Komunikasi Akses Wireless

Multiple Antennas

Telkom Engineering School

Faculty of Electrical Engineering
Bandung – 2020

4G Approaches

Access Scheme	All-IP Network
Advanced Antenna	Cognitive Radio

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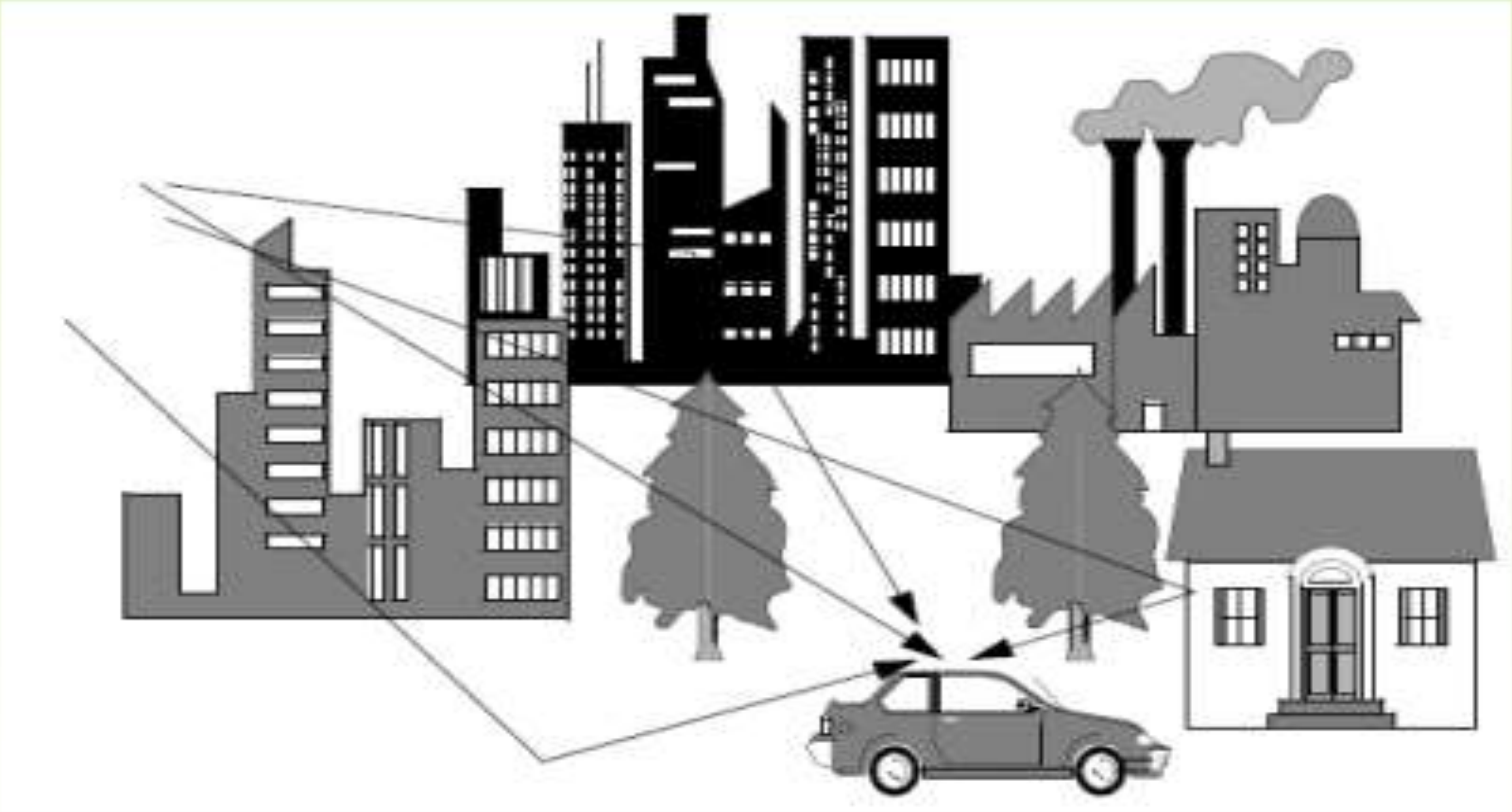
Transmission on a multipath channel

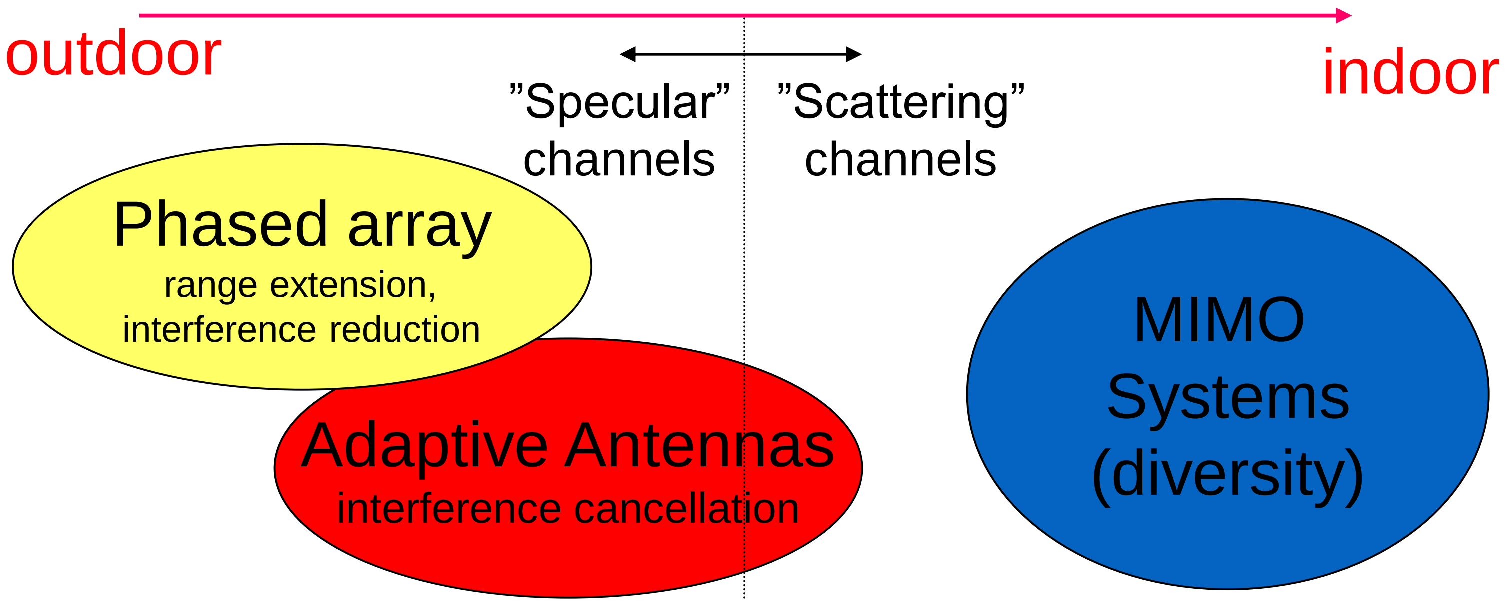
In wireless communication the propagation channel is characterized by multipath propagation due to scattering on different obstacles



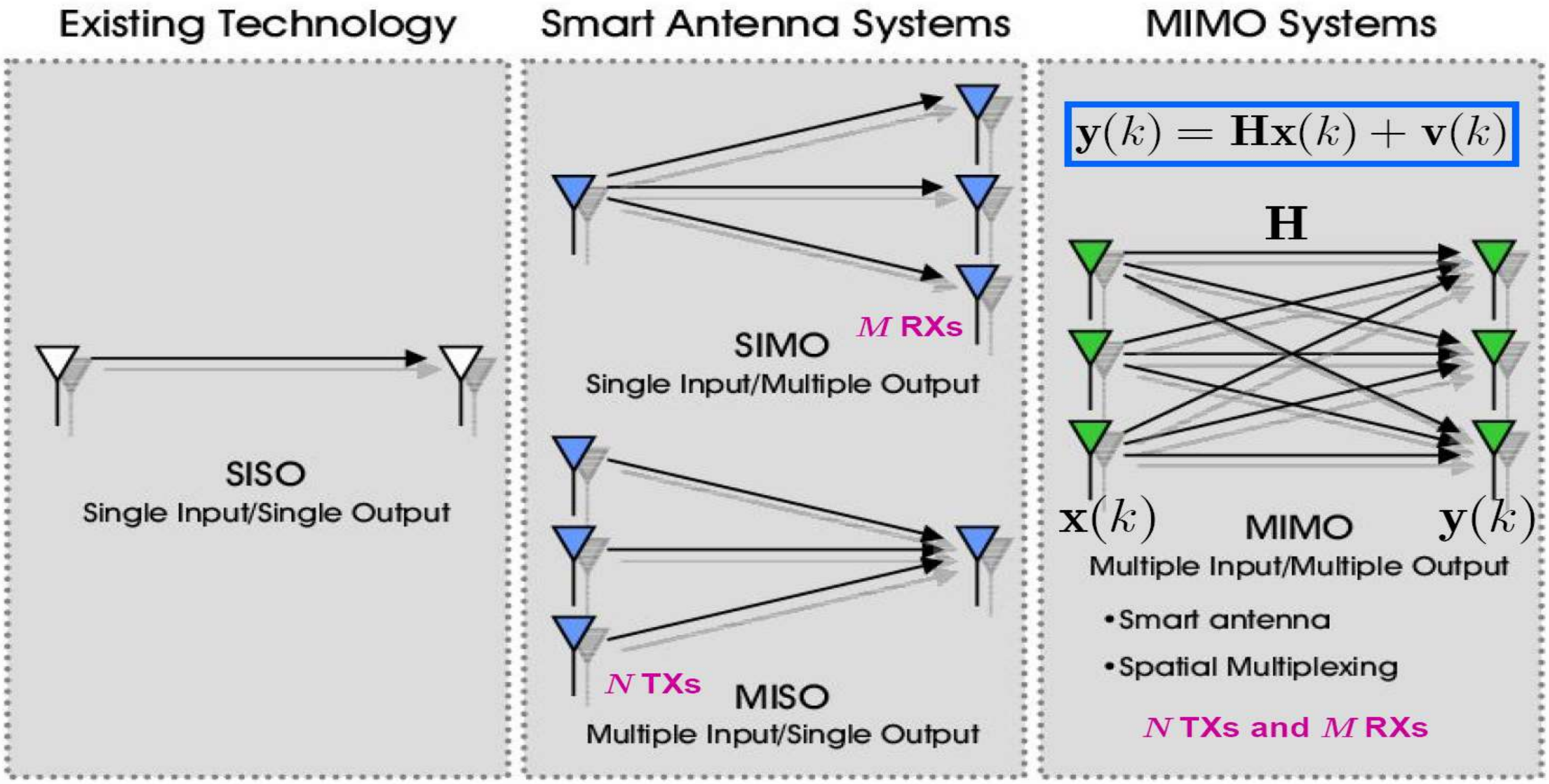
- Time variations: Fading => SNR variations
- Time spread => frequency selectivity

Why multiple antennas ????

- Frequency and time processing are at limits
- Space processing is interesting because it does not increase bandwidth

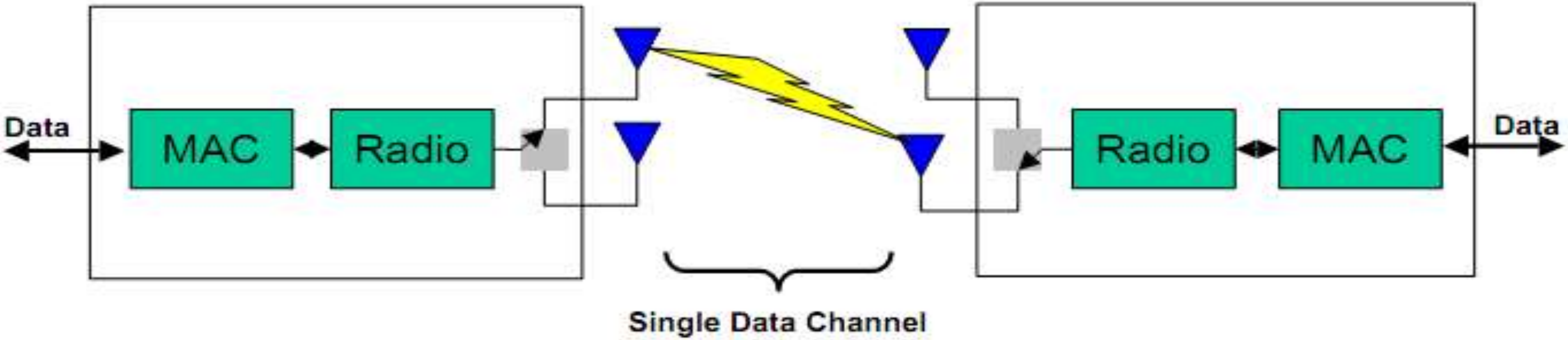


Multiple Antenna Technique: Four Basic Model



What is SISO?
Single-Input Single-Output

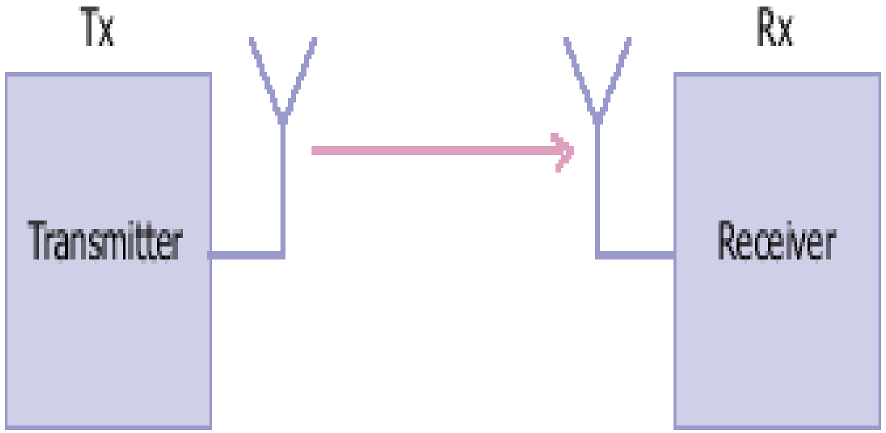
Traditional – SISO Architecture



- One radio, only one antenna used at a time (e.g., 1 x 1)
- Antennas constantly switched for best signal path
- Only one data “stream” and a single data channel

SISO

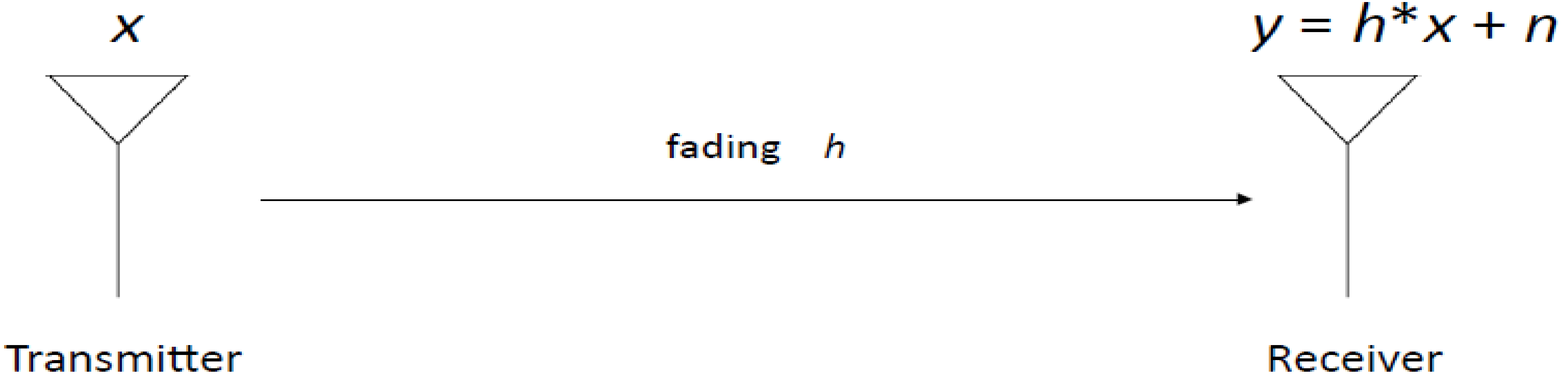
Radio transmissions traditionally use one antenna at the transmitter and one antenna at the receiver.
This system is termed Single Input Single Output (SISO).



Picture. Single Input Single Output (SISO)
One antenna at both the transmitter and the receiver.
Employs no diversity technique.

Both the transmitter and the receiver have one RF chain (that's coder and modulator). SISO is relatively simple and cheap to implement and it has been used age long since the birth of radio technology.
It is used in radio and TV broadcast and our personal wireless technologies (e.g. Wi-Fi and Bluetooth).

Mathematical Model



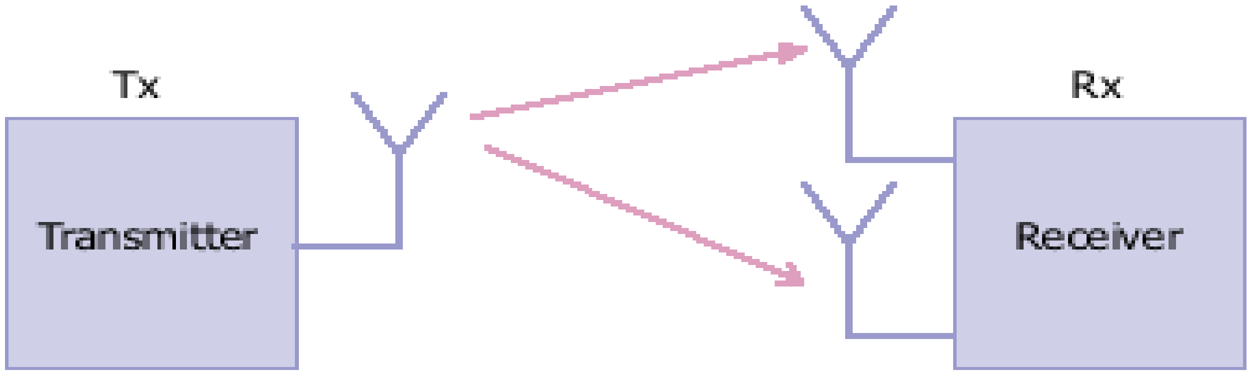
- SNR (signal-to-noise ratio): measure of quality of communication

$$SNR = \frac{\|h\|^2 P_x}{P_n}$$

- channel variations → SNR variations

SIMO

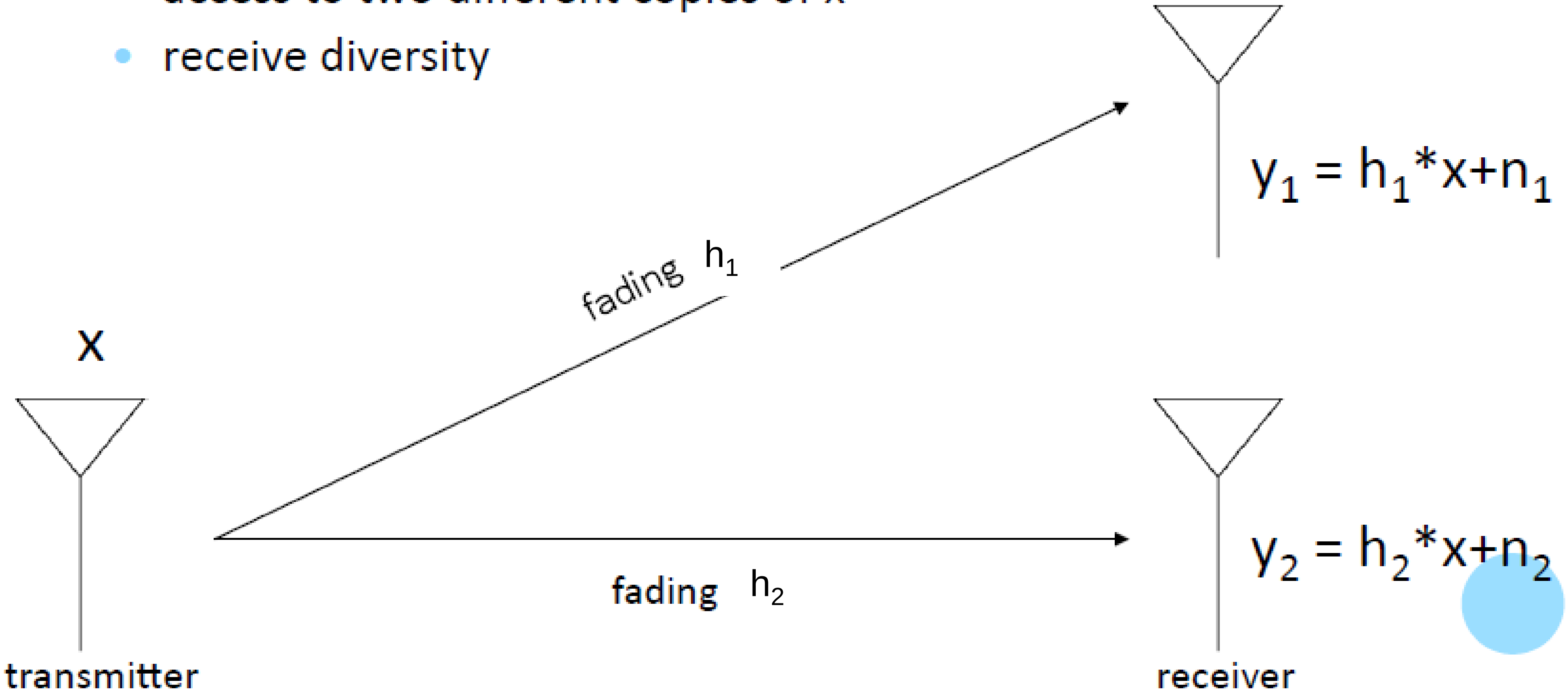
To improve performance, a multiple antenna technique has been developed. A system which uses a single antenna at the transmitter and multiple antennas at the receiver is named Single Input Multiple Output (SIMO). The receiver can either choose the best antenna to receive a stronger signal or combine signals from all antennas in such a way that maximizes SNR (Signal to Noise Ratio). The first technique is known as switched diversity or selection diversity. The latter is known as maximal ratio combining (MRC).



Picture. Single Input Multiple Output (SIMO), 1x2
One antenna at the transmitter, two antennas the receiver.
Employs a receive diversity technique.

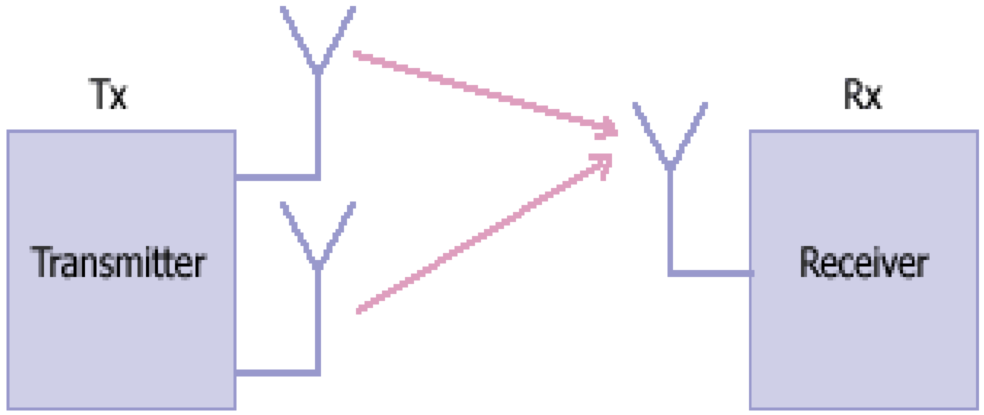
SIMO

- No impact on capacity
- Two receive antennas:
  - access to two different copies of x
  - receive diversity



MISO

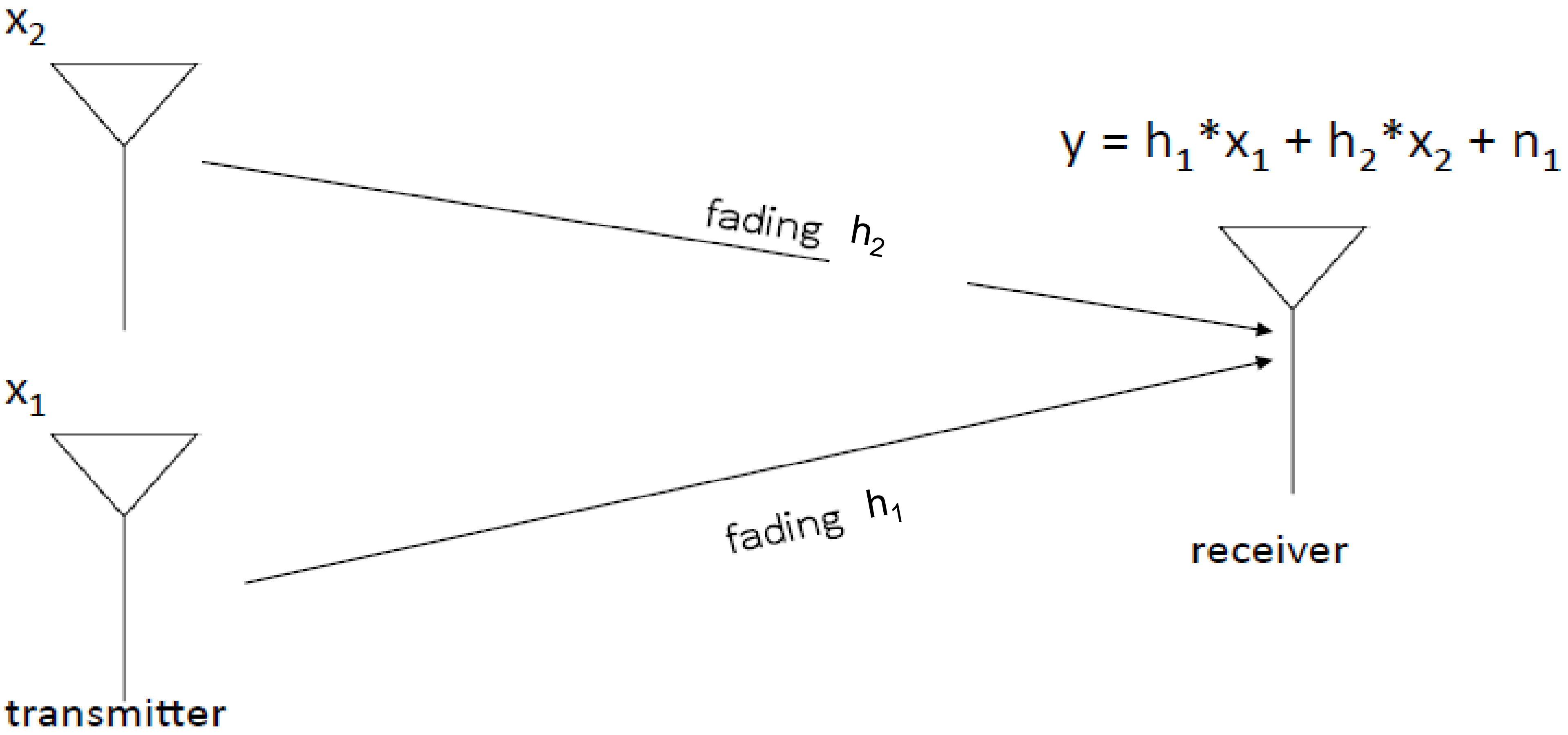
A system which uses multiple antennas at the transmitter and a single antenna at the receiver is named Multiple Input Single Output (MISO). A technique known as Alamouti STC (Space Time Coding) is employed at the transmitter with two antennas. STC allows the transmitter to transmit signals (information) both in time and space, meaning the information is transmitted by two antennas at two different times consecutively.



Picture. Multiple Input Single Output (MISO), 2x1
Two antennas at the transmitter, one antenna at the receiver.
Employs a transmit diversity technique.

MISO

- No impact on capacity
- Transmit two different symbols
  - access to two different copies of x
  - transmit diversity



MIMO

MIMO = Multi Input Multi Output

Why MIMO?

Gains:

- capacity
- reliability
- coverage

Origin of all gains

- new dimension for communication: space
- combating fading

Why MIMO

- Motivation: current wireless systems
  - Capacity constrained networks
  - Issues related to quality and coverage
- MIMO exploits the *space* dimension to improve wireless systems capacity, range and reliability
- MIMO-OFDM – the corner stone of future broadband wireless access
  - WiFi – 802.11n
  - WiMAX – 802.16e (a.k.a 802.16-2005)
  - 3G / 4G

MIMO Gains

Multiplexing Gain

- Requires multiple transmit and receive antennas
- Multiple data streams are transmitted
- Increases data rate for given bandwidth and power

Diversity Gain:

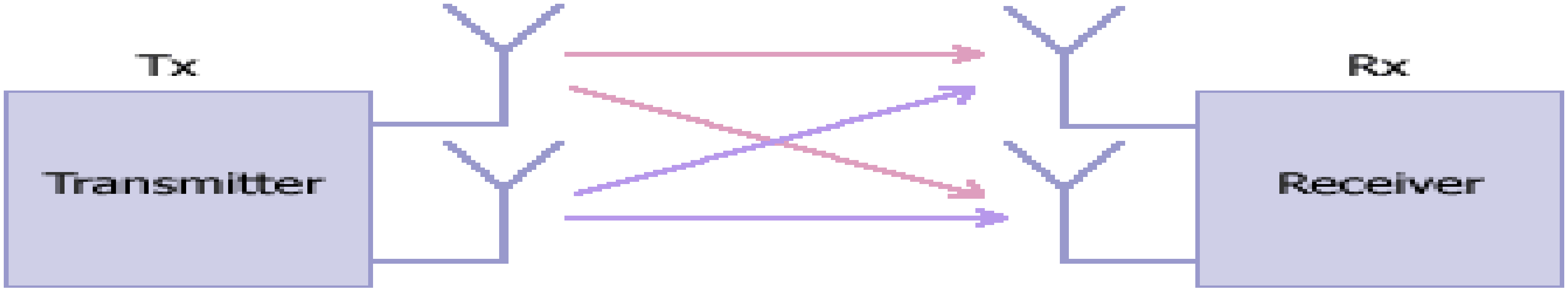
- Requires multiple transmit or receive antennas
- One data stream is viewed multiple times via different fading (decrease the undesired effects of fading)

Cost:

- Hardware cost
- Additional processing

MIMO

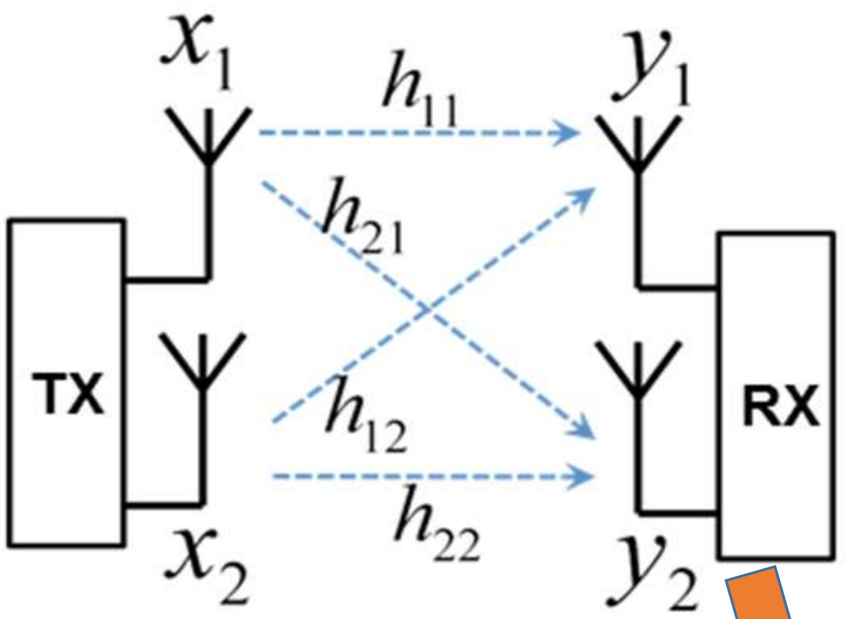
To multiply throughput of a radio link, multiple antennas (and multiple RF chains accordingly) are put at both the transmitter and the receiver. This system is referred to as Multiple Input Multiple Output (MIMO). A MIMO system with similar count of antennas at both the transmitter and the receiver in a point-to-point (PTP) link is able to multiply the system throughput linearly with every additional antenna. For example, a 2x2 MIMO will double the throughput.

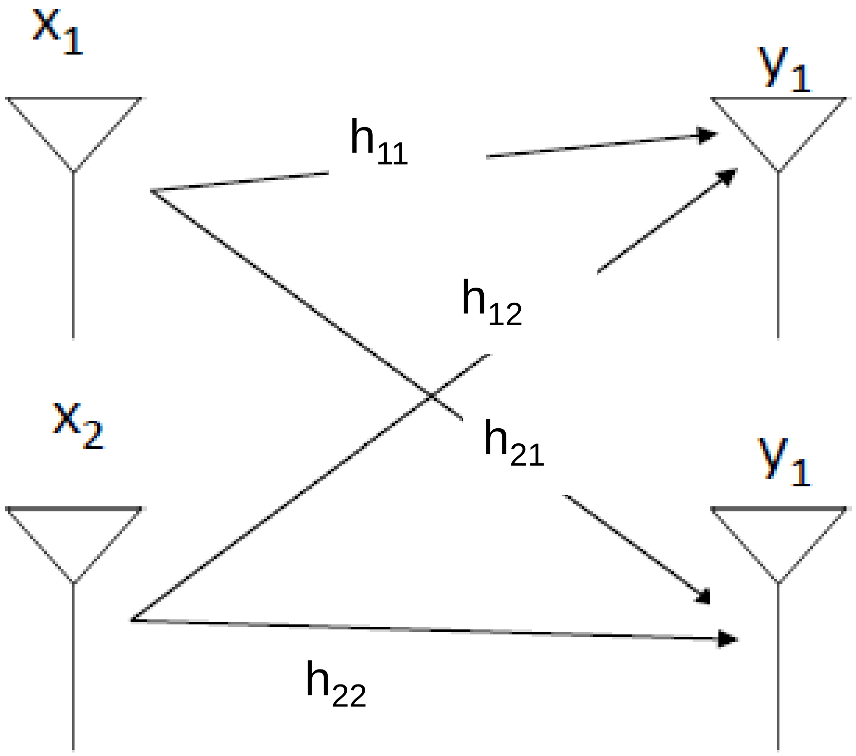


Picture. Multiple Input Multiple Output (MIMO), 2x2
Two antennas at both the transmitter and the receiver.

MIMO

- Combine MISO and SIMO
- Improve:
  - Capacity
  - Reliability





$$y_1 = h_{11} x_1 + h_{12} x_2 + n_1$$
$$y_2 = h_{21} x_1 + h_{22} x_2 + n_2$$

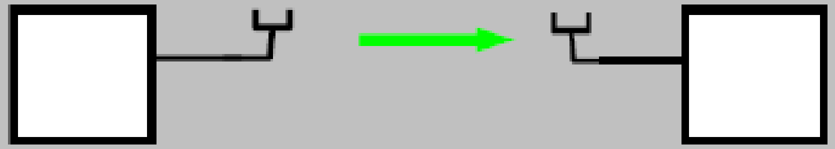
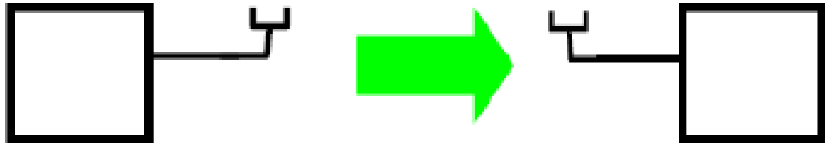
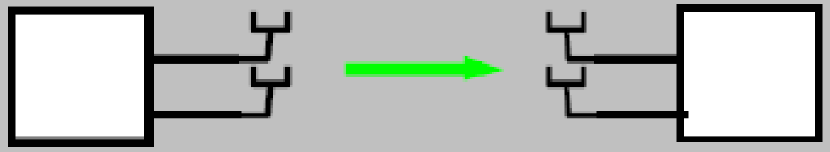
$$y_1 = h_{11} x_1 + h_{12} x_2$$
$$y_2 = h_{21} x_1 + h_{22} x_2$$

$$\begin{vmatrix} y_1 \\ y_2 \end{vmatrix} = \begin{vmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{vmatrix} \begin{vmatrix} x_1 \\ x_2 \end{vmatrix} + \begin{vmatrix} n_1 \\ n_2 \end{vmatrix}$$

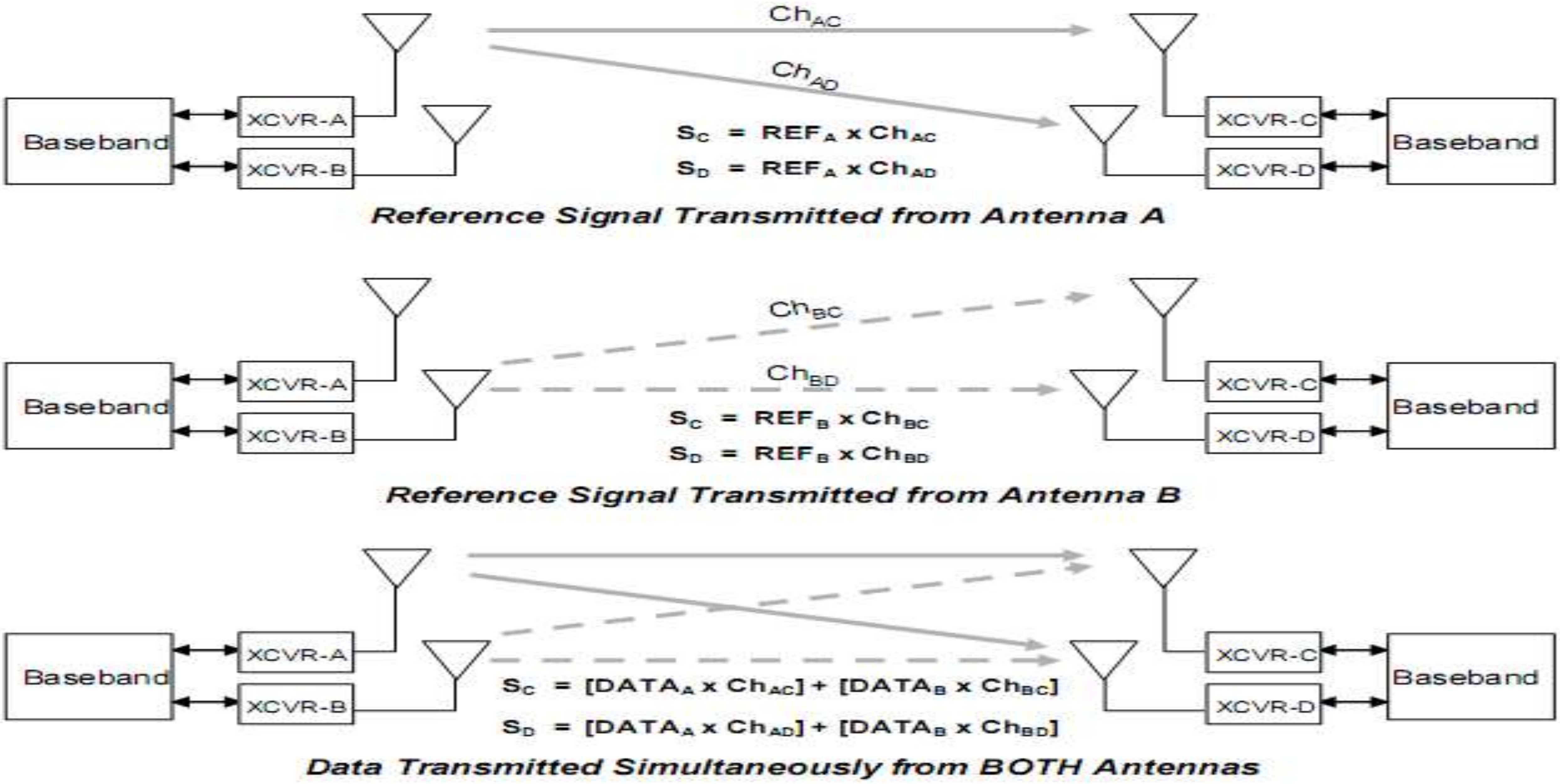
Capacity Improvement

Assume: P_n = 1 mW

$C = \log_2(1+SNR)$

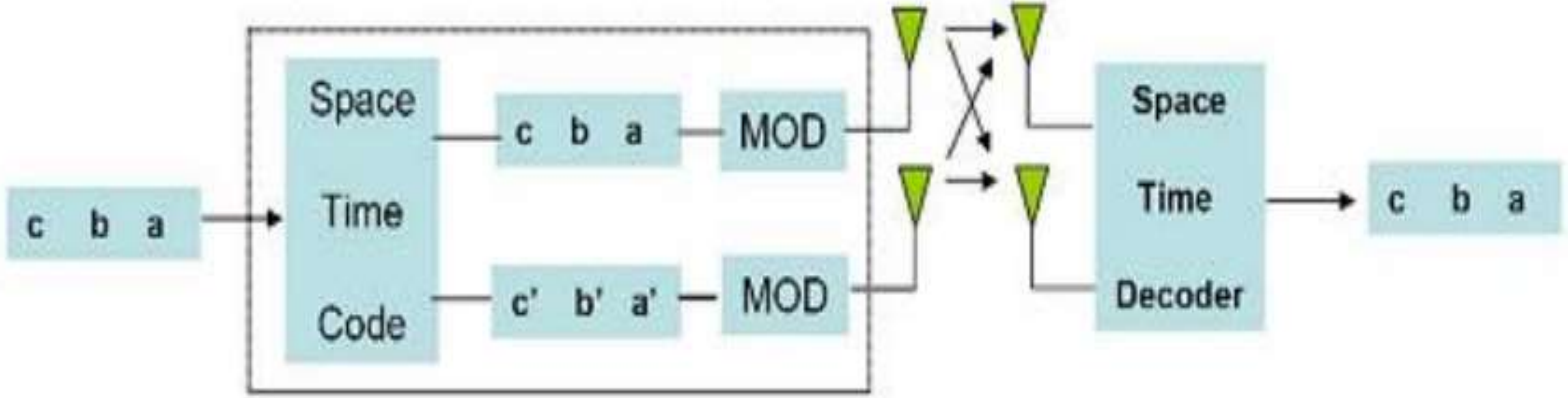
	Transmit power	Capacity
	10 milliwatts	$\log_2(1+10)=$ **3.5 bps/Hz**
	24 Megawatts	$\log_2(1+2.4\text{x}10^{10})=$ **35 bps/Hz**
 10 transmit antennas, 10 receive antennas	10 milliwatts	$10\log_2(1+10)=$ **35 bps/Hz**

MIMO Operation



Spatial Diversity

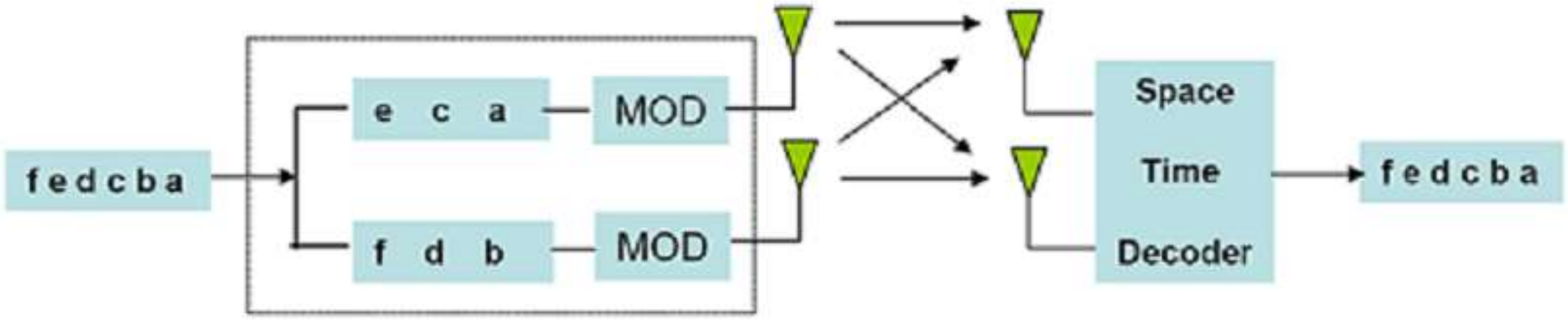
Beberapa replika sinyal informasi dikirim dari beberapa antenna yang berbeda (data informasi yang dikirim yaitu data info asli dan replika). Tujuan *spatial diversity* yaitu untuk meningkatkan SNR dengan cara mengurangi *fading* dan meningkatkan kualitas *link* antara pengirim dengan penerima.



Spatial Multiplexing

Spatial multiplexing bertujuan untuk meningkatkan kapasitas dengan cara mengirimkan beberapa aliran data secara paralel pada waktu yang bersamaan.

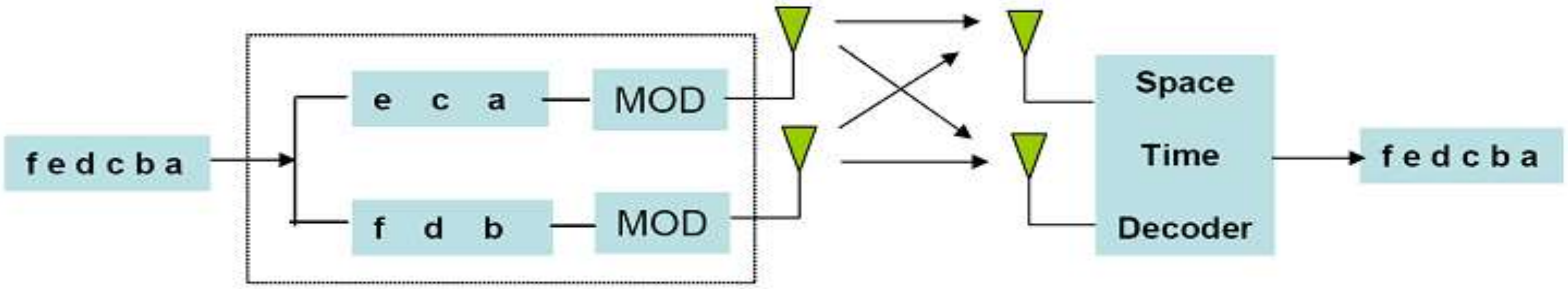
Prinsip kerja dari *spatial multiplexing* adalah mengirim sinyal dari dua atau lebih antenna yang berbeda dengan beberapa aliran data dan aliran data dipisahkan dipenerima dengan proses *signal processing*, oleh karena itu peningkatan *bit rate* berdasarkan konfigurasi antenna mimo (2 untuk antenna mimo 2 by 2 and 4 untuk antena mimo 4 by 4)



Spatial Multiplexing

MIMO Multiplexing

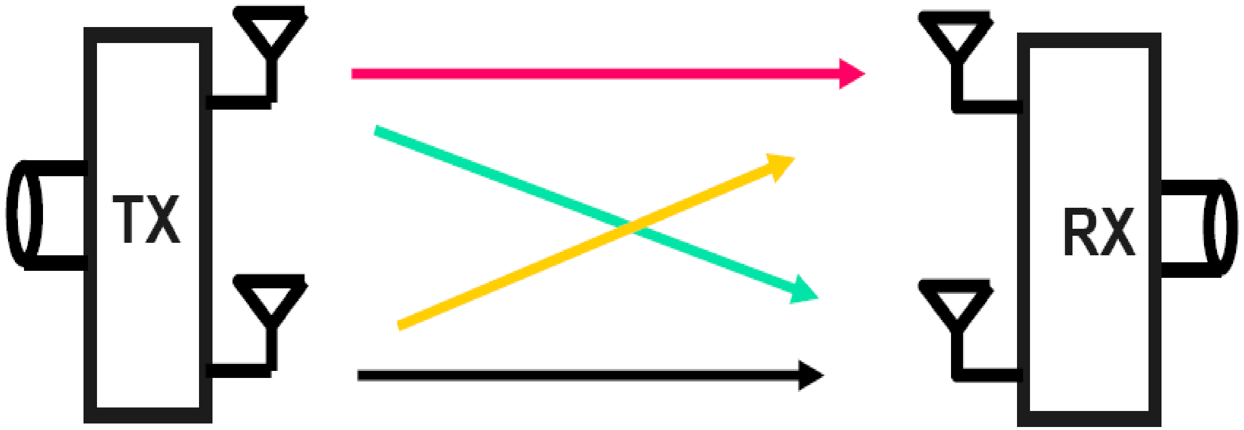
- Data is not redundant – less diversity but less repetition
- Provides multiplexing gain to increase data-rate
- Low (no) diversity compared with STC

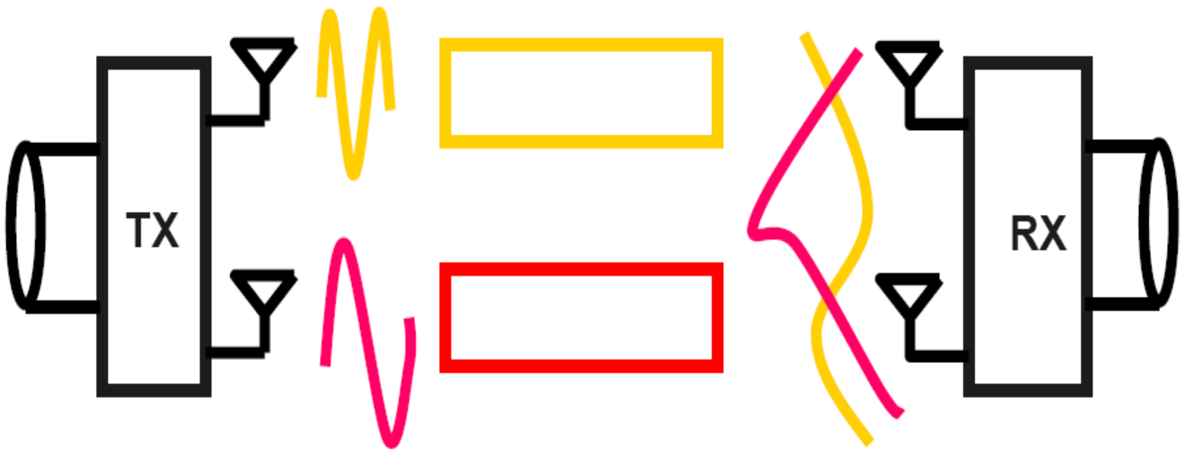


$$\text{Capacity:} \quad C_{MIMO} = \log\det\left(\mathbf{I} + \frac{SNR}{N_t}(\mathbf{H}'\mathbf{H})\right) \simeq min(N_t, N_r)C_{SISO}$$

Multiple Antenna Technique

Two popular techniques in MIMO wireless systems:





Spatial Diversity: Increased SNR

- **Receive and transmit diversity mitigates fading and improves link quality**

Spatial Multiplexing: Increased rate

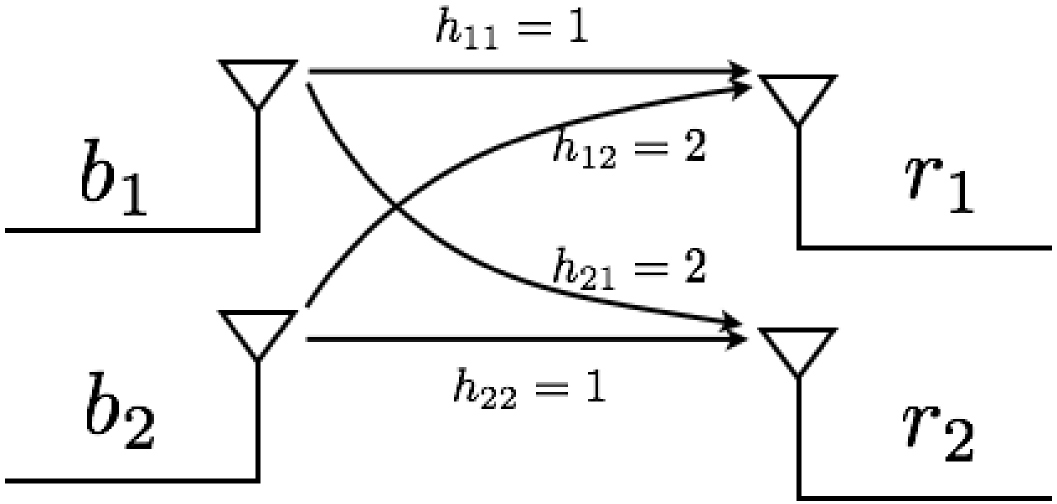
- **Spatial multiplexing yields substantial increase spectral efficiency**

Spatial Diversity and Spatial Multiplexing

- Spatial Diversity
  - Signal copies are transferred from multiple antennas or received at more than one antenna
  - redundancy is provided by employing an array of antennas, with a minimum separation of $\lambda/2$ between neighbouring antennas

- Spatial Multiplexing
  - the system is able to carry more than one data stream over one frequency, simultaneously

Contoh MIMO



a. Tuliskan matrix untuk MIMO channel tersebut.
b. Carilah singular value untuk MIMO channel tersebut.

Jawab (a)

a. Tuliskan matrix untuk MIMO channel tersebut.

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

Channel matrix untuk MIMO tersebut adalah

$$\mathbf{H} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$$

Dengan n_1 dan n_2 adalah noise yang masing-masing terdapat pada antenna 1 dan antenna 2.

Jawab (b)

b. Carilah singular value untuk MIMO channel tersebut.

Singular value didapat dengan mencari eigenvalue dari matrix MIMO berikut

$$\mathbf{H}\mathbf{H}^T = \begin{bmatrix} 1 & 2 \\ 2 & 1 \end{bmatrix} \begin{bmatrix} 1 & 2 \\ 2 & 1 \end{bmatrix} = \begin{bmatrix} 5 & 4 \\ 4 & 5 \end{bmatrix} \qquad \begin{bmatrix} 5 & 4 \\ 4 & 5 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \lambda \begin{bmatrix} x_1 \\ x_2 \end{bmatrix}$$

Dikelompokkan menjadi

$$\begin{bmatrix} (5-\lambda) & 4 \\ 4 & (5-\lambda) \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = 0$$

Dengan membuat determinan *ad-bc=0*, didapat

$$(5-\lambda)^2 - 16 = 0 \qquad \lambda^2 - 10\lambda + 9 = 0 \qquad \lambda_1 = 9, \lambda_2 = 1$$

Sehingga diperoleh singular value $d_1 = \sqrt{\lambda_1} = 3, d_2 = \sqrt{\lambda_2} = 1$