Wireless Communication System

Modul 7 Konsep Dasar Multiple Antena

Telkom University

Faculty of Electrical Engineering
Bandung – 2015

Subject

a. Macam-macam Multiple Antenna (Diversitas dan MIMO)

b. Model Sistem SISO, SIMO, MISO, MIMO

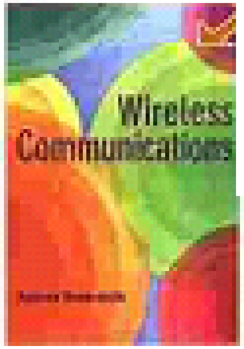
Text Book

Related text book

A) MIMO communications

E.Biglieri, R.Calderbank, A.Constantinides, A.Goldsmith, A.Paulraj, and H.V.Poor, "*MIMO Wireless Communications*," Cambridge Univ. Press, 2007.

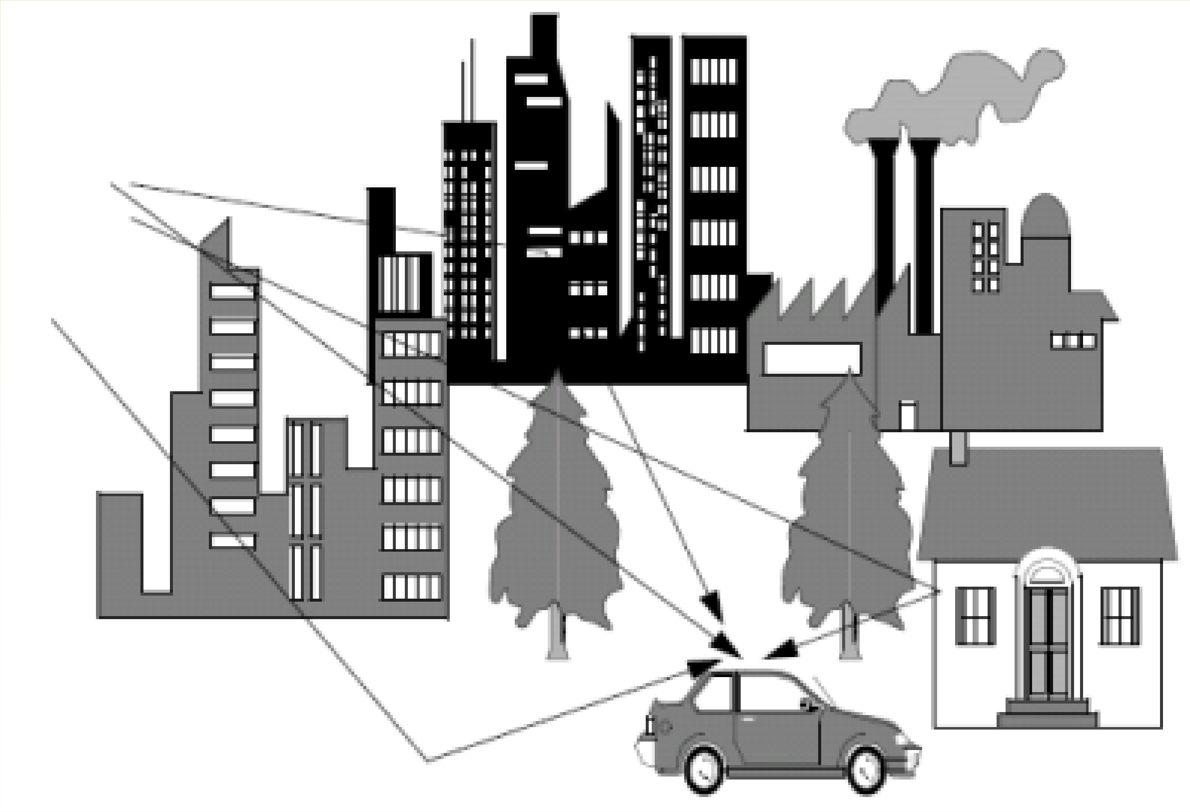
B) Fundamentals of wireless communications



A.Goldsmith, "*Wireless Communications*," Cambridge Univ. Press, 2005.

Transmission on a multipath channel

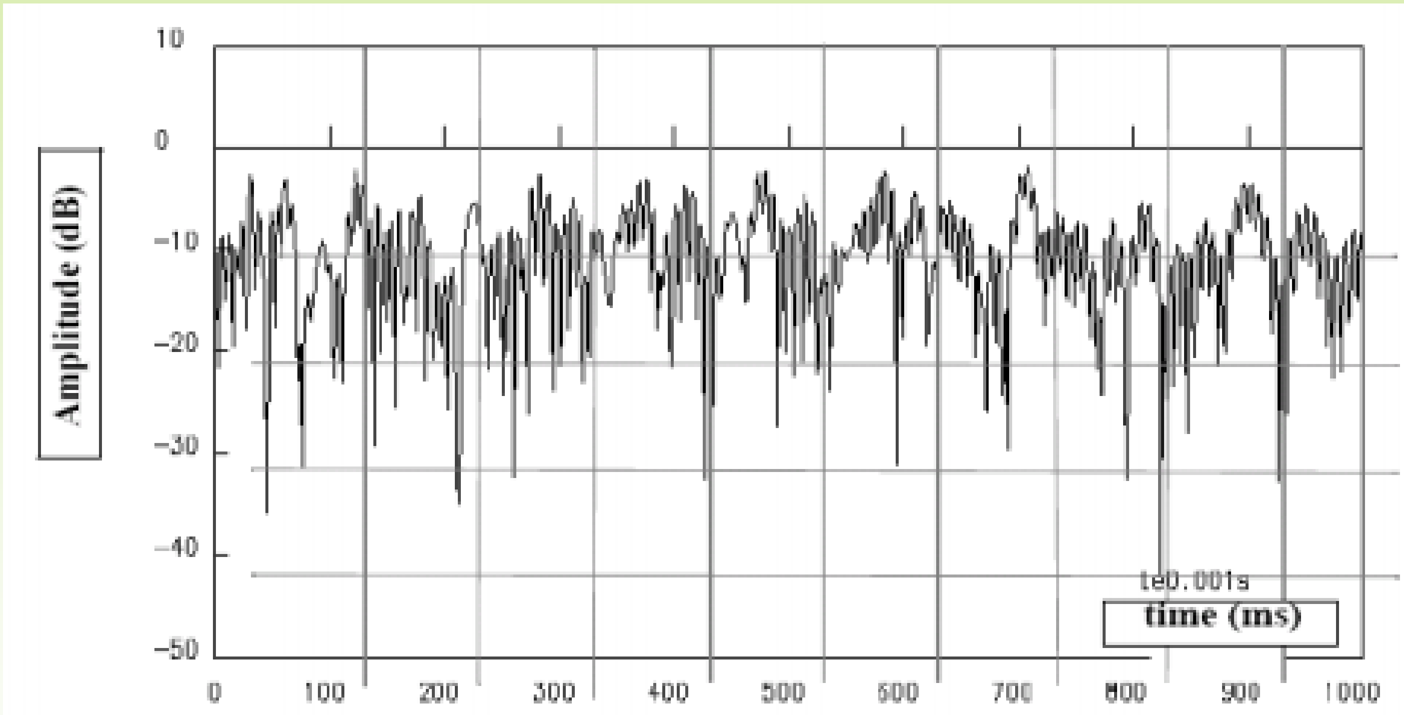
In wireless communication the propagation channel is characterized by multipath propagation due to scattering on different obstacles



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

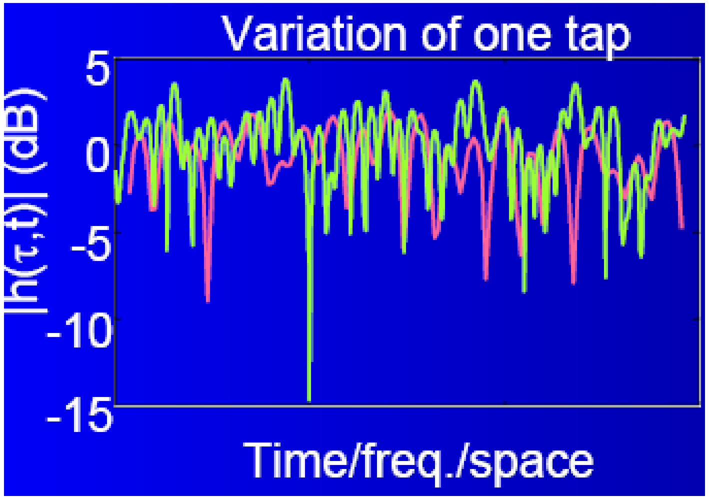
Transmission on a multipath channel

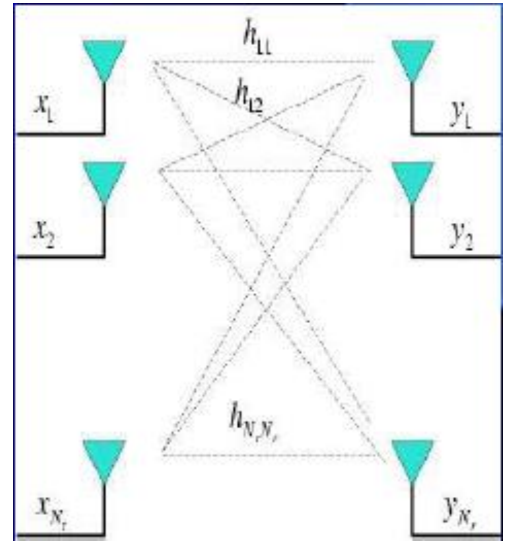
Fading:



- The received level variations result in SNR variations
- The received level is sensitive to the transmitter and receiver locations

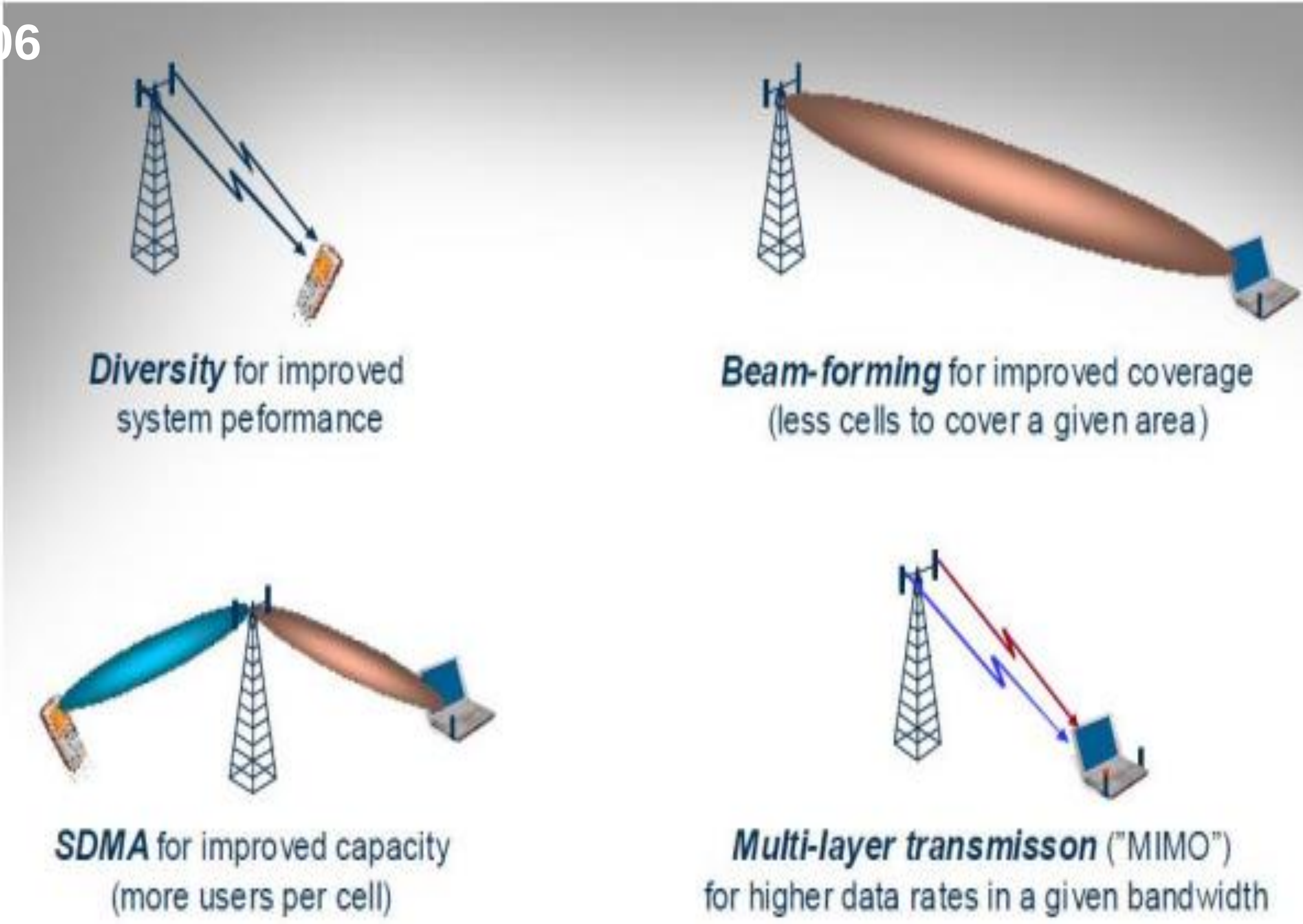
Multiple Antenna vs Fading



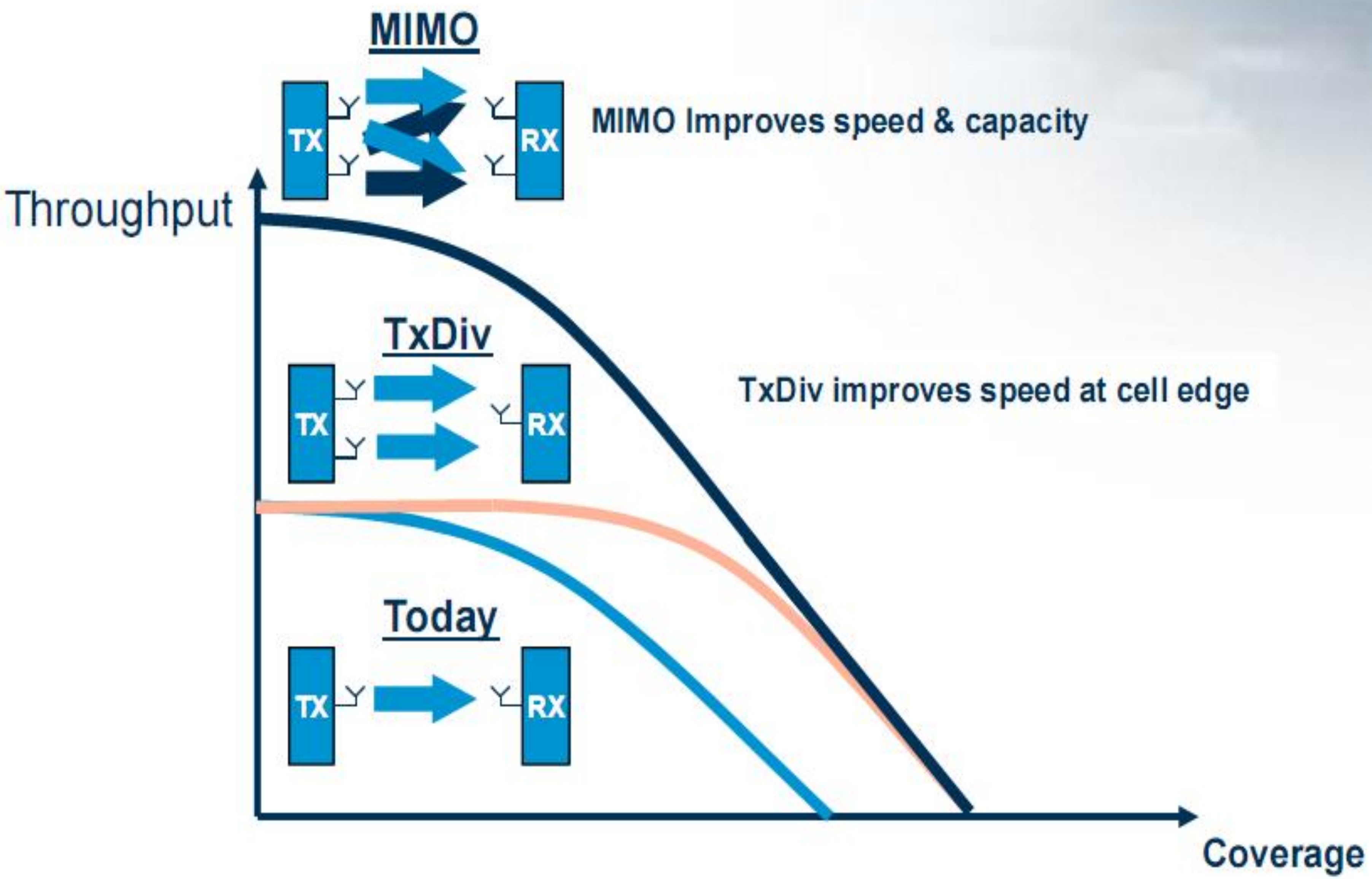


- Diversity ↑ with *NtNr*
- Rate ↑ with *Nt*
- Capacity ↑ min(*Nt*, *Nr*) [Foschini'98]

- Diversity → multiple copies
- Time/freq. Diversity → BW expansion
- Antenna Diversity → cost, but no BW expansion


Diversity for improved
system peformance
Beam-forming for improved coverage
(less cells to cover a given area)
SDMA for improved capacity
(more users per cell)
Multi-layer transmisson ("MIMO")
for higher data rates in a given bandwidth

Diversity & MIMO

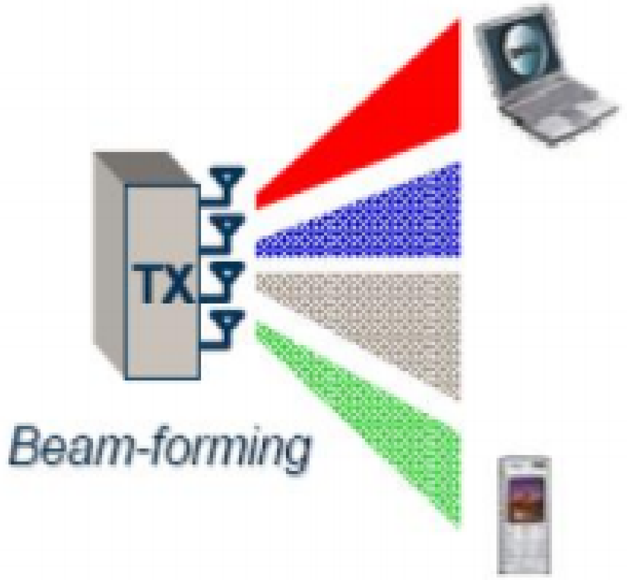


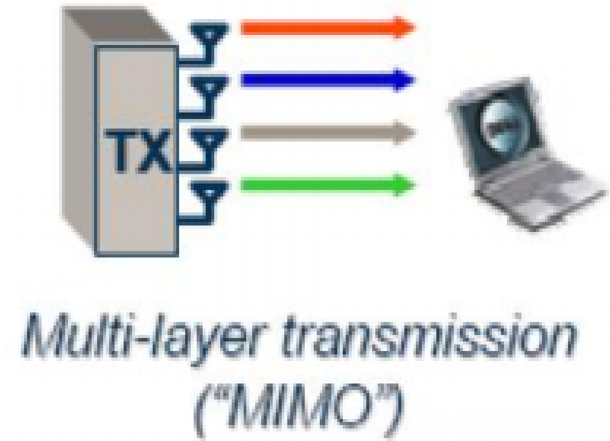
Teknik Multi Antena

- MIMO menggunakan multi antena pada sisi transmit untuk perbaikan kinerja air interface.
- MIMO menggunakan space-time coding pada data stream yang sama untuk dipetakan ke antena transmit.
- MIMO processing juga mendayagunakan spatial multiplexing sehingga memungkinkan data stream yang berbeda dikirim secara simultaneously ke beberapa antena pengirim untuk mendapatkan lajudata yang lebih tinggi
- Bila informasi kondisi kanal diketahui, MIMO dpat juga dimanfaatkan untuk mengimplementasikan beam-forming sehingga lajudata dan efisiensi spektrum menjadi lebih meningkat.

Teknik Advanced Antenna

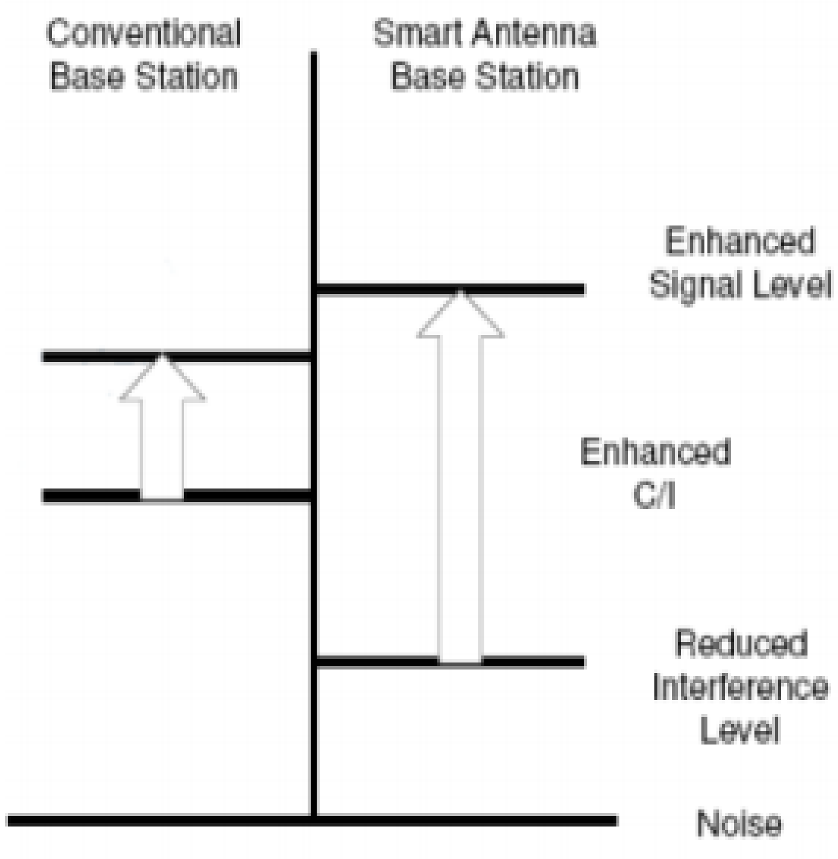
- Single data stream / user
- Beam-forming
  - Coverage, longer battery life
- Spatial Division Multiple Access (SDMA)
  - Multiple user pada sumberdaya radio yang sama
- Multiple data stream / user Diversity
  - Link robustness
- Spatial multiplexing
  - Spectral efficiency, high data rate support



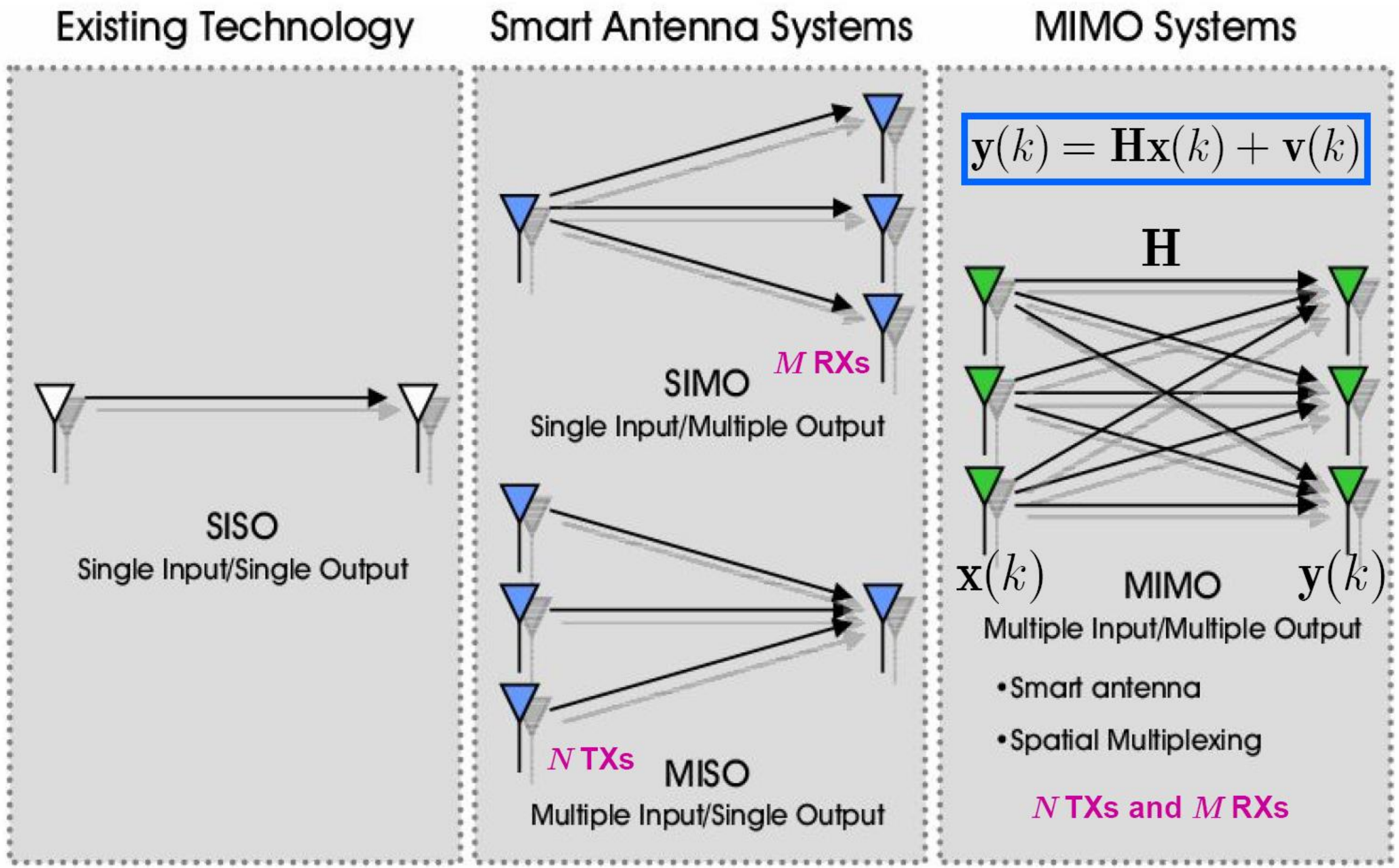


MIMO Beamforming

- Memperbaiki penerimaan sinyal melalui directional array gain.
- Memperbesar cell coverage
- Menekan interference pada space domain
- Memperbesar kapasitas sistem
- Memperpanjang usia battery
- Menyediakan informasi angular untuk user tracking

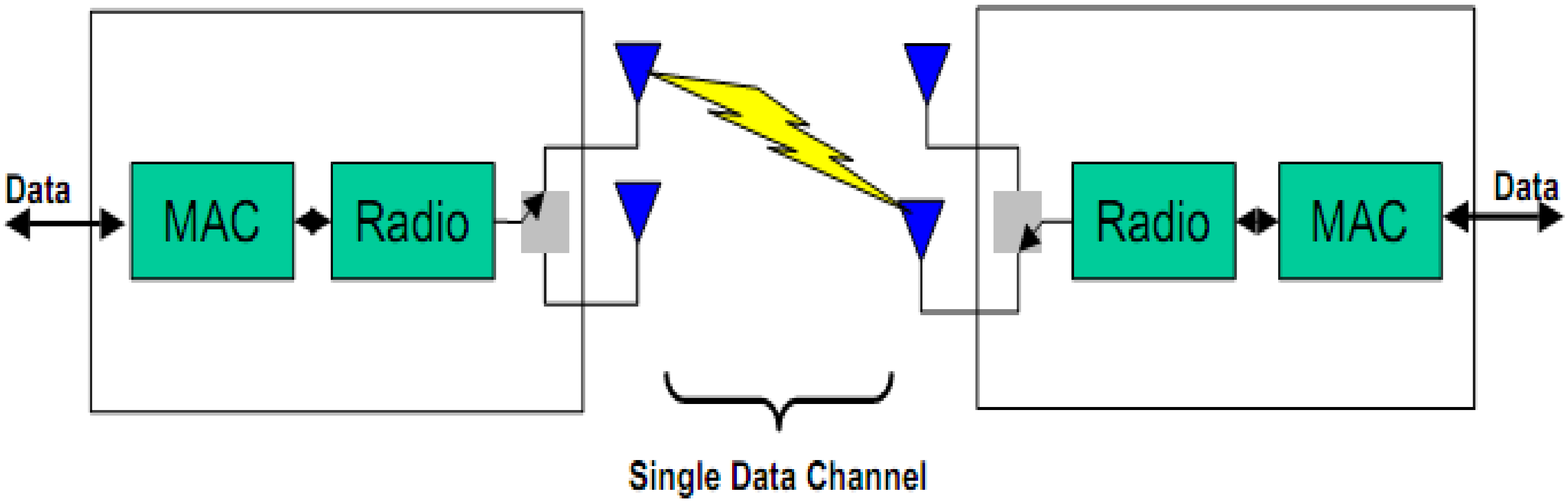


Multiple Antenna Technique: Four Basic Model



What is SISO?
Single-Input Single-Output

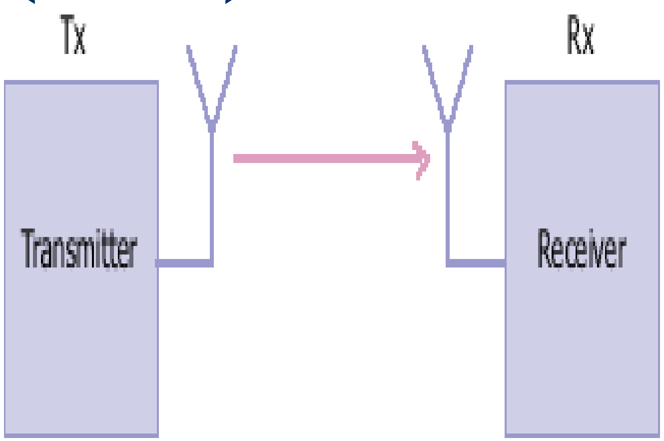
Traditional – SISO Architecture



- 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).

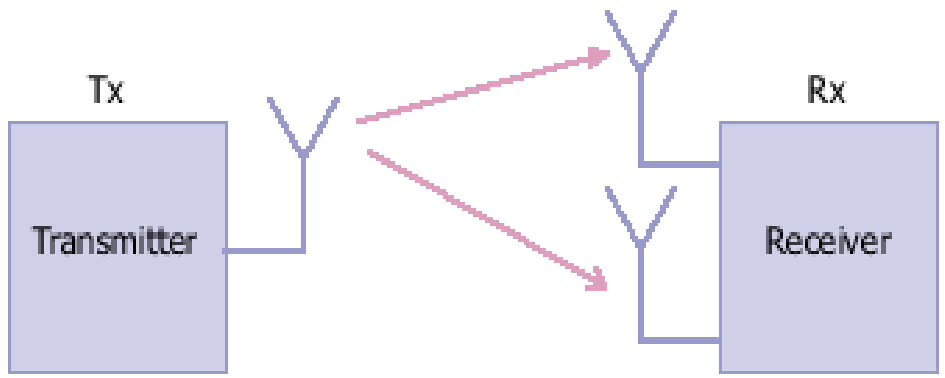


Picture. Single Input Single Output (SISO)
One antenna at both the transmitter and the receiver.
Employs no diversity technique.

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).

SIMO

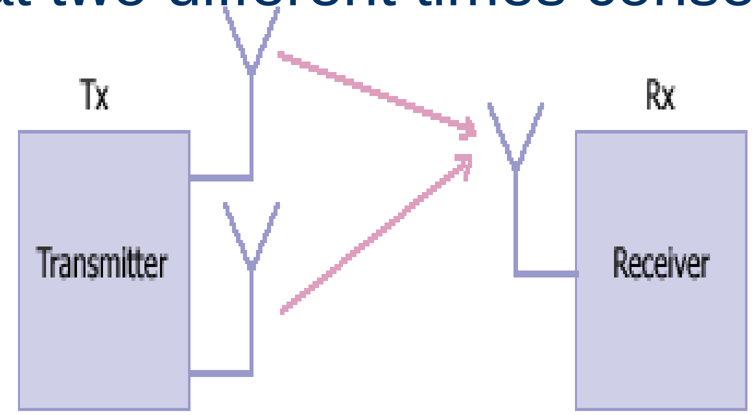
To improve performance, a multiple antenna technique has been developed. A system which uses a single antenna at the transmitter and multiple antennas at the receiver is named Single Input Multiple Output (SIMO). The receiver can either choose the best antenna to receive a stronger signal or combine 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.

MISO

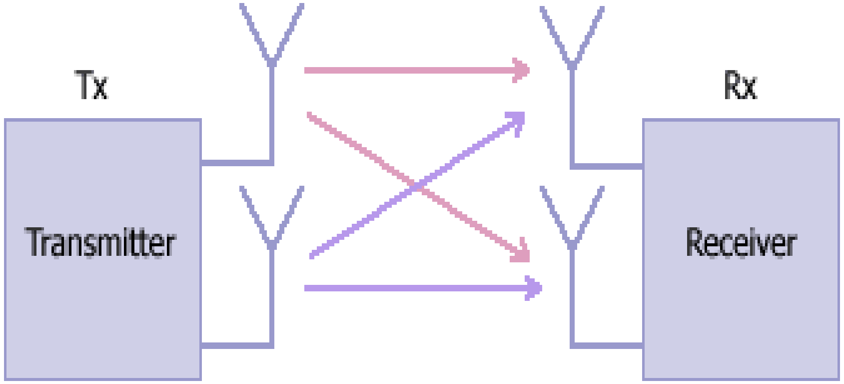
A system which uses multiple antennas at the transmitter and a single antenna at the receiver is named Multiple Input Single Output (MISO). A technique known as Alamouti STC (Space Time Coding) is employed at the transmitter with two antennas. STC allows the transmitter to transmit signals (information) 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.

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.

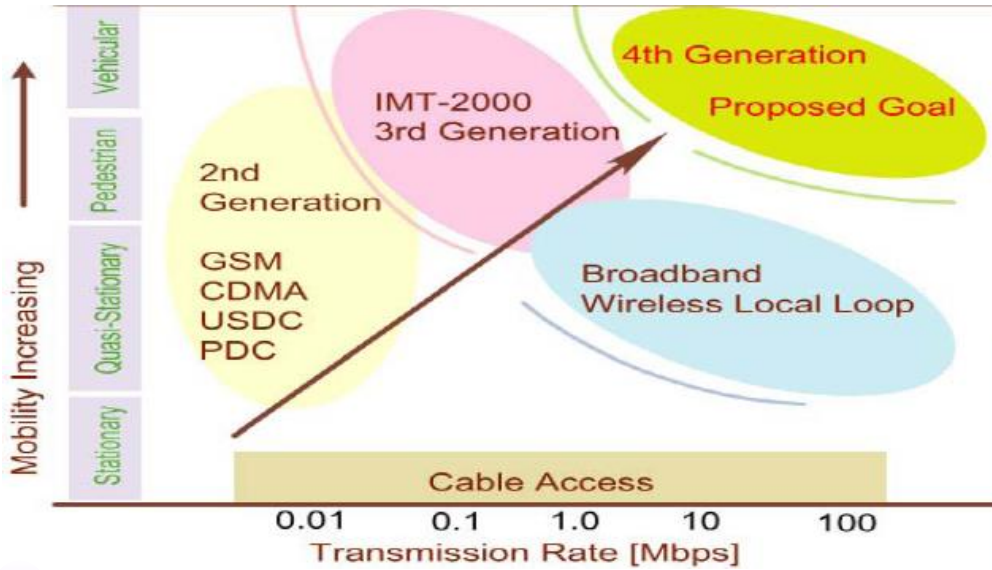


Picture. Multiple Input Multiple Output (MIMO), 2x2
Two antennas at both the transmitter and the receiver.

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

- **Objective : to support *private and public access***
  - **high data rate transmission**
  - **high mobility**
  - **High signal performance**



Selective fading
Costly to estimate
the channel accurately
Performance degradation
Multi users

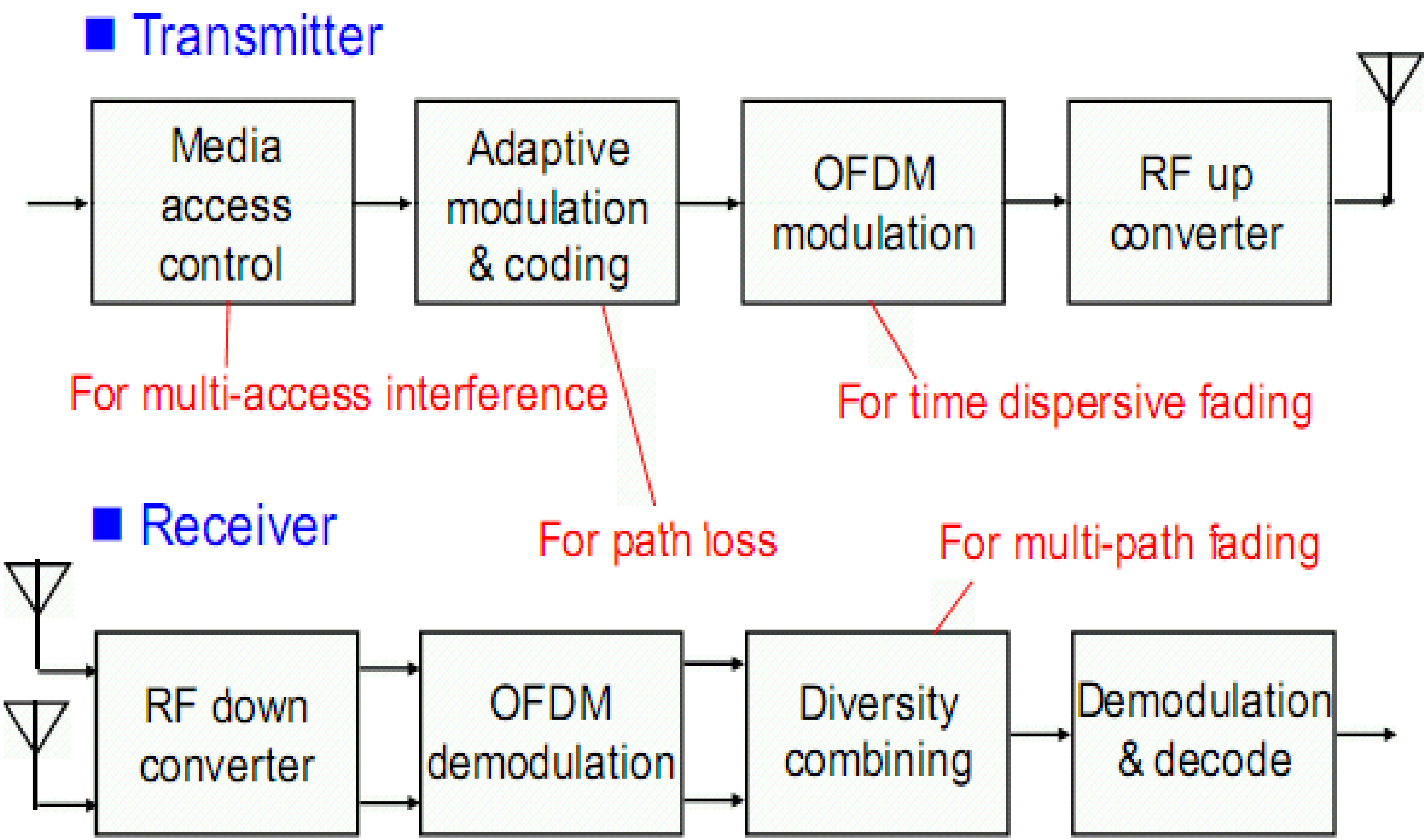
New transmission techniques

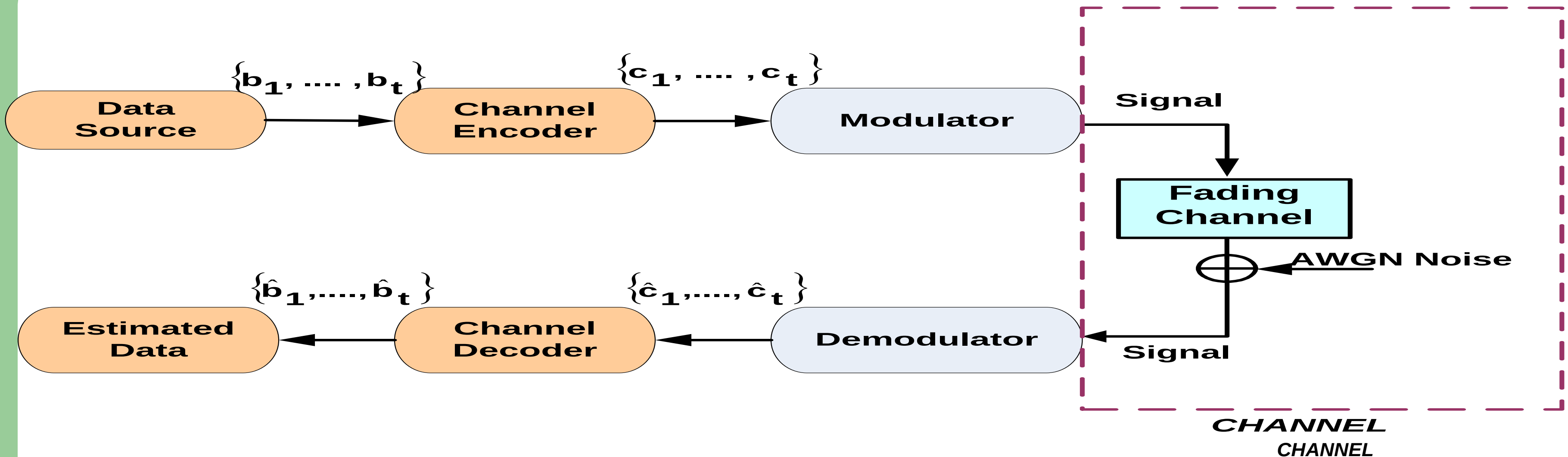
Problems

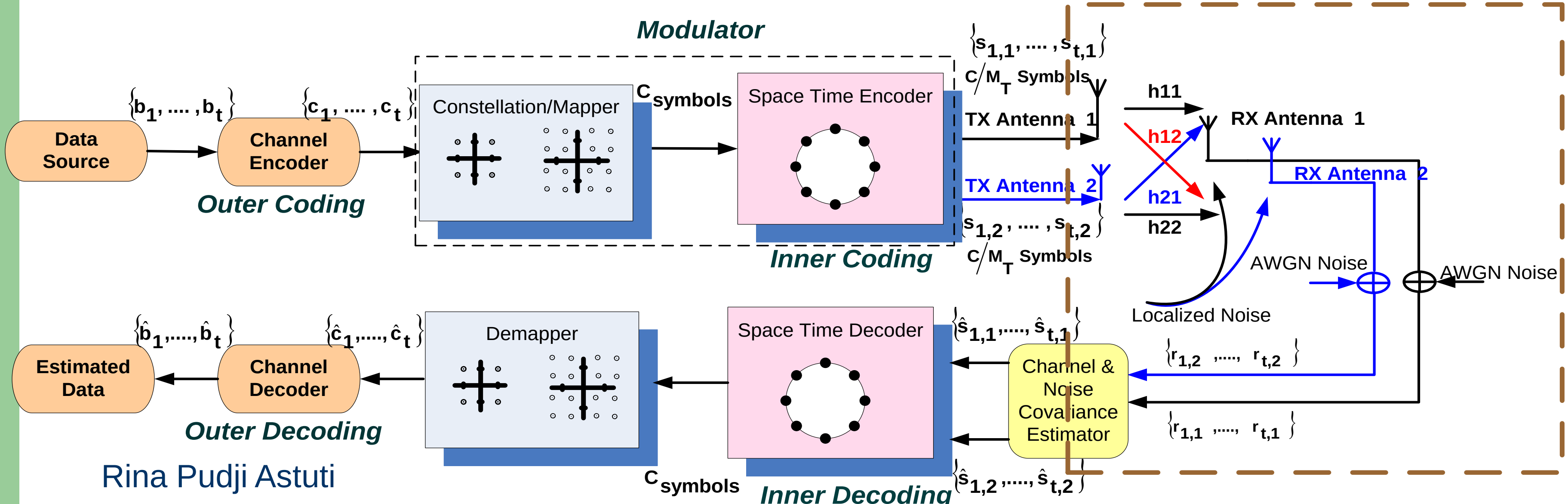
Multiple antennas & multi-carrier techniques
Non coherent transmission scheme
Coding techniques
Multiple access

Examples :
OFDM, Coded OFDM, OFCDM, MC-CDMA
Differential modulation
outer & *inner coding*
FDMA, TDMA, CDMA

Modern Wireless Transceiver

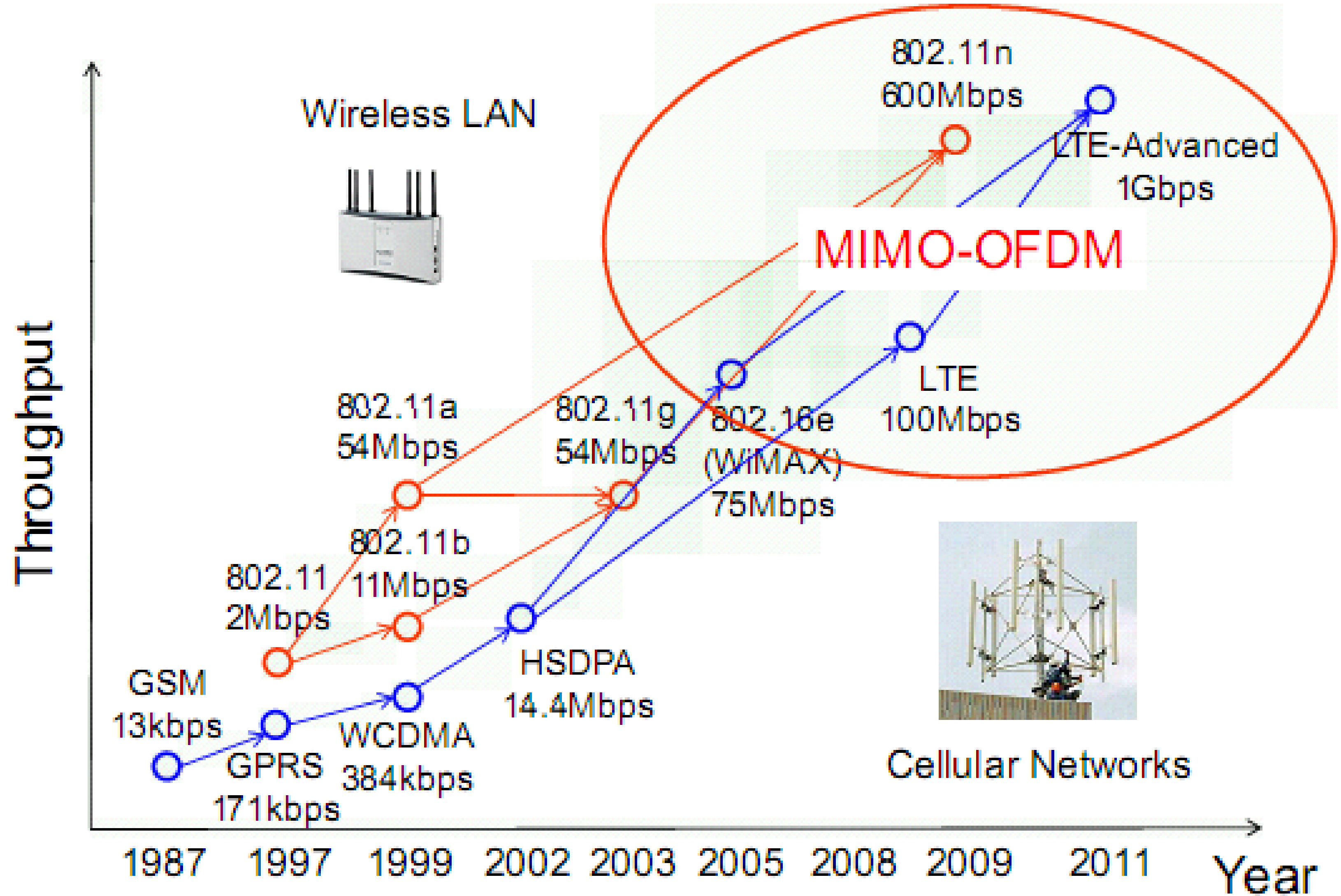






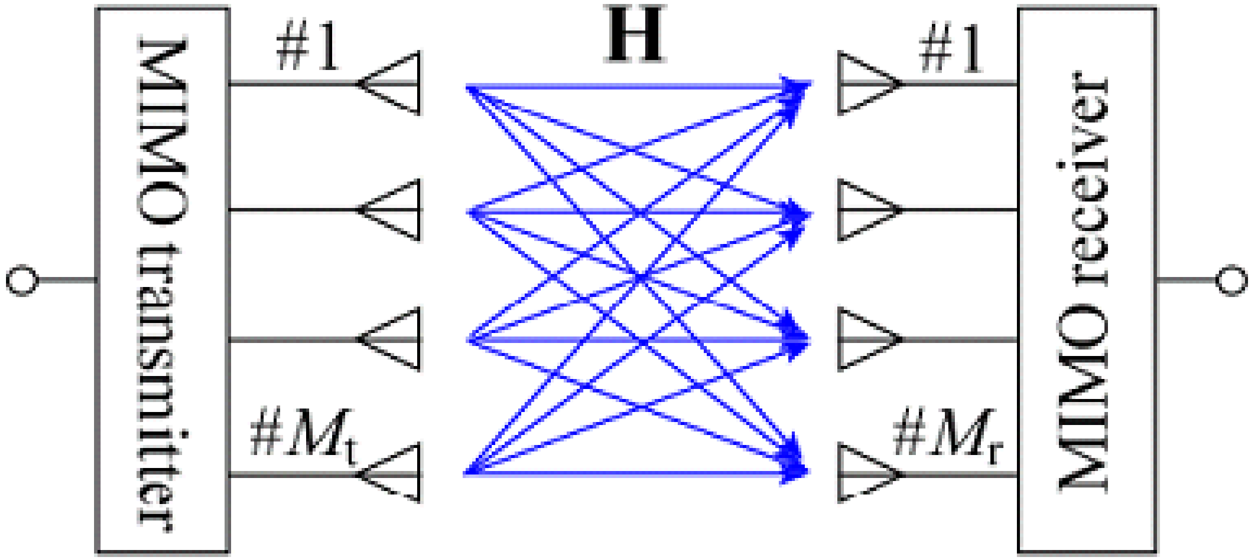
Rina Pudji Astuti

Innovation of Wireless Systems

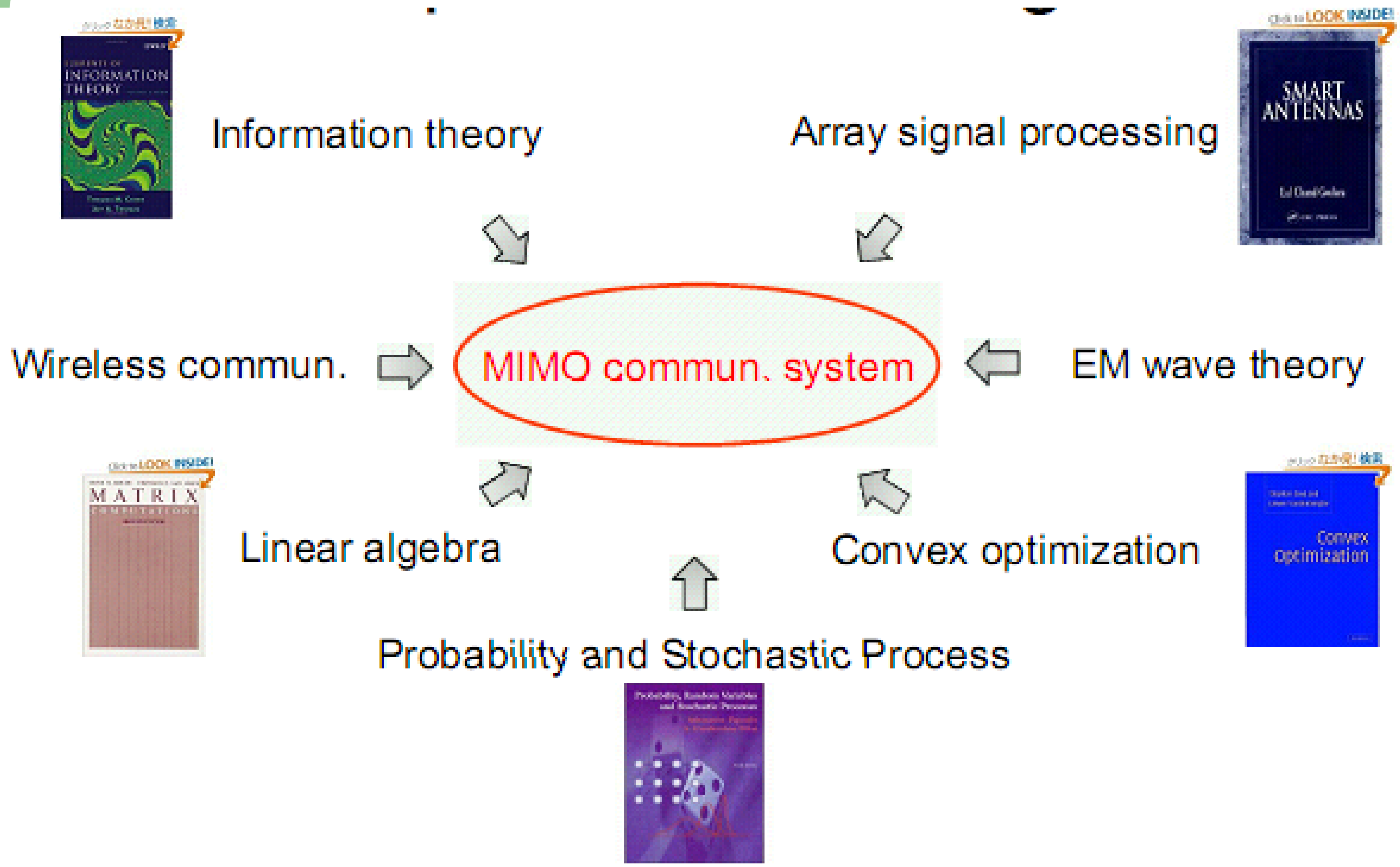


What is MIMO ?

- Multiple antennas both at transmitter & receiver (MIMO)
- Different information streams are spatially multiplexed at the same time and same frequency
- Channel capacity of MIMO system increases linearly with respect to the number of antennas
- Benefits of MIMO are throughput & area coverage enhancement

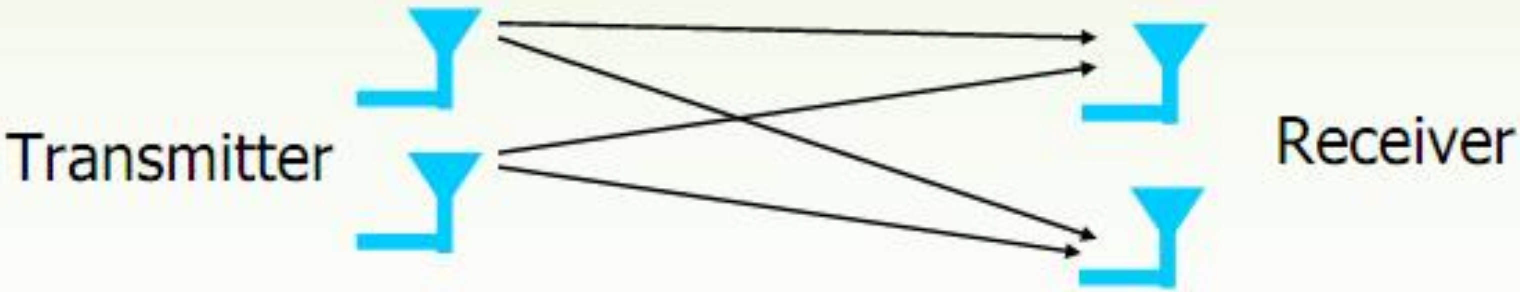


Required Knowledge



MIMO Defined

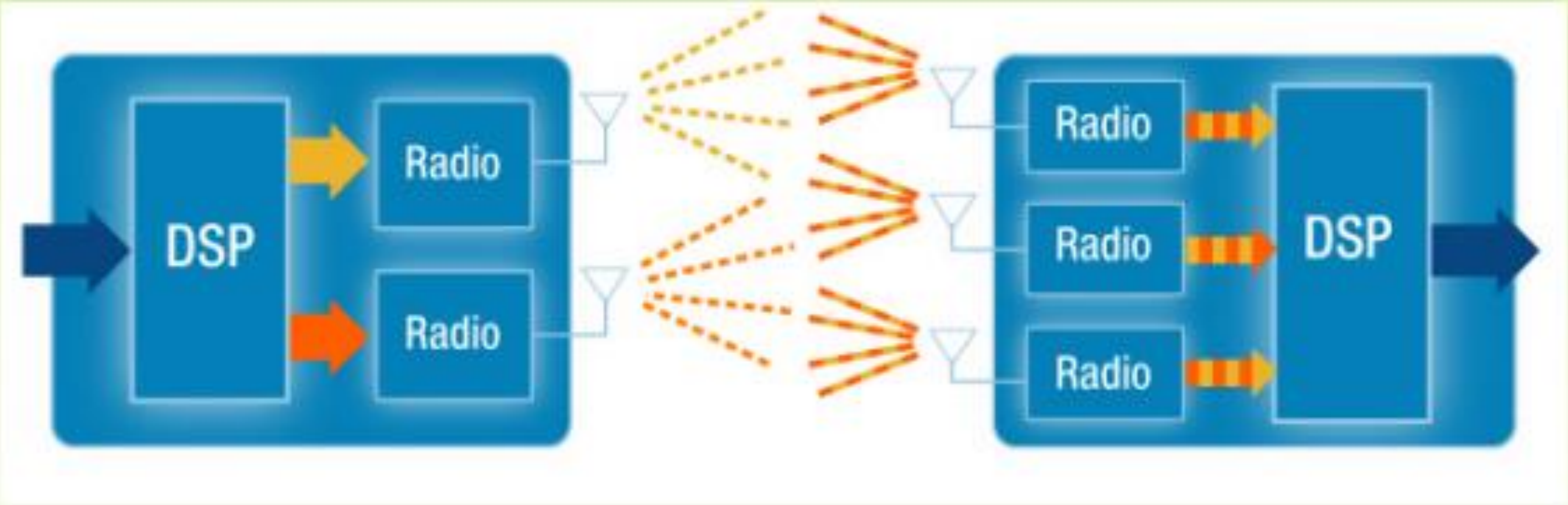
- MIMO is an acronym that stands for **M**ultiple **I**nput **M**ultiple **O**utput.
- It is an antenna technology that is used both in transmission and receiver equipment for wireless radio communication.
- There can be various MIMO configurations. For example, a 2x2 MIMO configuration is 2 antennas to transmit signals (from base station) and 2 antennas to receive signals (mobile terminal).



How MIMO Works

- MIMO takes advantage of multi-path.
- MIMO uses multiple antennas to send multiple parallel signals (from transmitter).
- In an urban environment, these signals will bounce off trees, buildings, etc. and continue on their way to their destination (the receiver) but in different directions.
- "Multi-path" occurs when the different signals arrive at the receiver at various times.
- With MIMO, the receiving end uses an algorithm or special signal processing to sort out the multiple signals to produce one signal that has the originally transmitted data.

How MIMO Works (cont.)

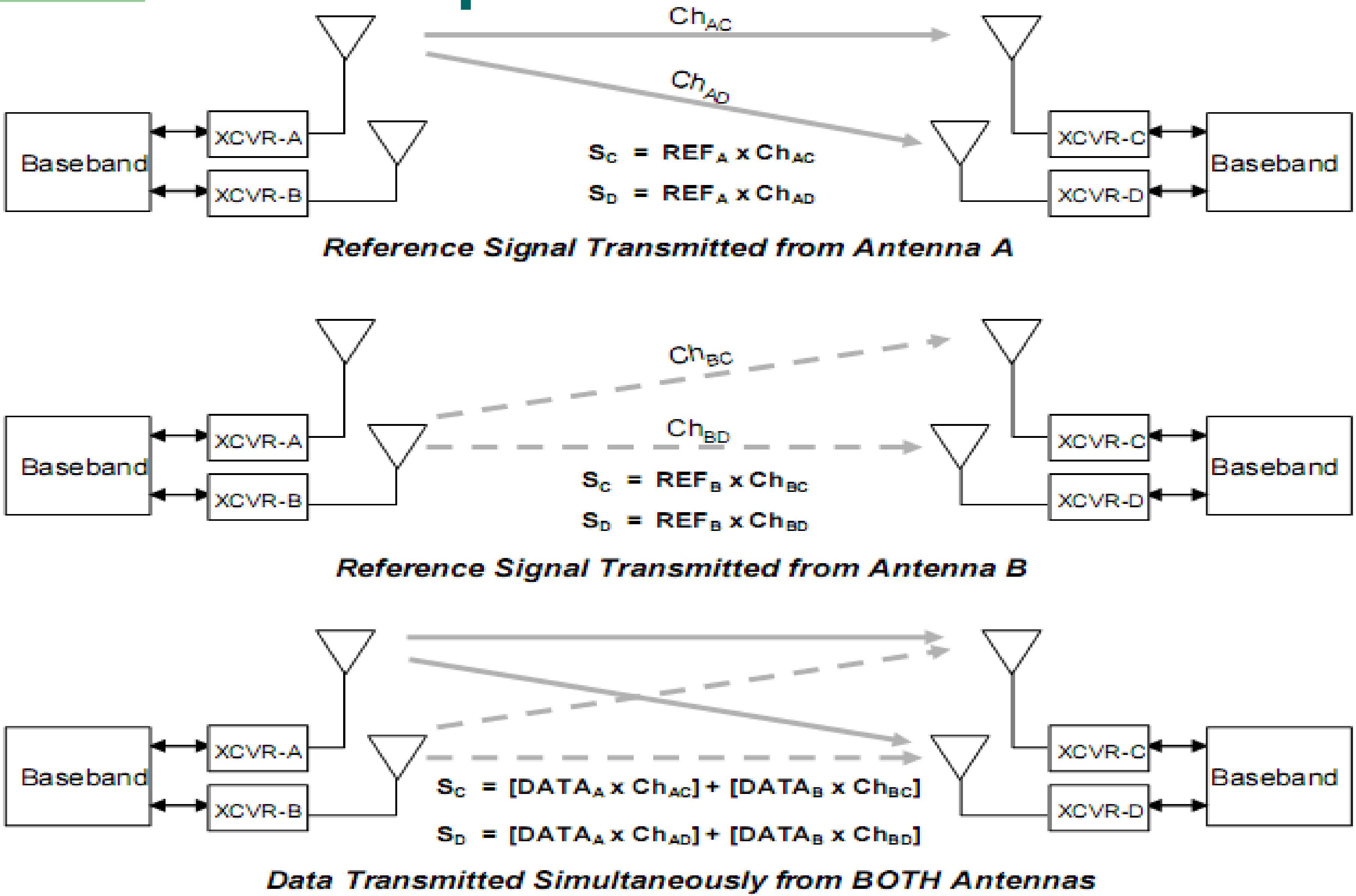


Multiple data streams transmitted in a single channel at the same time

Multiple radios collect multipath signals

Delivers simultaneous speed, coverage, and reliability improvements

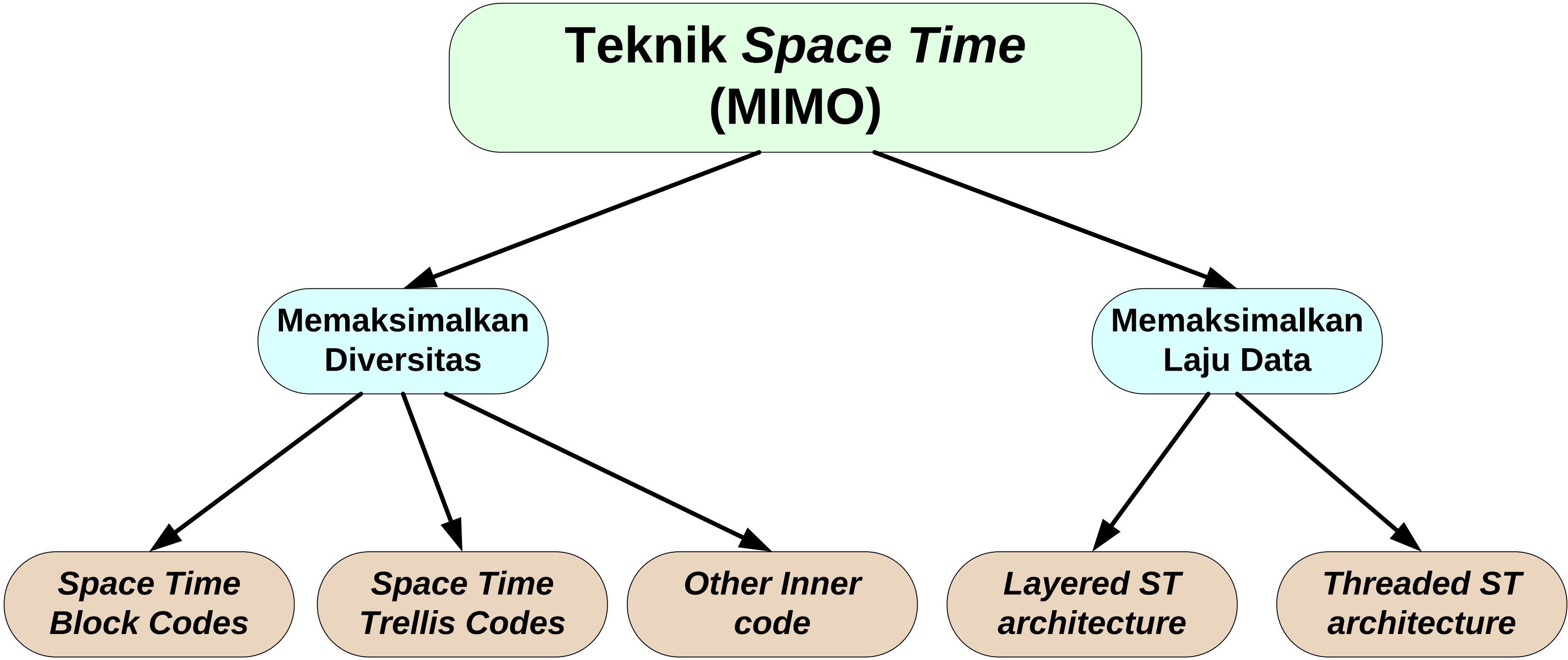
MIMO Operation



Types of MIMO

- MIMO involves Space Time Transmit Diversity (STTD), Spatial Multiplexing (SM) and Uplink Collaborative MIMO.
- ***Space Time Transmit Diversity (STTD)*** - The same data is coded and transmitted through different antennas, which effectively doubles the power in the channel. This improves Signal Noise Ratio (SNR) for cell edge performance.
- ***Spatial Multiplexing (SM)*** - the "Secret Sauce" of MIMO. SM delivers parallel streams of data to CPE by exploiting multi-path. It can double (2x2 MIMO) or quadruple (4x4) capacity and throughput. SM gives higher capacity when RF conditions are favorable and users are closer to the BTS.
- ***Uplink Collaborative MIMO Link*** - Leverages conventional single Power Amplifier (PA) at device. Two devices can collaboratively transmit on the same sub-channel which can also double uplink capacity.

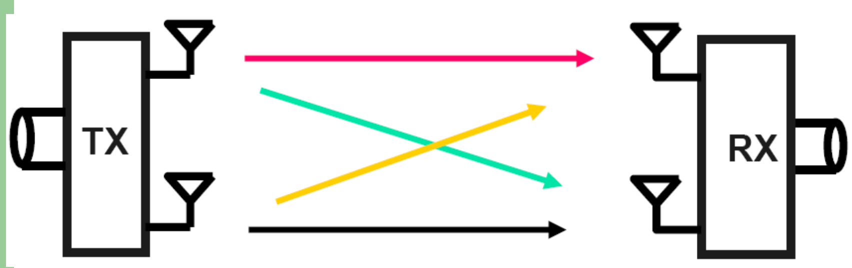
Macam-2 Teknik Space Time

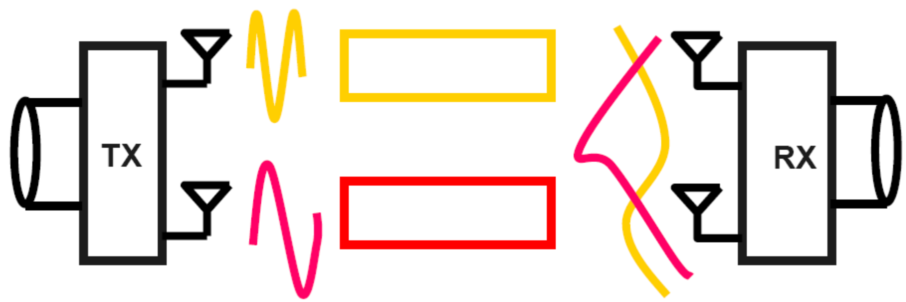


→ **performance-rate complexity tradeoffs**

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

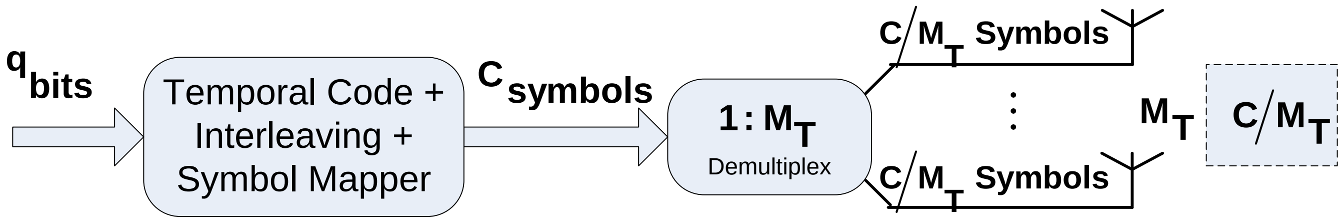
- Spatial multiplexing yields substantial increase spectral efficiency

Spatial Diversity and Spatial Multiplexing

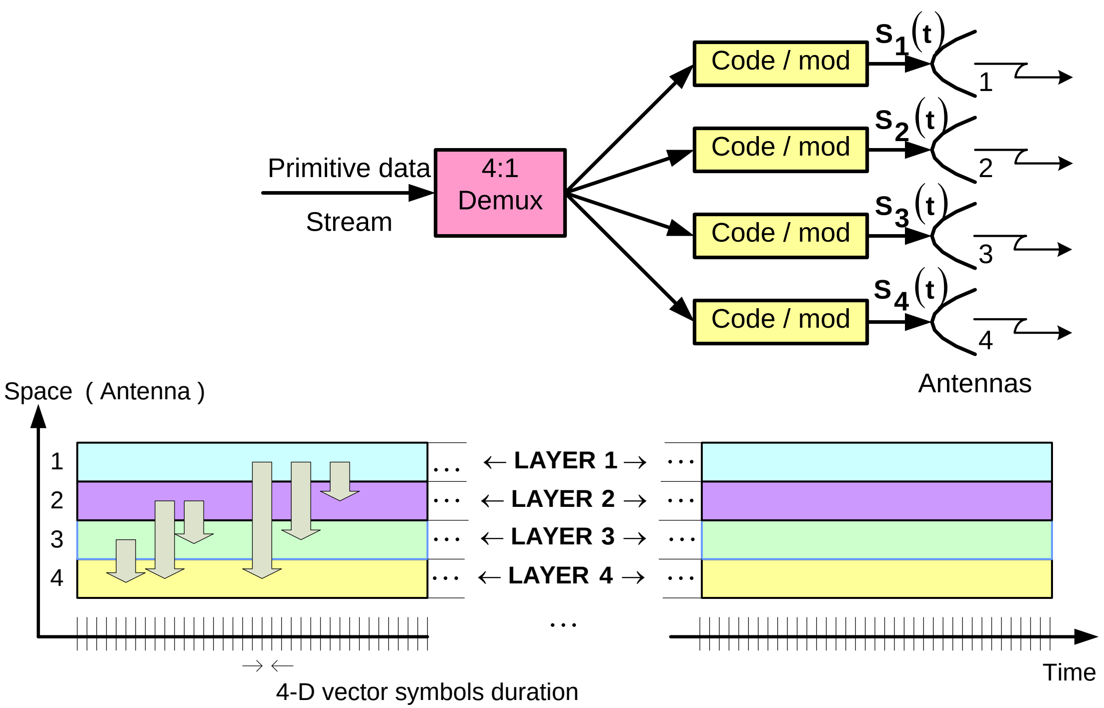
- Spatial Diversity
  - Signal copies are transferred from multiple antennas or received at more than one antenna
  - redundancy is provided by employing an array of antennas, with a minimum separation of $\lambda/2$ between neighbouring antennas
- Spatial Multiplexing
  - the system is able to carry more than one data stream over one frequency, simultaneously

Spatial Multiplexing
Maximize Data Rate (rate oriented)

- MIMO dengan Skema *Vertical Encoding*

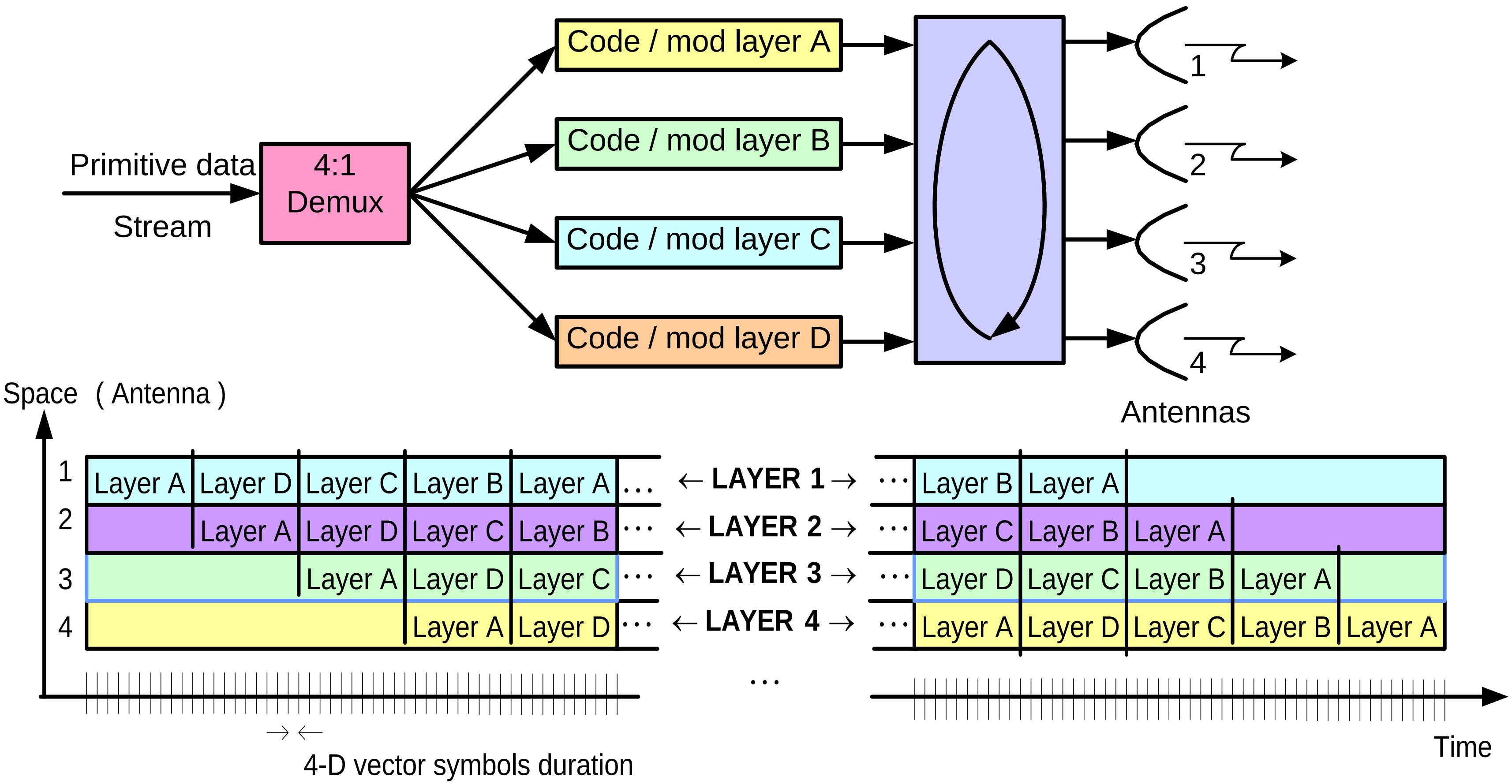


- MIMO dengan Skema *Horizontal Encoding*



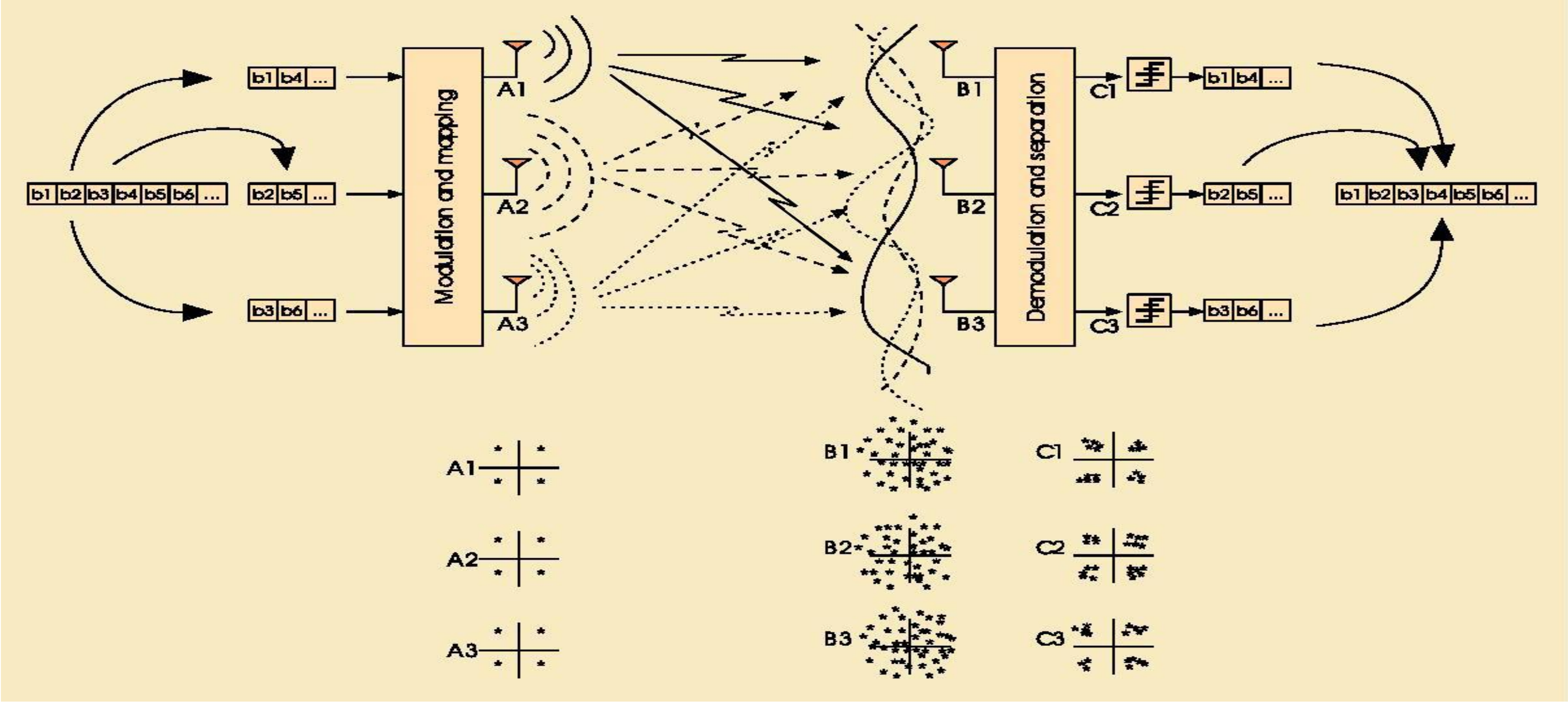
Spatial Multiplexing

- MIMO dengan Skema *Diagonal Encoding*



Spatial Multiplexing

- MIMO channels can be decomposed into a number of R parallel independent channels → Multiplexing Gain
  - Principle: Transmit independent data signals from different antennas to increase the throughput, capacity.



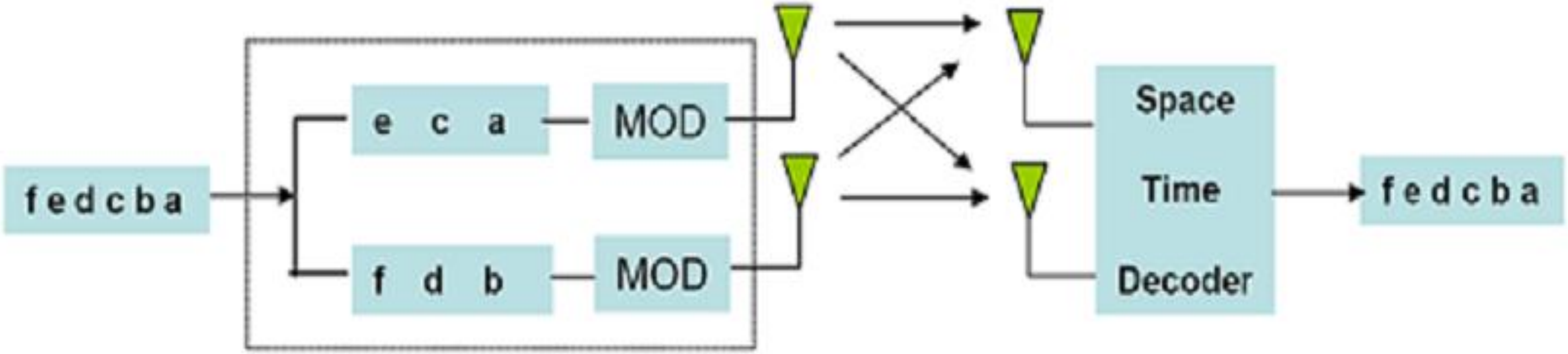
Source: An Overview of MIMO Systems in Wireless Communications

www.iet.ntnu.no/projects/beats/Documents/mimo.pdf

Spatial Multiplexing

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

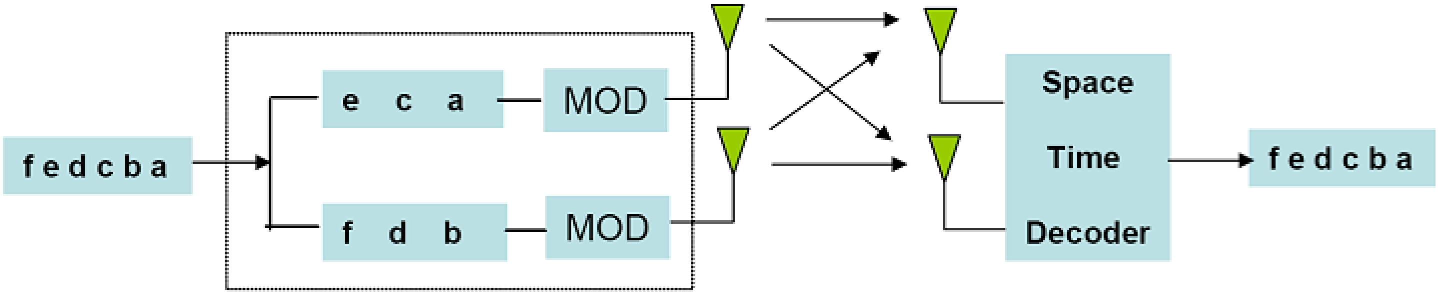
Prinsip kerja dari *spatial multiplexing* adalah mengirim sinyal dari dua atau lebih antenna yang berbeda dengan beberapa aliran data dan aliran data dipisahkan dipenerima dengan proses *signal processing*, oleh karena itu peningkatan *bit rate* berdasarkan konfigurasi antenna mimo (2 untuk antenna mimo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



Spatial Multiplexing

MIMO Multiplexing

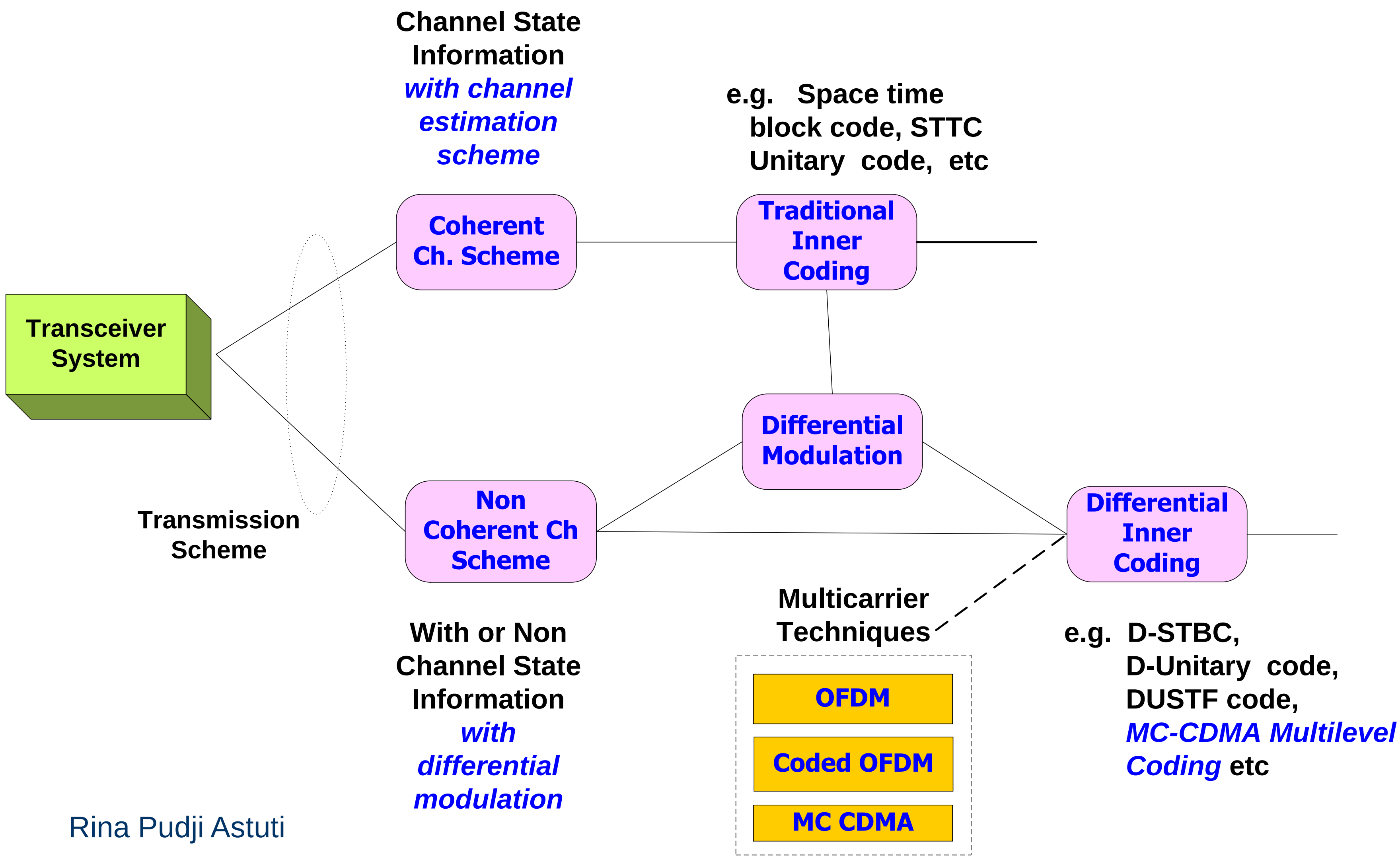
- Data is not redundant – less diversity but less repetition
- Provides multiplexing gain to increase data-rate
- Low (no) diversity compared with STC



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

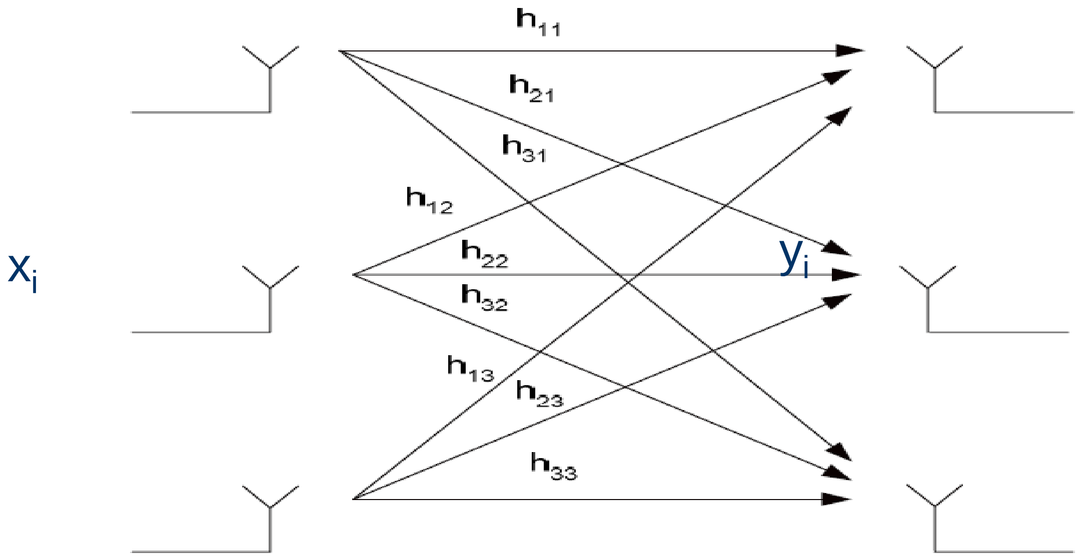
Maximize Diversity Transmission Scheme

(performance oriented) in MIMO Wireless Systems



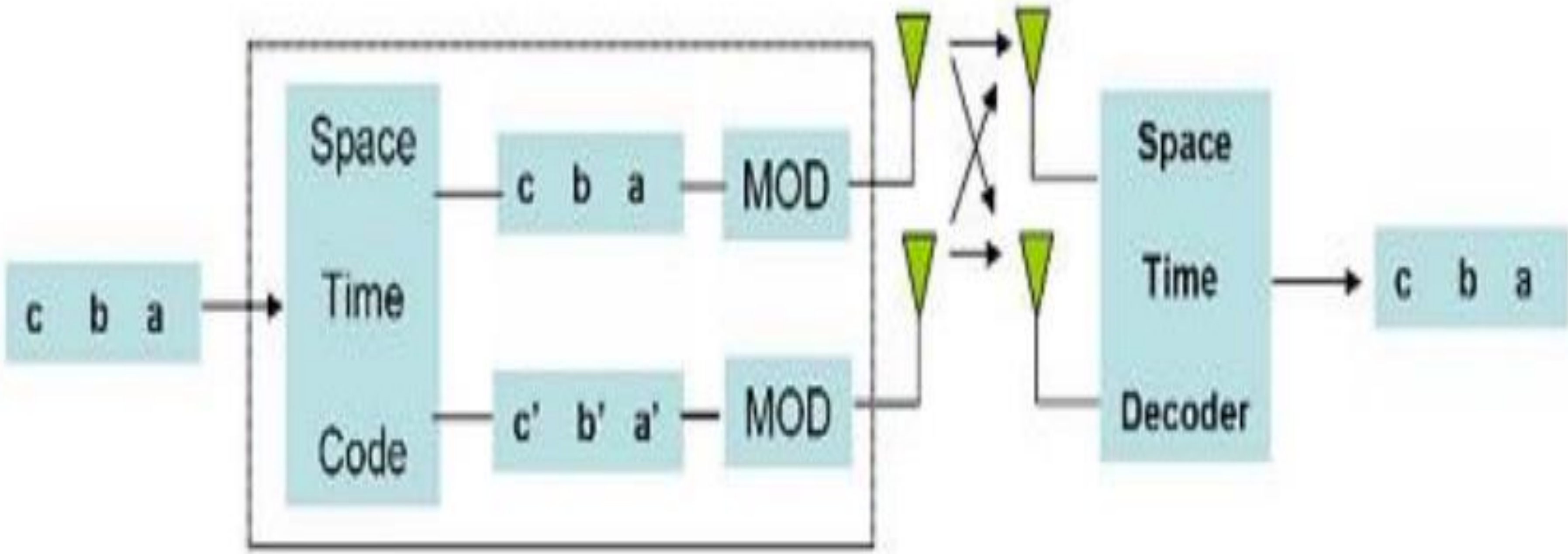
Spatial Diversity

- Improves the signal quality and achieves a higher SNR at the receiver-side
- Principle of diversity relies on the transmission of structured redundancy



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.

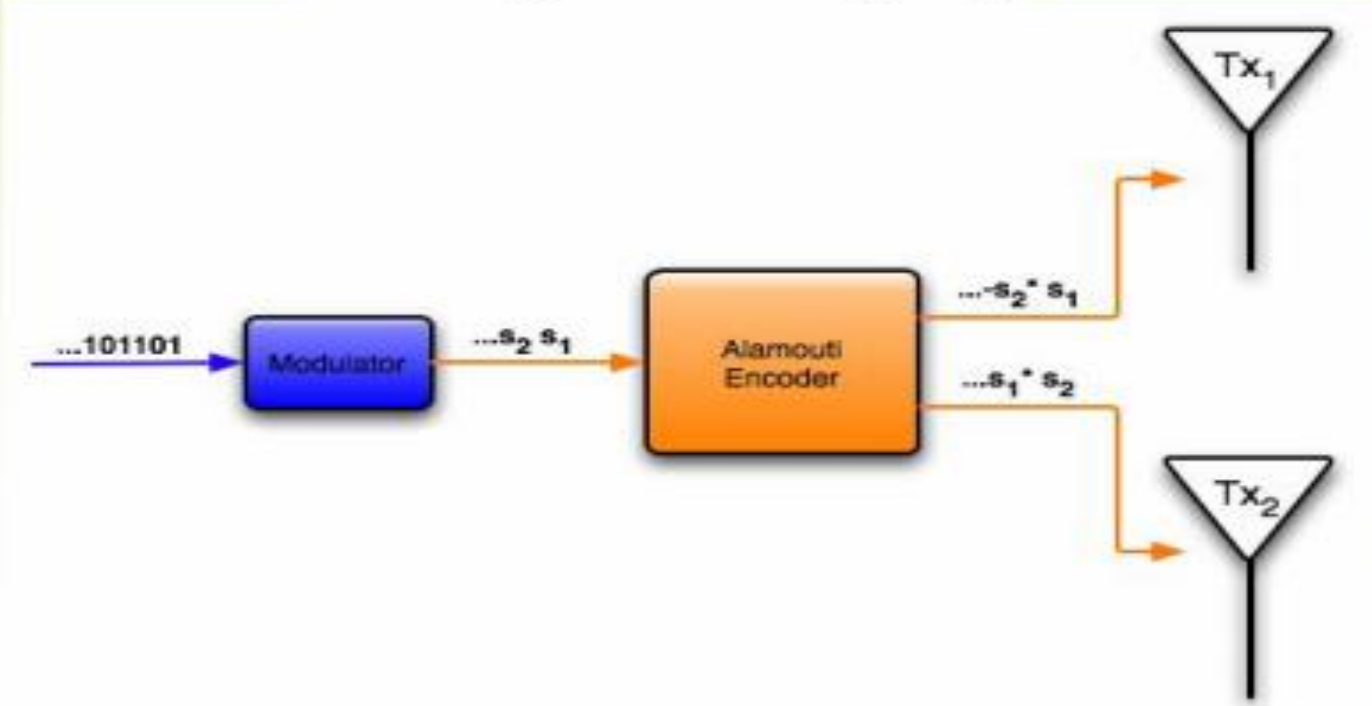


Space-Time Transmit Diversity

Alamouti Code

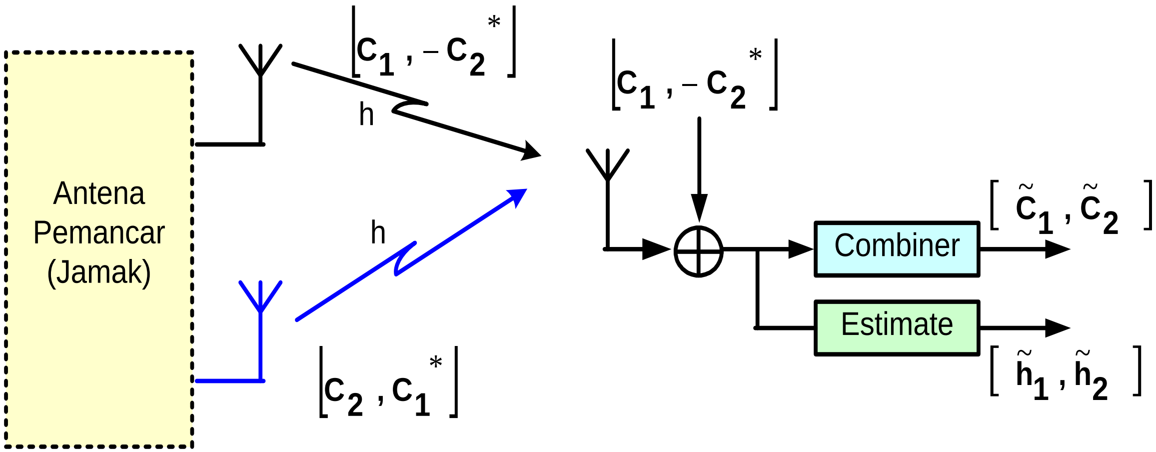
time

$$X = \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix}$$ space



Space Time Coding

- ***Space Time Block Code* (STBC) [Alamouti1998]**



virtual MIMO matrix

$$H = \begin{bmatrix} h_1^* & -h_2 \\ h_2^* & h_1 \end{bmatrix}$$

$$\mathbf{y} = \mathbf{H}.\mathbf{c} + \mathbf{n}$$

$$\mathbf{y} = \begin{bmatrix} y_1 & -y_2^* \end{bmatrix}$$

$$\mathbf{c} = [c_1 \quad c_2]^T$$

- **At the Receivers, after demodulator :**

$$[\tilde{c}_1 \quad \tilde{c}_2] = \begin{bmatrix} h_1^* & -h_2 \\ h_2^* & h_1 \end{bmatrix} \begin{bmatrix} y_1 \\ -y_2^* \end{bmatrix}$$

$$= \begin{bmatrix} \left(|h_1|^2 + |h_2|^2\right)c_1 + \underbrace{h_1^* n_1 + h_2 n_2^*}_{n_1'} & \left(|h_1|^2 + |h_2|^2\right)c_2 + \underbrace{h_1 n_2^* + h_2^* n}_{n_2'} \end{bmatrix}$$

dual diversity $\quad g = \left(|h_1|^2 + |h_2|^2\right)$

Space Time Coding

- ***Space Time Block Code* (STBC) [Tarokh1999]**
- **Alamouti Model, 2 Tx antennas and 2 Rx**
- **At the Receivers, after demodulator :**

$$\begin{bmatrix}\tilde{c}_1 & \tilde{c}_2\end{bmatrix} = \begin{bmatrix} h_1^* & -h_2 \\ h_2^* & h_1 \end{bmatrix}\begin{bmatrix} y_1 \\ -y_2^* \end{bmatrix} + \begin{bmatrix} h_3^* & -h_4 \\ h_4^* & h_3 \end{bmatrix}\begin{bmatrix} y_3 \\ -y_4^* \end{bmatrix}$$

$$= \left(|h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2\right)c_1 + \underbrace{h_1^* n_1 + h_2 n_2^* + h_3^* n_3 + h_4 n_4^*}_{n_1^*}$$

$$+ \left(|h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2\right)c_2 + \underbrace{h_1 n_2^* + h_2^* n_1 + h_3^* n_3 + h_4 n_4^*}_{n_2^*}$$

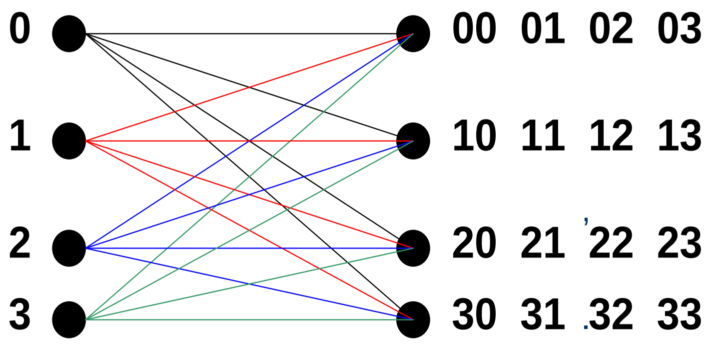
$$\tilde{\mathbf{c}} = g.\mathbf{c} + n'$$

- ***Quadruple diversity***

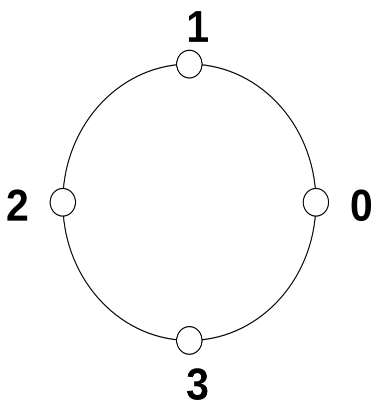
$$g = \left(|h_1|^2 + |h_2|^2 + |h_3|^2 + |h_4|^2\right)$$

Space Time Coding

- ***Space Time Trellis Code* (STTC)** [Tarokh1998]
  - 2 – space time code, 4 PSK, 4 – state, 2 b/s/Hz



Input : 02321103
Tx1 : 00232110
Tx2 : 02321103



Deretan bit masukan $\mathbf{d}^1 = \left(d_k^1, d_k^1, \cdots, d_k^1, \cdots\right)$ $\mathbf{d}^2 = \left(d_k^2, d_k^2, \cdots, d_k^2, \cdots\right)$

Derajat memory: v_2 dan v_1 dengan $v = v_1 + v_2$ sehingga jumlah state $2^v = 4$

Pasangan koefisien pengkode:

$$\mathbf{g}^1 = \left[\left(g_{0,1}^1, g_{0,2}^1\right), \left(g_{1,1}^1, g_{1,2}^1\right), \cdots \left(g_{v_1,1}^1, g_{v_1,2}^1\right)\right]$$

$$\mathbf{g}^2 = \left[\left(g_{0,1}^2, g_{0,2}^2\right), \left(g_{1,1}^2, g_{1,2}^2\right), \cdots \left(g_{v_1,1}^2, g_{v_1,2}^2\right)\right]$$

dimana. $g_{i,l}^j \in \{0,1,2,3\}$

KeluaranSTTC: $s_l(k) = \sum_{j=1}^{2} \sum_{i=0}^{v_j} g_{i,l}^j d_{k-i}^j \bmod 4$ dengan $l = 1,2$

Space Time Coding

- Aliran bit masukan, *d* : $\mathbf{d} = \left(\mathbf{d}_0, \mathbf{d}_1, \cdots, \mathbf{d}_k, \cdots\right)$ merupakan masukan sebuah modulasi M-PSK yang difungsikan sebagai pemeta simbol(mapper), dimana

$$\mathbf{d}_k = \left(d_k^1, d_k^2, \cdots, d_k^m\right)^T$$

- Pengkode STTC yang terdiri dari *m* feedforward shift register akan memetakan deretan bit masukan menjadi himpunan sinyal M-PSK.
- Deretan bit masukan ke *k,* dimasukkan ke shift register ke *k* dan dikalikan dengan sebuah himpunan koefisien pengkode, berupa himpunan konstelasi M-PSK. Keluaran pengkode pada saat *k*, berupa sinyal v_k-sinyal termodulasi membentuk simbol berbasis ruang-waktu (space time symbol), dapat dinyatakan sebagai berikut:

$$\mathbf{s}_k = \left(s_1(k), s_1(k), \cdots, s_{M_T}(k)\right)^T$$

$$s_l(k) = \sum_{j=1}^{m} \sum_{i=0}^{v_j} g_{i,l}^j d_{k-i}^j \bmod M$$

M_T adalah jumlah antena pemancar

$g_{i,l}^j$ adalah elemen himpunan konstelasi M-PSK

v_k adalah derajat memori shift register ke *k*