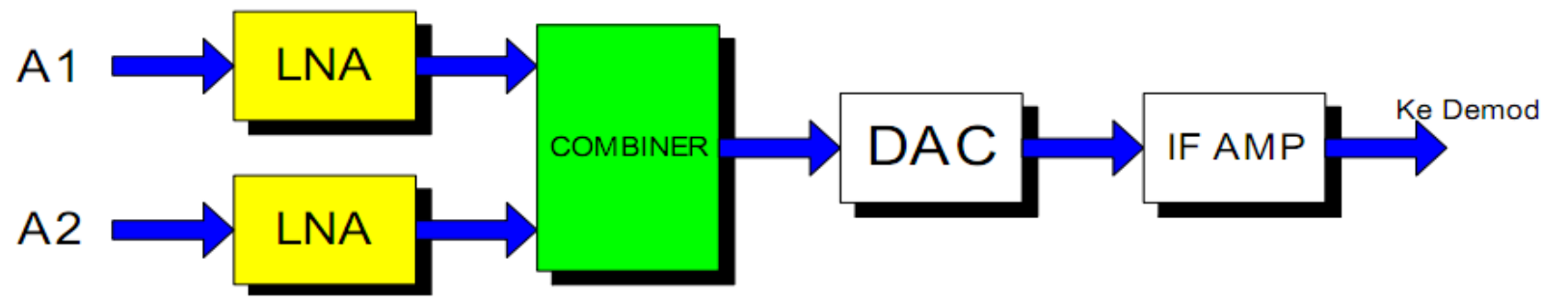
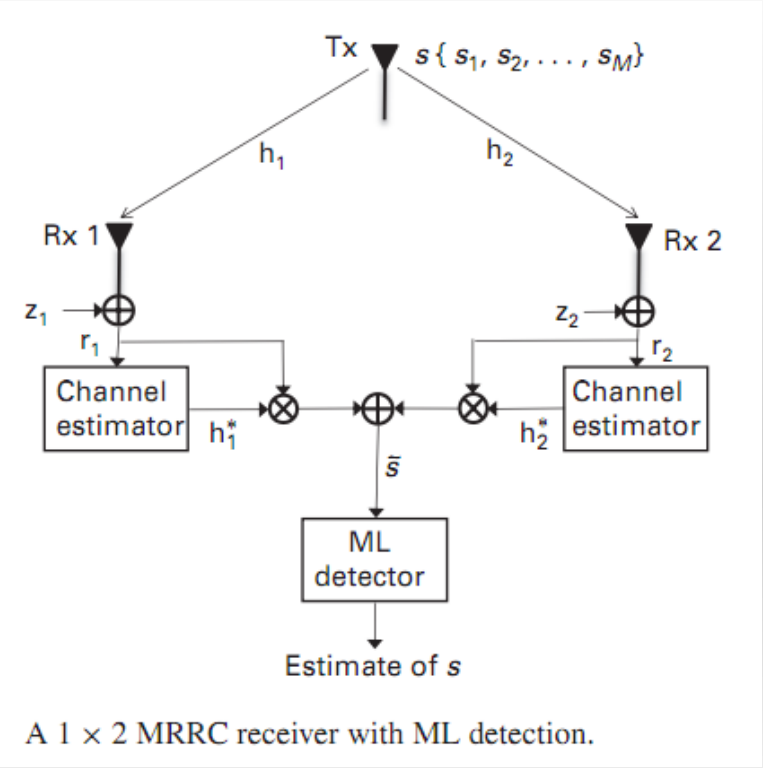



**Maximal Ratio combining,** the replicas are added together in the same way as they are in equal gain combining, but prior to being added they are first scaled in proportion to the signal-to-noise ratio of each replica

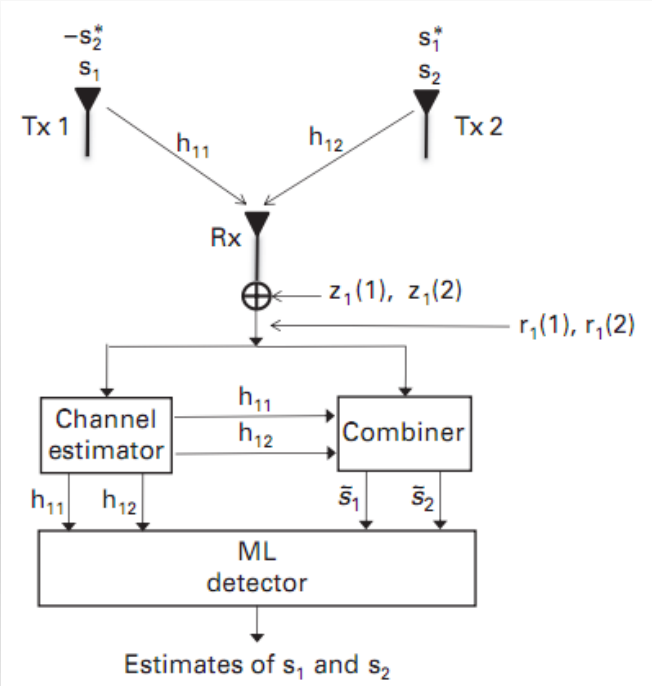
# Multiple Antenna Technique

## Konsep Diversity

Maximal ratio receive combining (MRRC) Vs Alamouti Coding




A 1 × 2 MRRC receiver with ML detection.




A 2 × 1 Alamouti communication system.

**MRRC**

**Alamouti Space Time Code**

# Multiple Antenna Technique

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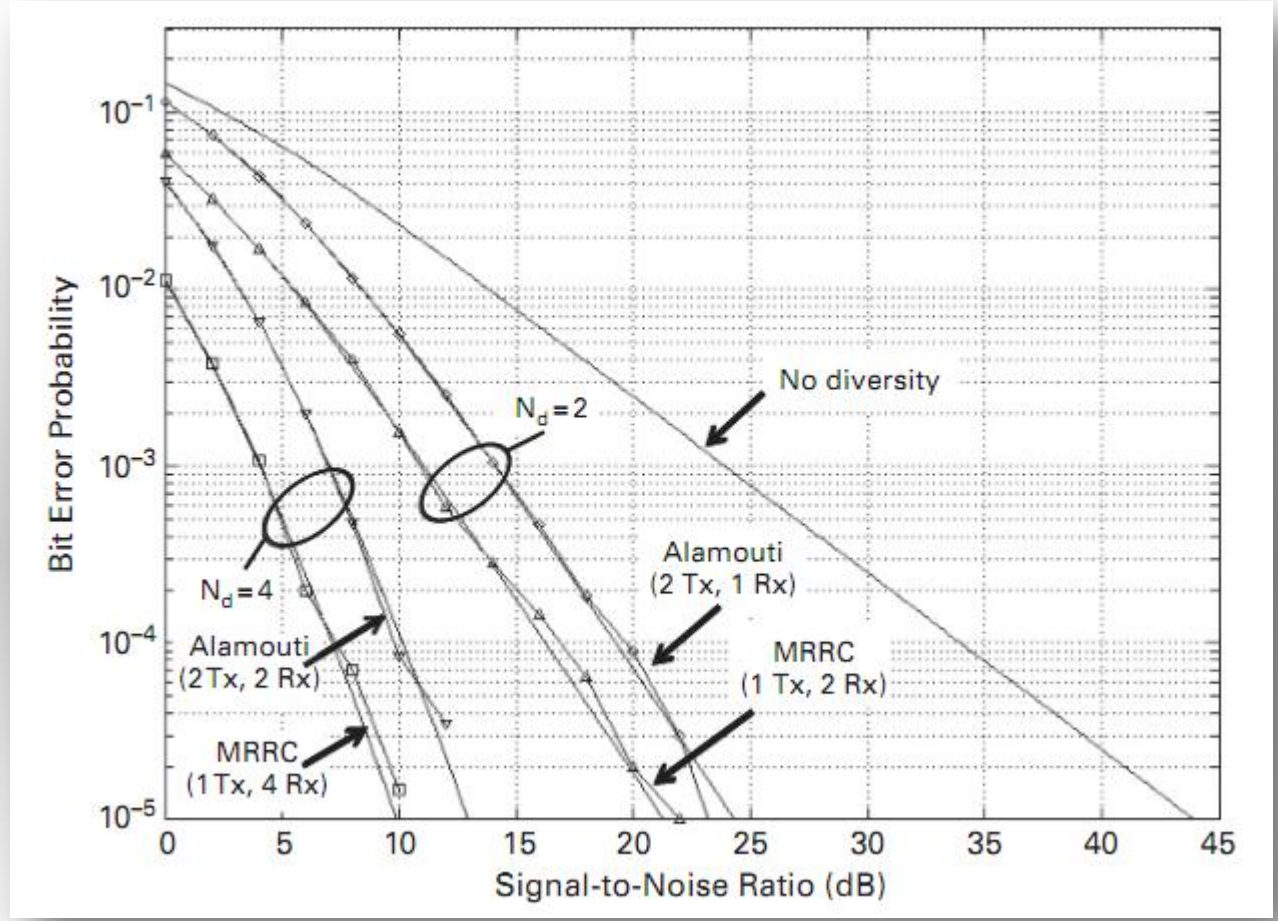

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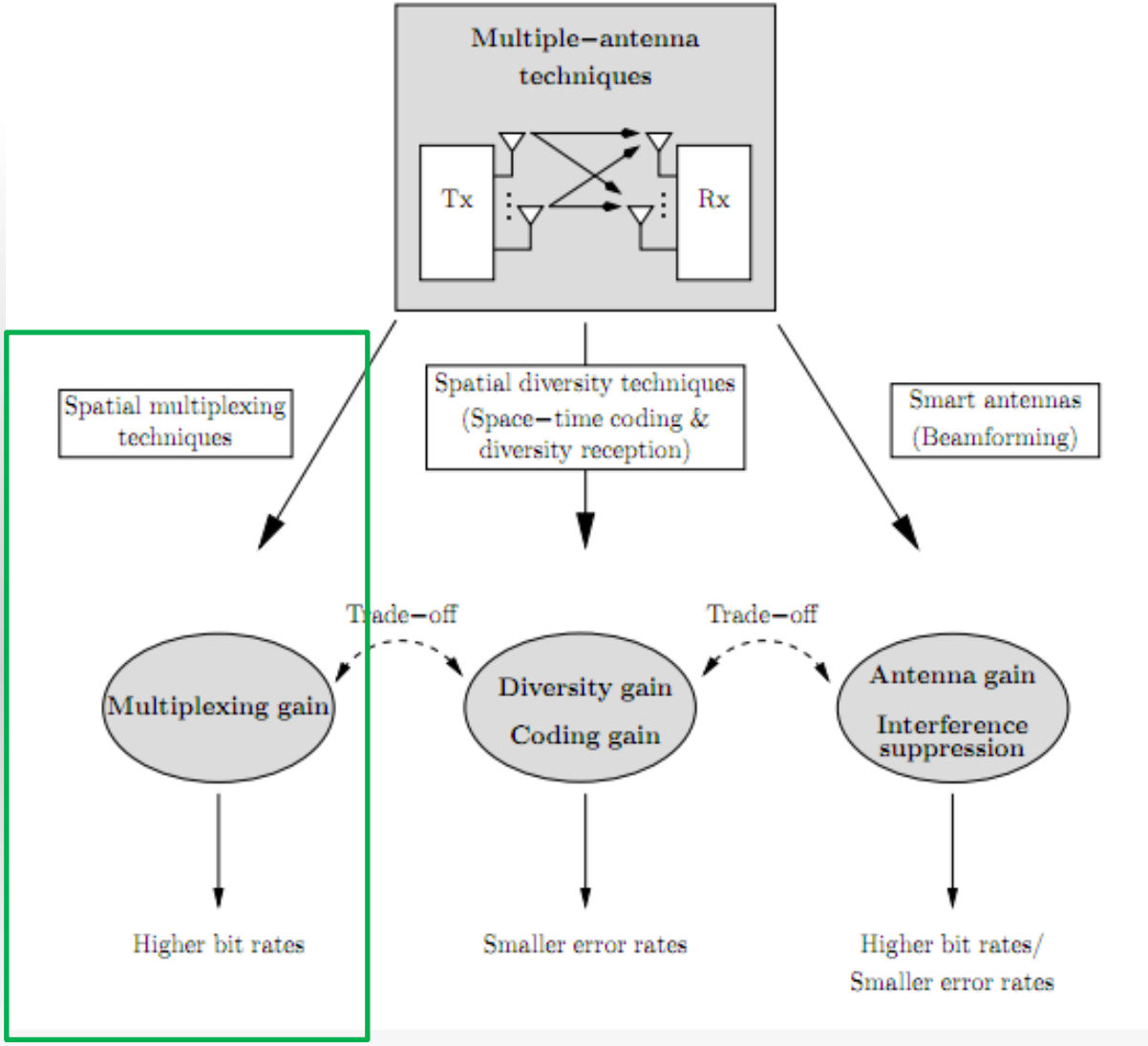
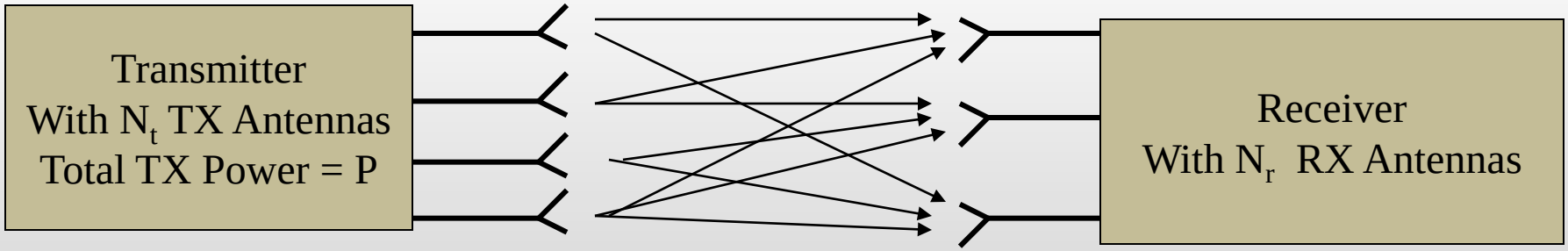


# MIMO

## Konsep MIMO → Spatial Multiplexing




$$H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1N_r} \\ h_{21} & h_{22} & \vdots & h_2 N_r \\ \vdots & \vdots & \vdots & \vdots \\ h_{N_t 1} & h_{N_t 2} & \vdots & h_{N_t N_r} \end{bmatrix}$$

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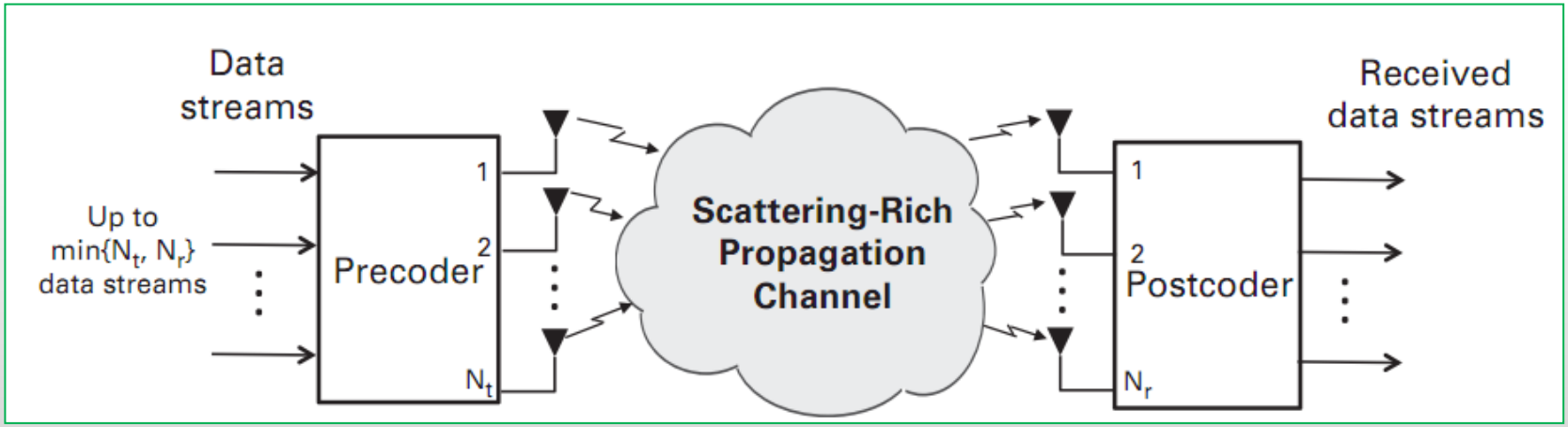


- Spatial multiplexing (SM) refers to transmitting multiple data streams over a multipath channel by exploiting multipath
- By so doing, multiple data channels are able to be transmitted simultaneously over the same frequency band, enabling potentially large numbers of bits per second to be transmitted per Hertz of spectrum
- Spatial multiplexing is analogous to other more common types of multiplexing schemes such as frequency division multiplexing (FDM) and time-division multiplexing (TDM)

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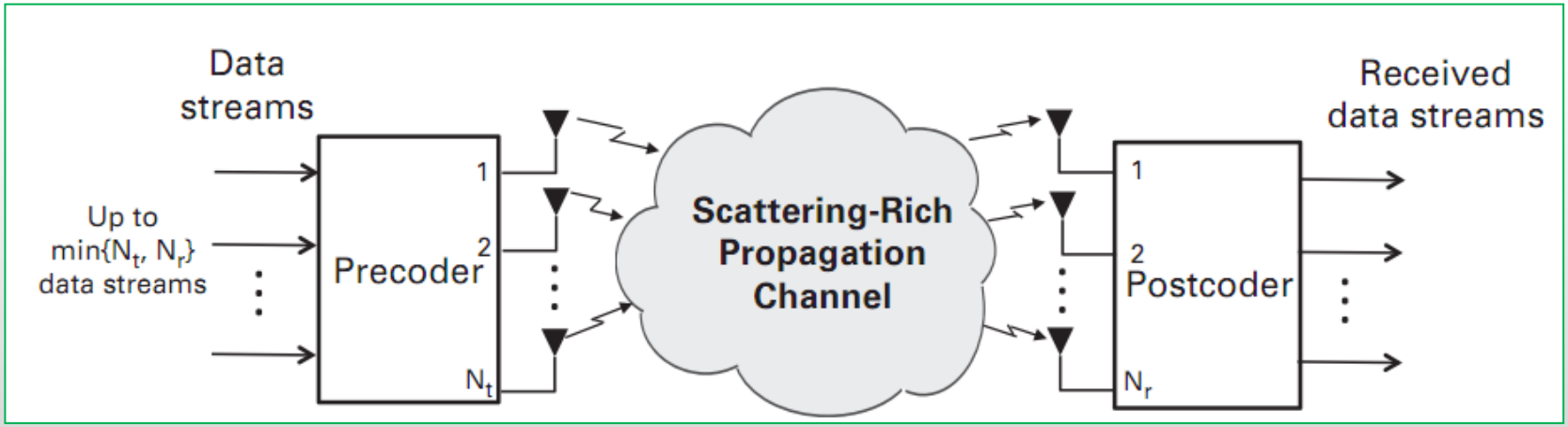


there are three main components to an SM system :

- PreCoder
- PostCoder
- Communication Channel

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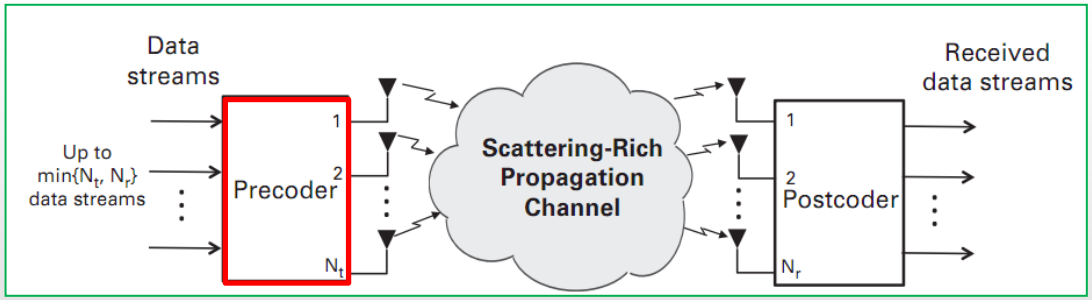


- Precoder purpose is to map the multiple input streams of data that are to be transmitted onto the set of transmit antennas
- The simplest form of precoder simply maps each data stream to a single unique antenna

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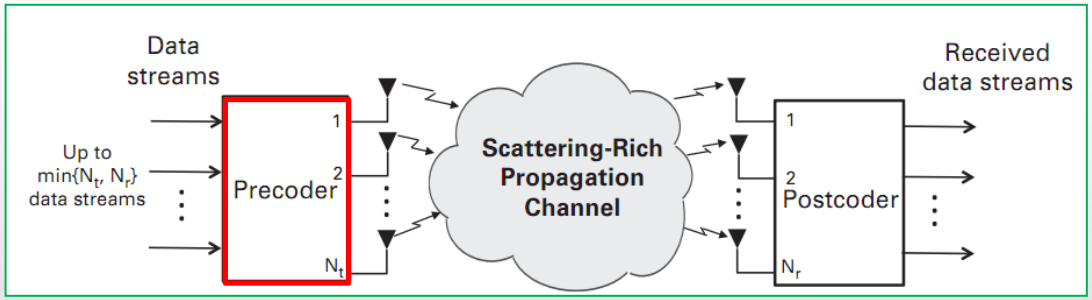


- Spatial multiplexing code :

1. Bell Laboratory layered space-time (BLAST) family of techniques:
   a) Vertical BLAST (V-BLAST);
   b) Horizontal BLAST (H-BLAST);
   c) Diagonal BLAST (D-BLAST);
2. Multi-group space-time coding (MGSTC);
3. Threaded space-time coding (TSTC).

- The Precoder block that performs this mapping may employ some combination of either space-time coding, additional conventional error coding, and modulation, depending on the particular type of spatial multiplexing scheme

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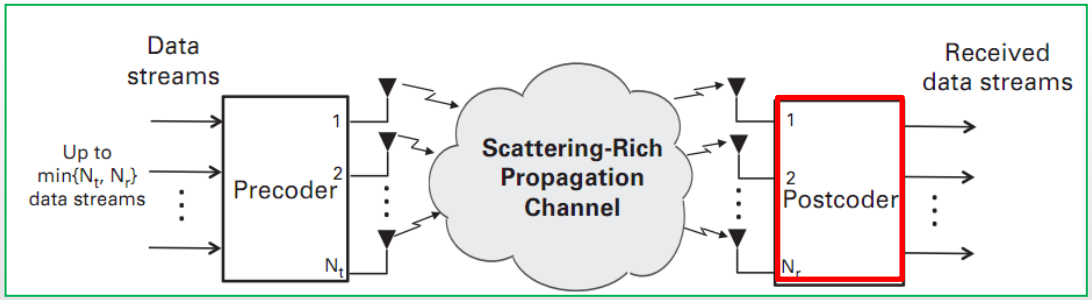


- Postcoder processes the signals from the receive antennas and generates estimates of the original input data streams that originally went into the precoder at the transmitter.
- Since the signal at each receive antenna consists of the sum of the signals from each of the transmit antennas, the post- coder must be able to, in essence, strip off each data stream from the composite received signal.

# MIMO

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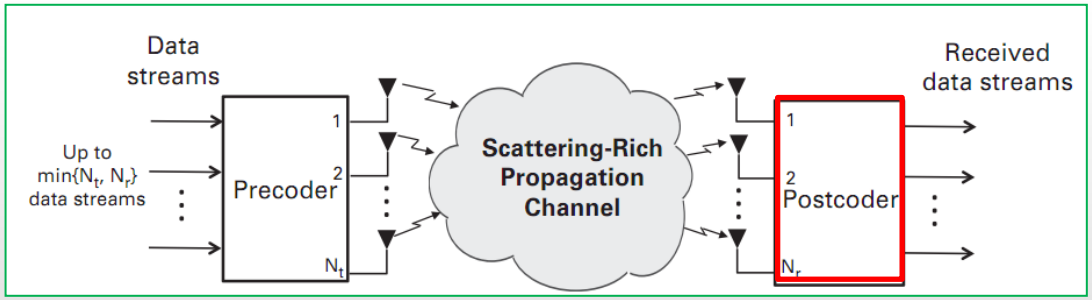


The type of decoding algorithm :

1. Zero forcing (ZF);
2. Zero forcing with interference cancellation (ZF-IC);
3. Linear minimum mean square error estimation (LMMSE);
4. LMMSE with interference cancellation (LMMSE-IC).

# MIMO

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there are three main components to an SM system :

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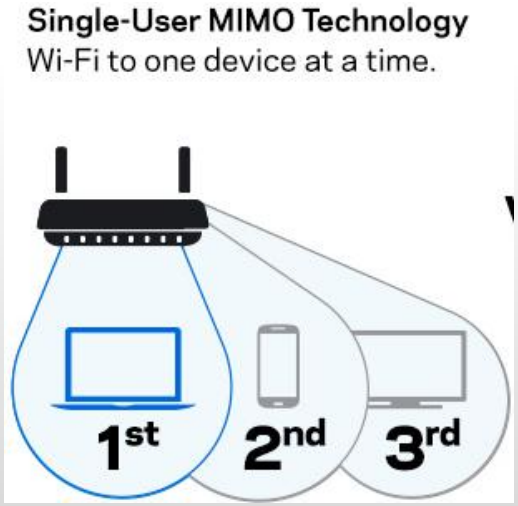
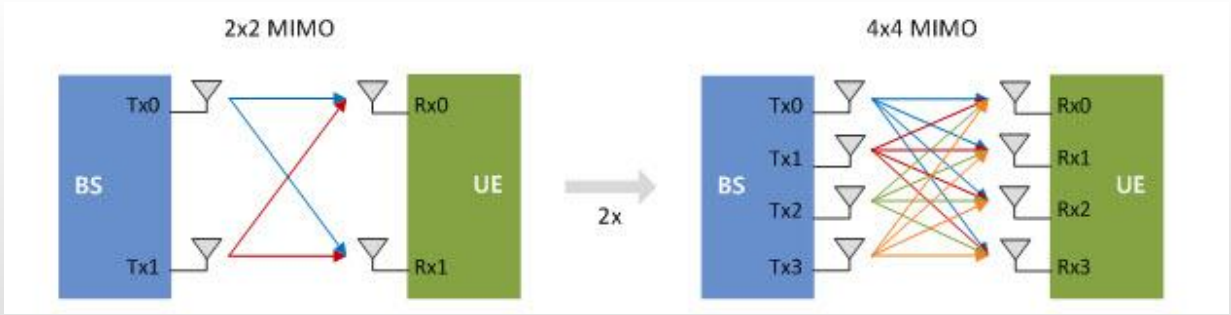
- In order for spatial multiplexing to work, the channel must have a significant amount of multipath scattering.
- This may seem odd since multipath is normally regarded as the enemy by communications engineers since it degrades the performance of conventional communication systems.
- However, since spatial multiplexing exploits multipath, its presence is necessary for SM techniques to work

# MIMO

## Single User–MIMO Vs Multi User-MIMO

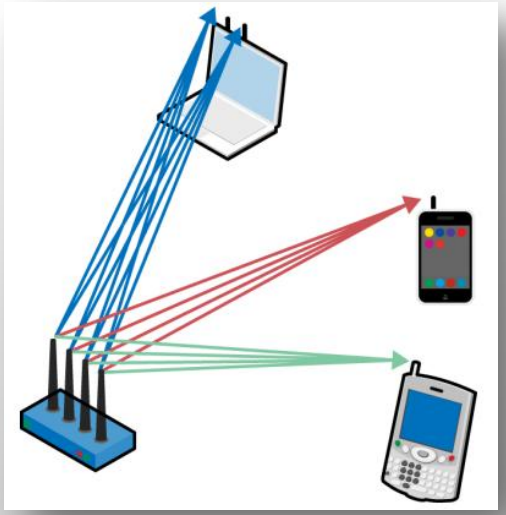



- Single-user MIMO (SU-MIMO) refers to conventional MIMO where there is a one transmitting node and one receiving node, and the transmitter node has multiple antennas.

# MIMO

## Single User–MIMO Vs Multi User-MIMO

- multi-user MIMO (MU-MIMO), mobile cellular users, each with a single antenna, transmit to a base station, and the base station processes the signals from each of the individual mobiles as if they were coming from multiple transmit antennas on a single node.
- In this case, the base station performs the same operations as the receiver , so multiple mobile users can transmit data over the same bandwidth, and the base station is able to decouple the individual data streams using spatial decoding techniques

# MIMO

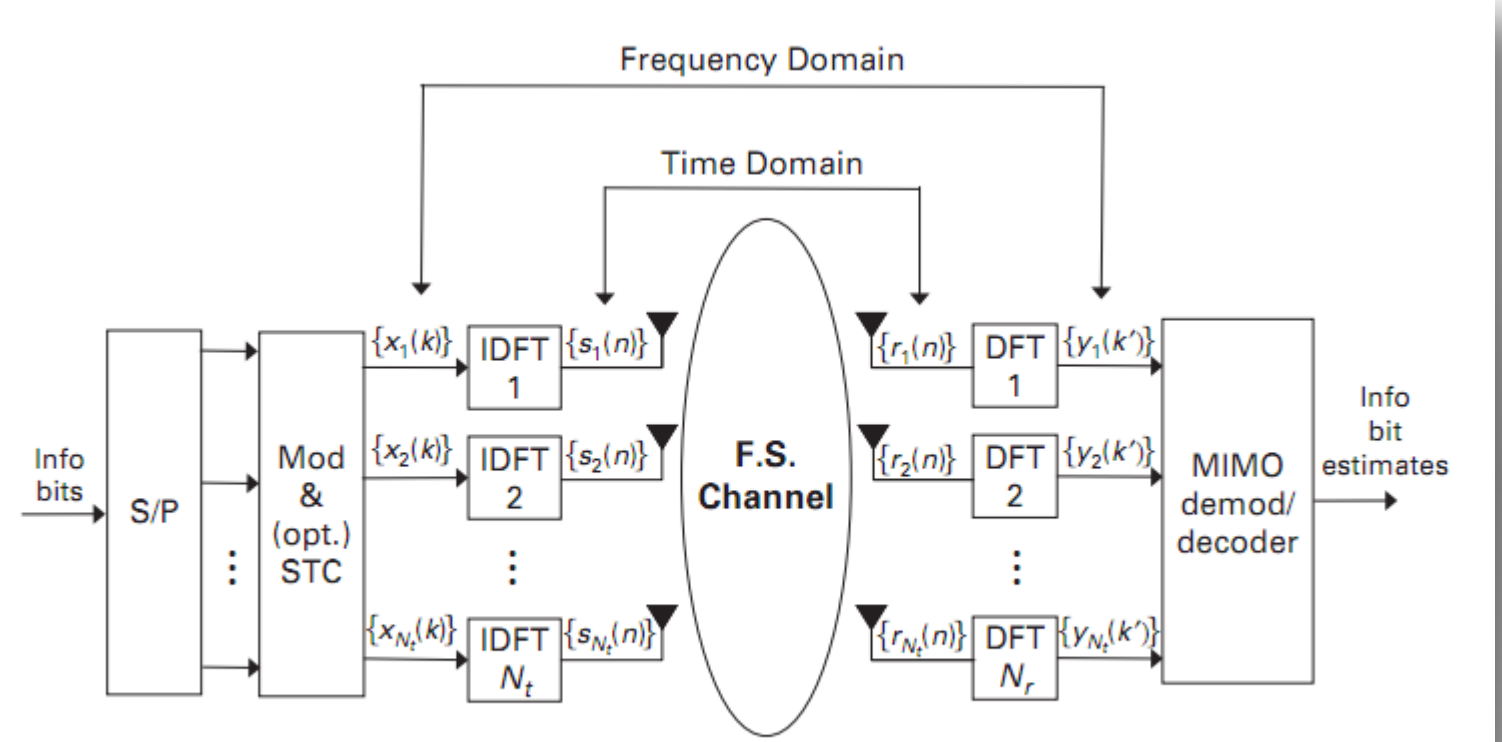
## Open and Close Loop MIMO

- MIMO techniques normally require that either the transmitter or the receiver have knowledge of the characteristics of the communications channel.
- MIMO techniques that require the transmitter to have knowledge of the channel are called **closed-loop** because they require the receiver to estimate the channel and to send that information back to the transmitter – hence, requiring a “closed loop”
- MIMO techniques that only require the receiver to have knowledge of the channel are called **open loop**

# MIMO

## MIMO OFDM

- Using OFDM and MIMO as system to combat Frequency Selective Fading




Implementation of OFDM in a MIMO system.

# PRACTICAL USE OF MIMO

## Commercial wireless standards that use MIMO technology

| Wireless standard | Antenna configurations |
|---|---|
| IEEE 802.11n (WiFi) | 4 × 4 |
| IEEE 802.16e (WiMAX) | 4 × 4 |
| HSPA$^{+}$ (Enhanced HSPA) | 2 × 2 |
| LTE (3.9G) | 4 × 4 |
| LTE-Advanced (4G) | 8 × 8 |
| 802.11ac (Enhanced 802.11n) | 8 × 8 |

Support the following types of multi-antenna techniques:

- Alamouti space-time coding for transmit diversity;
- Eigenbeamforming spatial multiplexing;
- BLAST spatial multiplexing architectures;
- Conventional beam and null forming;
- Conventional receive diversity.

# MIMO PERFORMANCE

Two performance metrics were used in these tests to quantify the performance improvement due to MIMO :

## Throughput Gain (TPG)

Is defined as the ratio of MIMO throughput over SISO throughput, given the same total transmit power, spectrum usage, and channel conditions

$$TPG = \frac{Throughput_{MIMO}}{Throughput_{SISO}}$$

## Transmit Power Savings (TPS)

Defined as the ratio of transmit power used in SISO divided by the required power forMIMO, when operating at the same throughput

$$TPS = \frac{TransmitPower_{SISO}}{TransmitPower_{MIMO}}$$

# MIMO PERFORMANCE

| | |
|---|---|
| **RF carrier** | 2.4 – 2.4835 GHz and 4.9 – 5.8 GHz |
| **Output power (total)** | 250 mW (2 W with external PA) |
| **Bandwidth** | 0.625, 1.25, 2.5, 5, 10, 20 MHz |
| **Data rates** | 1.5 Mbps – 260 Mbps |
| **Modulation** | Coded – OFDM with 64/128 FFT sizes |
| **Antenna configuration** | $m \times n \;\; 1 \leq m, n \leq 4$ |
| **MIMO processing** | Spatial multiplexing, Space-time coding<br>Eigenbeamforming, Receive diversity |
| **Number of data streams** | 1, 2, 3, 4 |

| LOS transmission | | NLOS transmission | |
|---|---|---|---|
| *TPG* | *TPS* | *TPG* | *TPS* |
| 3.1 | 40.0 | 6.1 | 4.4 |
| 1.7 | 5.0 | 2.7 | 11.6 |
| 1.2 | 16.9 | 4.2 | – |
| 3.3 | 2.7 | 3.3 | 2.7 |
| 1.3 | 2.7 | 2.5 | 4.7 |
| 1.3 | 5.7 | 5.0 | 6,1 |
| 1.6 | 2.7 | 1.6 | 22.2 |
| 1.3 | 4.7 | 2.3 | 6.1 |
| 1.7 | 1.8 | 6.0 | 16.9 |
| 1.7 | 11.6 | 1.6 | 2.7 |
| 2.0 | 4.7 | 2.6 | 14.7 |
| 2.7 | 2.7 | – | – |
| 1.9 | 31.3 | – | – |
| 1.4 | 22.6 | – | – |
| **1.9** | **10.5** | **3.3** | **9.2** |

measured MIMO performance improvement from (Mobile Networked MIMO) MNM radio field demonstrations

Hung-Quoc Lai, B. Zannetti, T. Chin, et al.Measurements of multiple-input multiple-output(MIMO) performance under army operational conditions. In Military Communications Conference, 2010 – MILCOM 2010, pp. 2119–2124, 31, 3 November 2010.

# THANK YOU

# REVIEW

1. Sebutkan jenisjenis teknik multiple antena yang digunakan dalam sistem komunikasi!
2. Jelaskan cara kerja beamforming antena!
3. Apa kegunaan beamforming antenna?
4. Apakah fungsi dari teknik diversity?
5. Apa yang dimaksud dengan Rake Receiver!
6. Apa perbedaan Frequency diversity dengan Space Diversity?
7. Apa fungsi dari spatial multiplexing?
8. Apa perbedaan Spatial diversity dengan Spatial multiplexing?
9. Jelaskan perbedaan antara receiver diversity dengan transmitter diversity! Jelaskan juga kelebihan dan kekurangannya!
10. Sebutkan jenis teknik pengkodean yang digunakan pada spatial Diversity dan Spatial multiplexing!