MIMO for LTE

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Contents

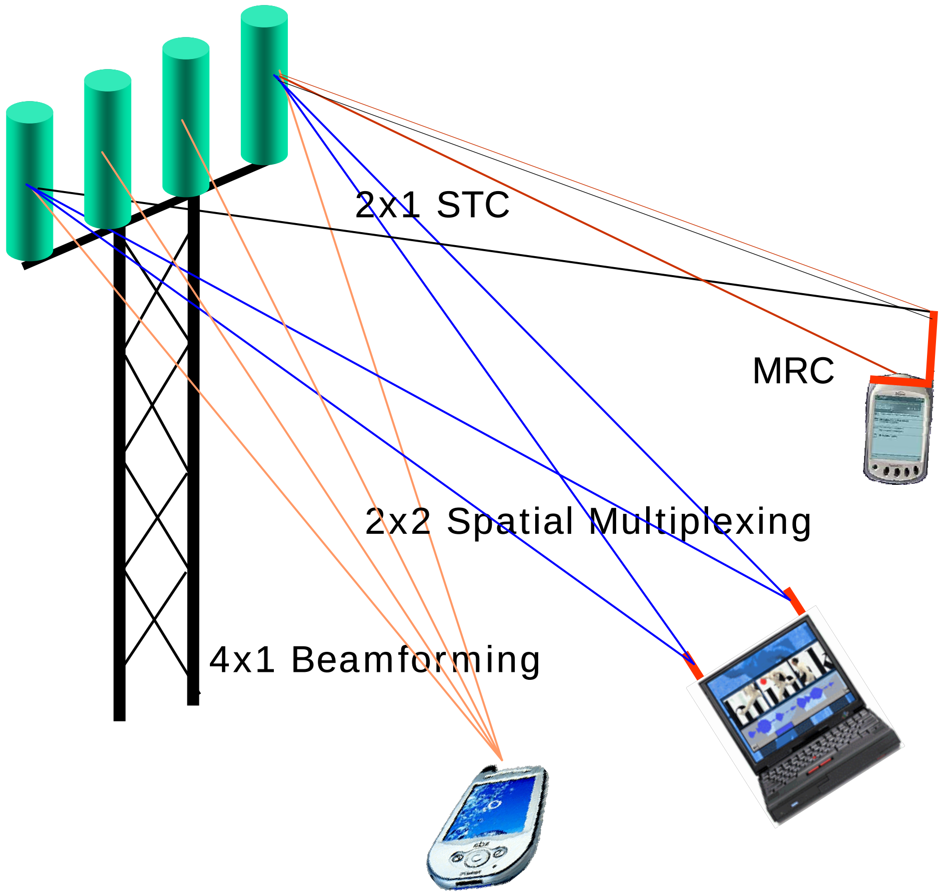
Antenna Technology

Antenna Technology

Too many terminologies...

- Smart Antenna Technology
- Multiple Antenna Technology
- MIMO (Multiple Input Multiple Output), SIMO, MISO, SISO
- Space Time Process
- Antenna Diversity
- Spatial Multiplexing
- Antenna Array
- Beam Forming
- AAS (Advanced Antenna System)
- Etc...

Smart Antennas

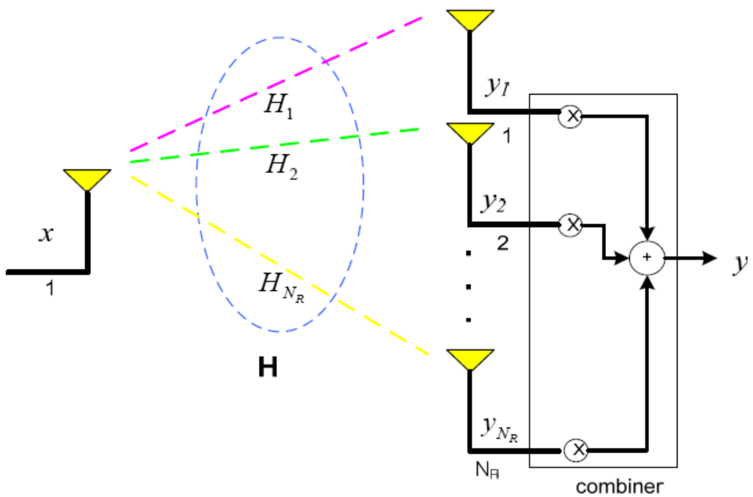


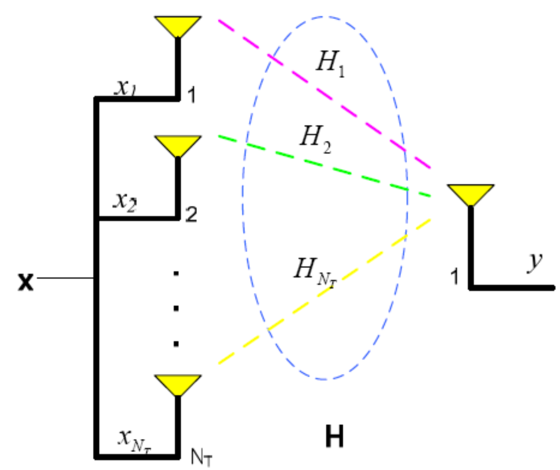
- Receive Spatial Diversity
  - Reduce fade margin, improve link budget
- Transmit Spatial Diversity
  - e.g. STC (Space-Time Coding)
- MIMO Spatial Multiplexing
  - Multiply capacity
- Beamforming (Adaptive Antenna Systems, AAS)
  - Improve link budget
  - Reduce interference

Smart antennas increase coverage and capacity & are key enablers of continued wireless advancement

SIMO and MISO

- SIMO
  - A single transmit antenna and N_R receive antennas
  - Receive Spatial (Antenna) Diversity
- MISO
  - N_T transmit antennas and a single receive antenna
  - Transmit Spatial (Antenna) Diversity

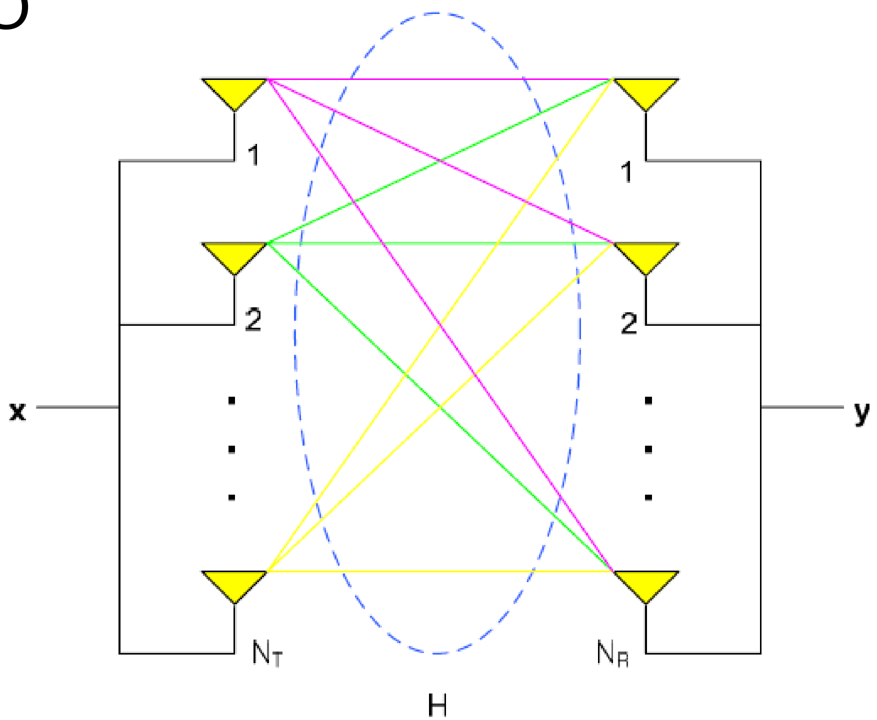




$$r = \mathbf{H}^T \mathbf{x} + n$$

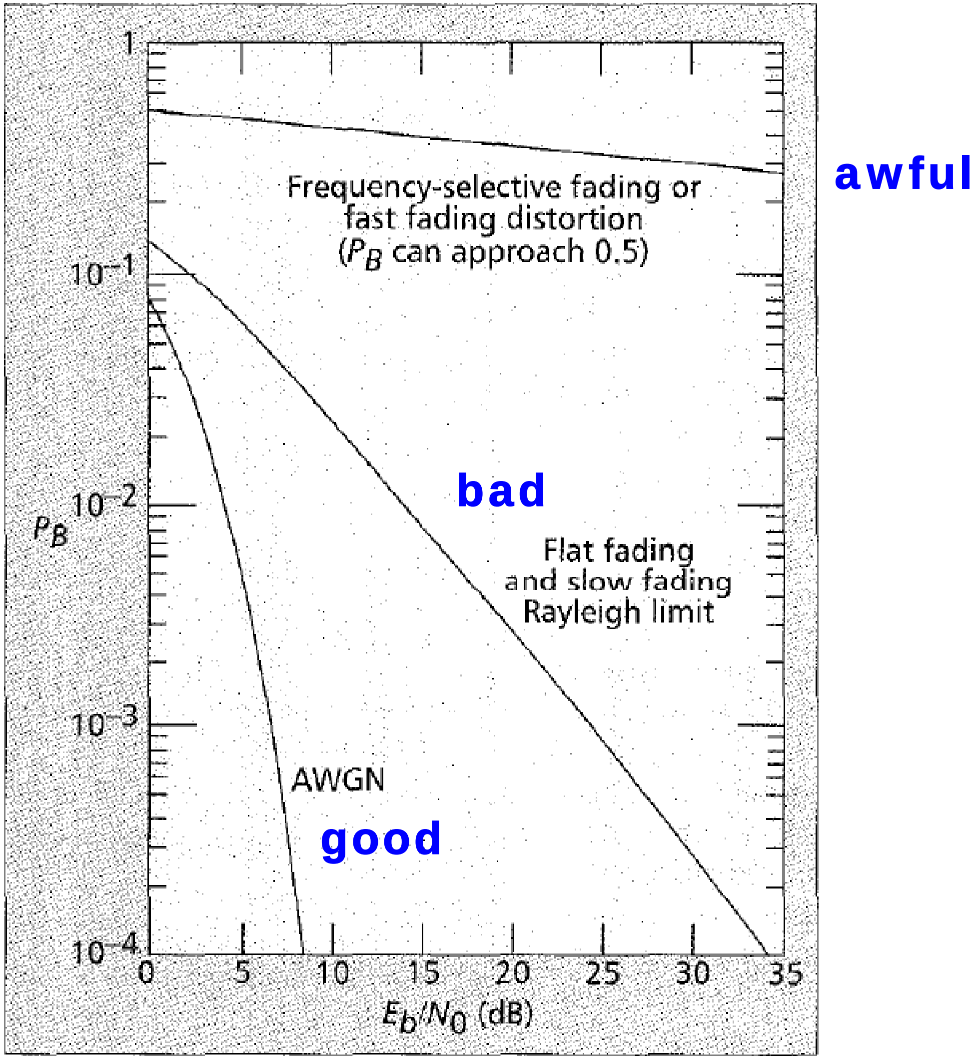
MIMO

- N_T transmit antennas and N_R receive antennas
- Diversity gain ~ $N_T N_R$
  Capacity ~ $\min(N_T, N_R)$
- Performance-oriented MIMO
  Data-rate-oriented MIMO



Space (Antenna) Diversity

Fading Channel Effect



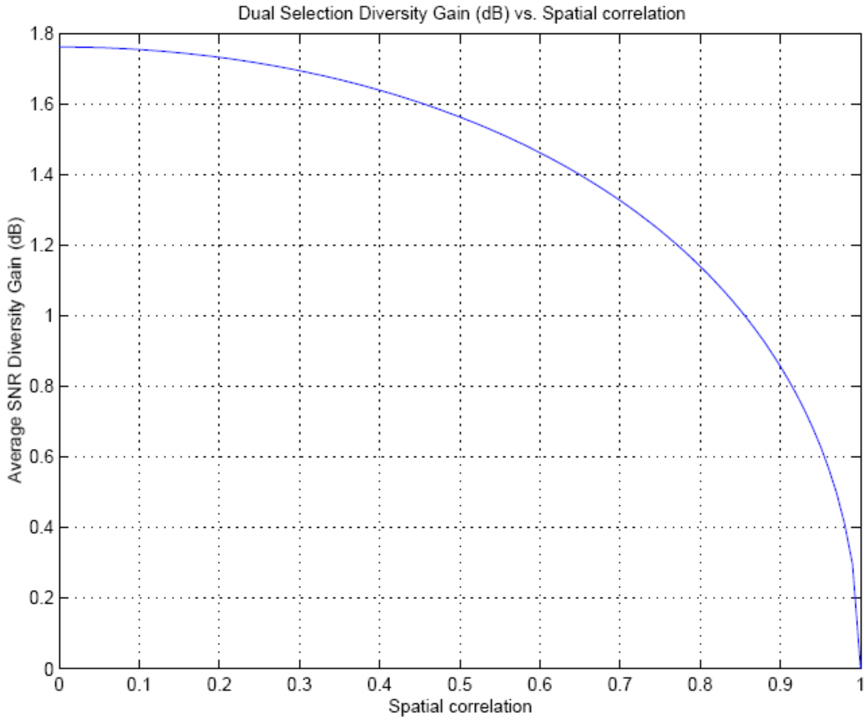
How can we reduce Fading effect?

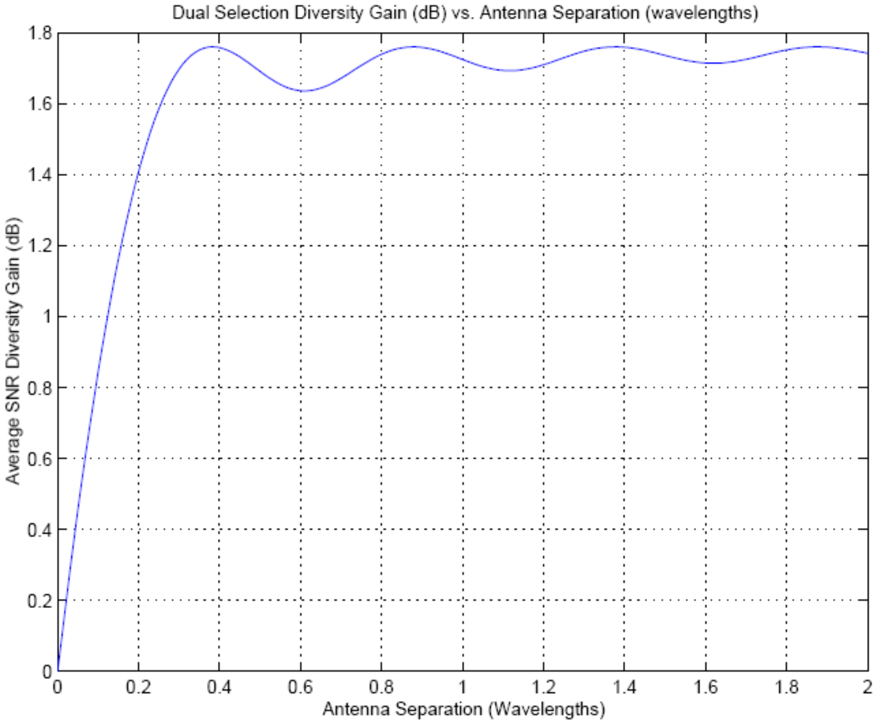
Diversity Can Do…

- Time Diversity
  - Channel coding (FEC) with interleaver, ARQ
- Frequency Diversity
  - Wideband system, Coded-OFDM
- Space Diversity
  - Multiple antennas with low correlation
- Polarization Diversity
  - Vertical & Horizontal

- Multiuser Diversity
  - Channel-aware scheduler
- Etc...

Antenna Diversity Gain



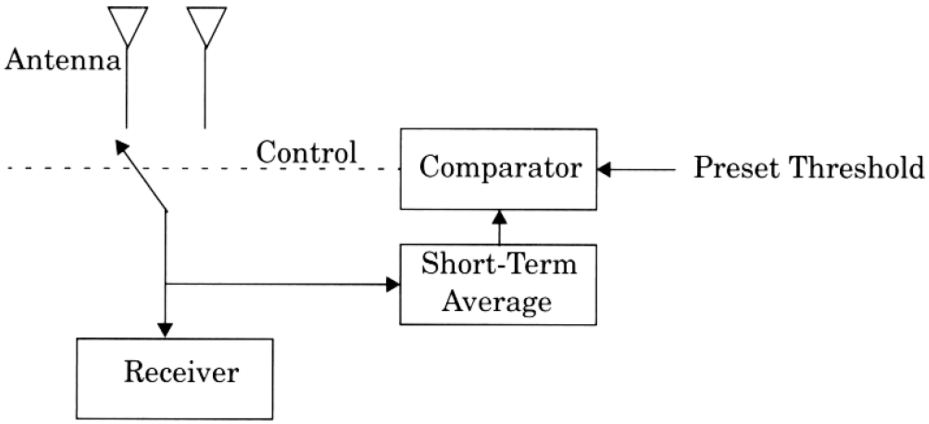


Diversity gain vs. Spatial correlation

Diversity gain vs. Antenna separation

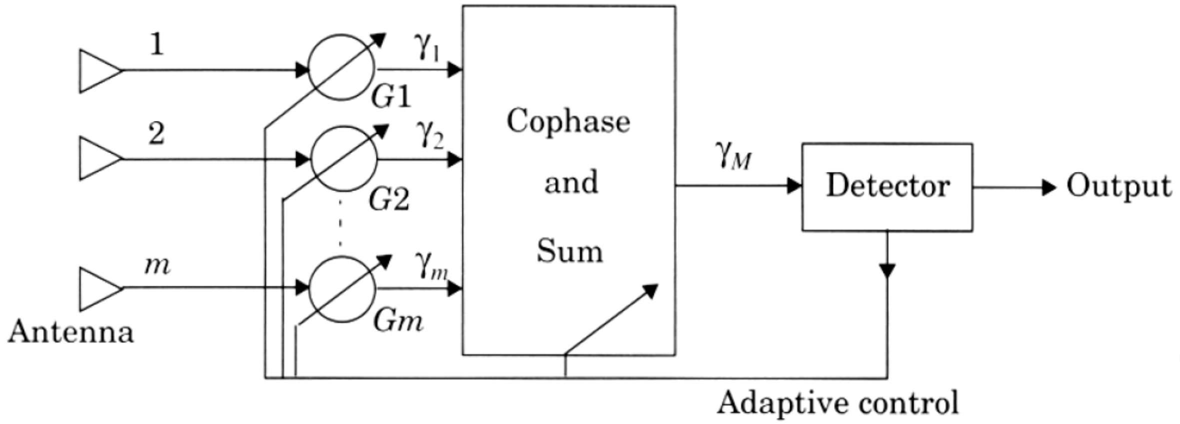
Receive Antenna Diversity

- Selection Diversity
  - Antenna element with the highest SNR (or other metric) is selected
  - Greatest SNR improvement when
    - Desired signal subject to independent (uncorrelated) fading and signal receiver with the same average power at each element
    - Background noise is AWGN, equal power and uncorrelated across elements
- Switched Diversity
  - Choose antenna element only when SNR undergoes a deep fade and the received SNR crossed a threshold
  - Perform worse than selection diversity
  - Requires only a single RF chain to serve all its antennas
  - Adaptive determination of the threshold

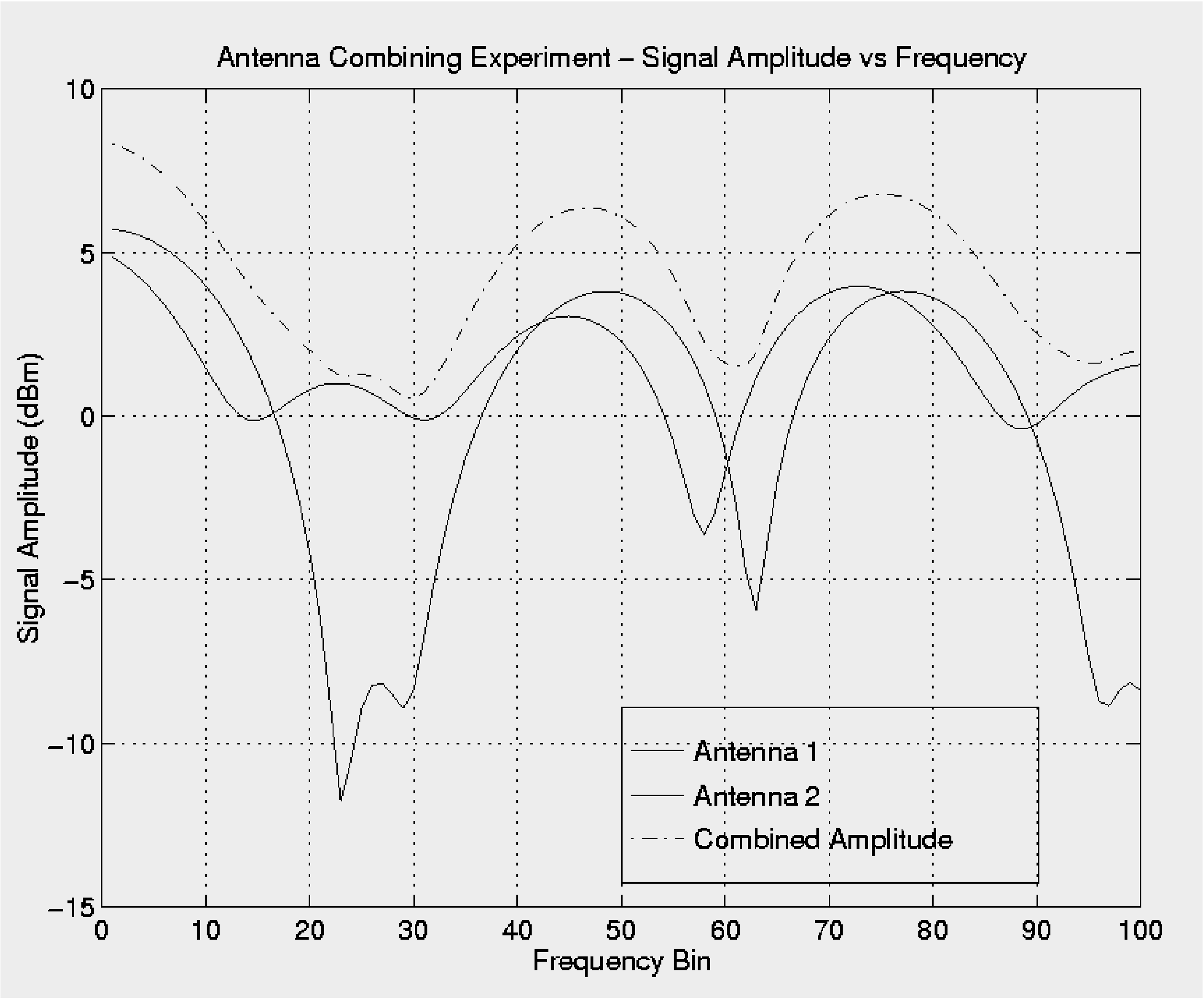


Receive Antenna Diversity – cont'd

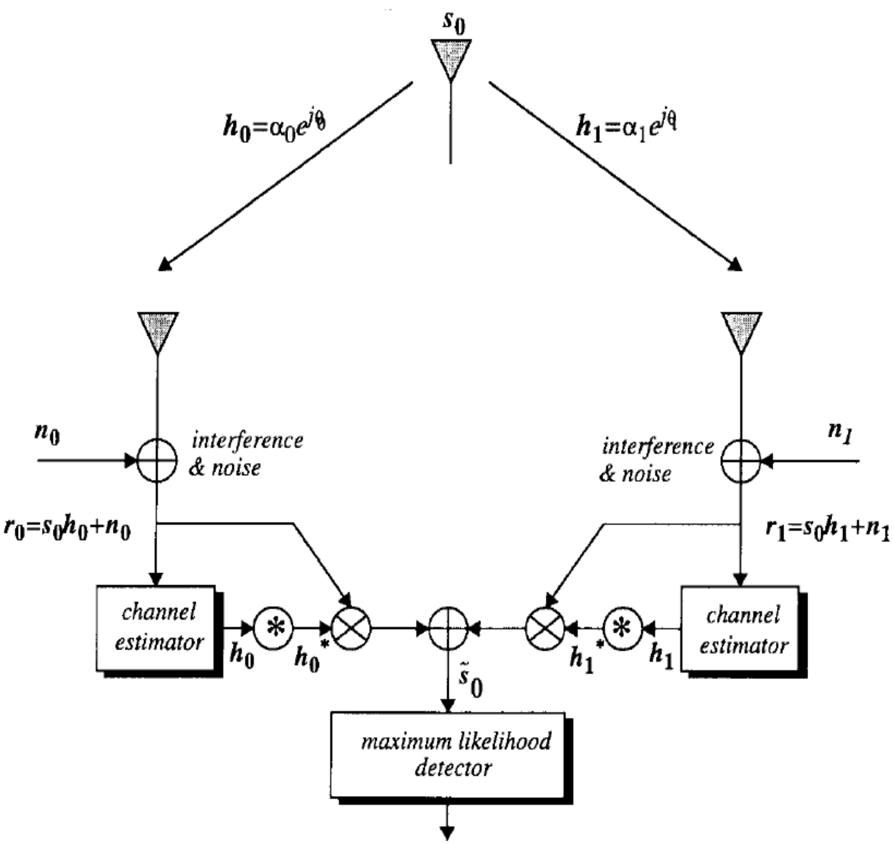
- Equal Gain Combining (EGC)
  - Co-phasing and summing the decision statistics at each element
  - LOS signal (no fading): equivalent to finding a beamforming weight vector w
  - Rayleigh fading signals: no longer optimum, but tends to achieve more diversity than selection diversity
- Maximal Ratio Combining (MRC)
  - Each sensor output is co-phased and weighted by its SNR before combining
    - MRC require design in receiver circuitry to achieve correct weighting factors
  - Optimal in the sense that provides best statistical reduction of fading of any linear combiner
  - Shows little improvement over EGC for Gaussian noise channel



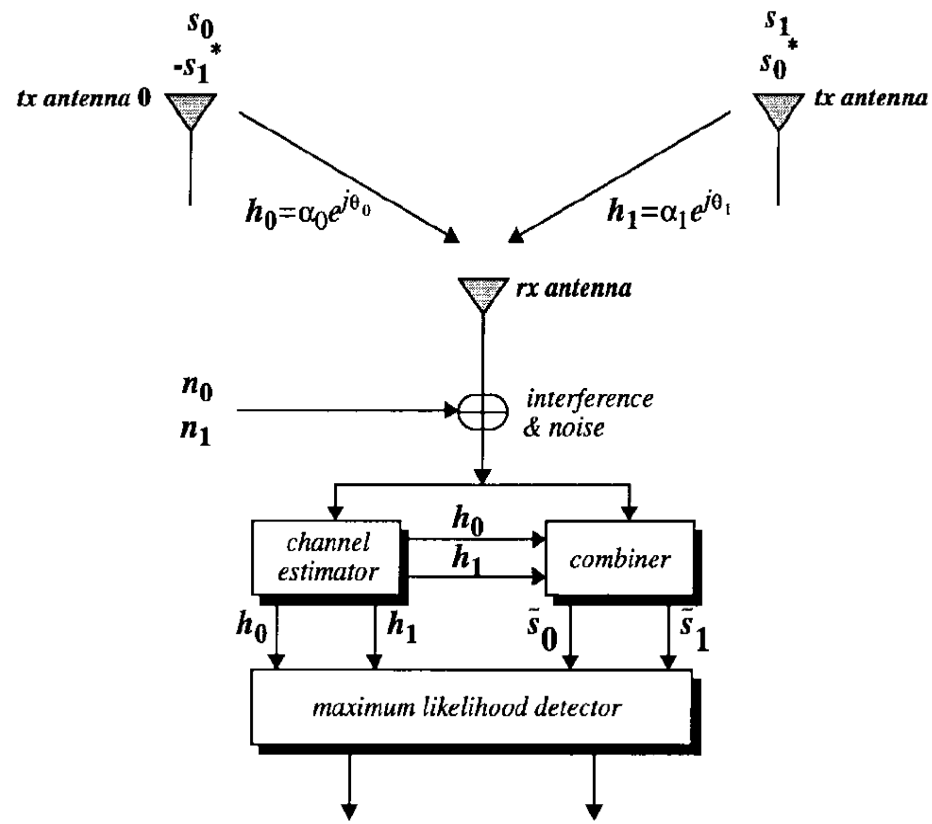
Antenna Combining Example



Rx MRC and Tx STC



$$\tilde{s}_0 = \left(\alpha_0^2 + \alpha_1^2\right)s_0 + h_0^* n_0 + h_1^* n_1$$

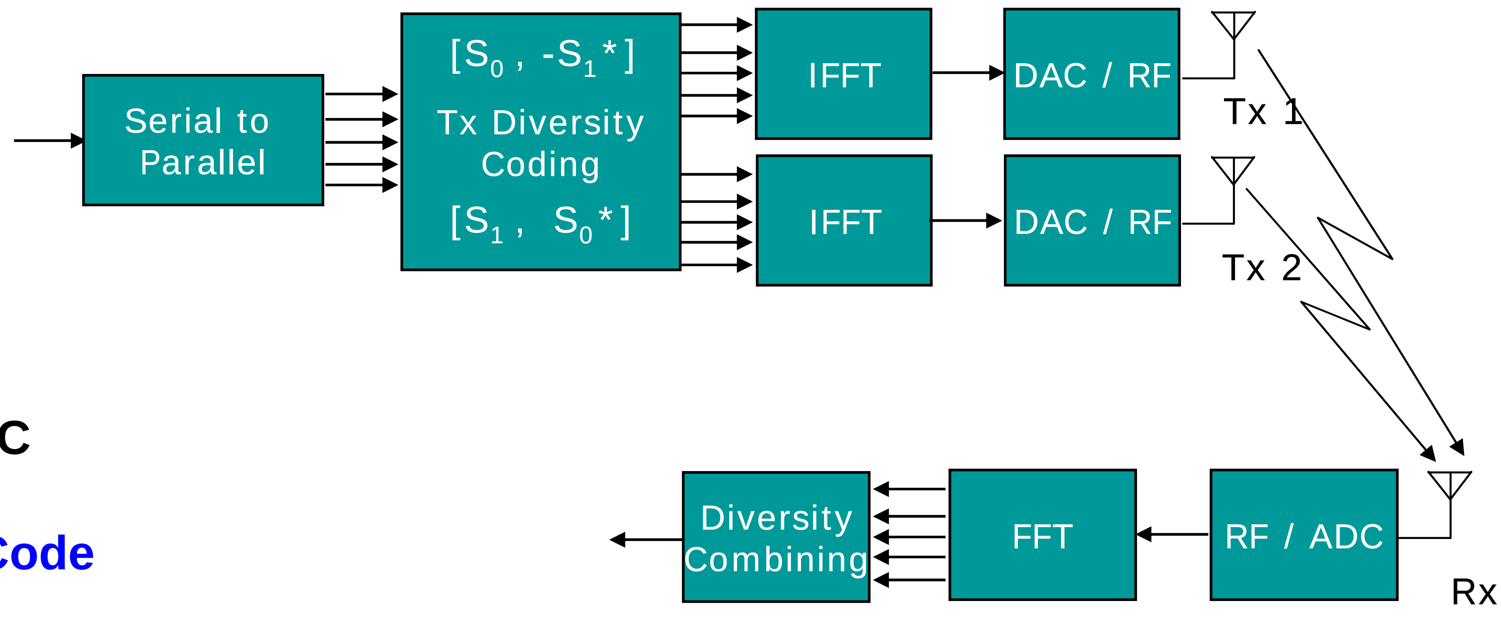


$$\tilde{s}_0 = \left(\alpha_0^2 + \alpha_1^2\right)s_0 + h_0^* n_0 + h_1 n_1^*$$

$$\tilde{s}_1 = \left(\alpha_0^2 + \alpha_1^2\right)s_1 - h_0 n_1^* + h_1^* n_0$$

* Siavash M. Alamouti, “A Simple Transmit Diversity Technique for Wireless Communications”, IEEE Journal on Selected Areas in Communications, vol. 16, no. 8, October 1998.

Transmit Spatial Diversity (STC)

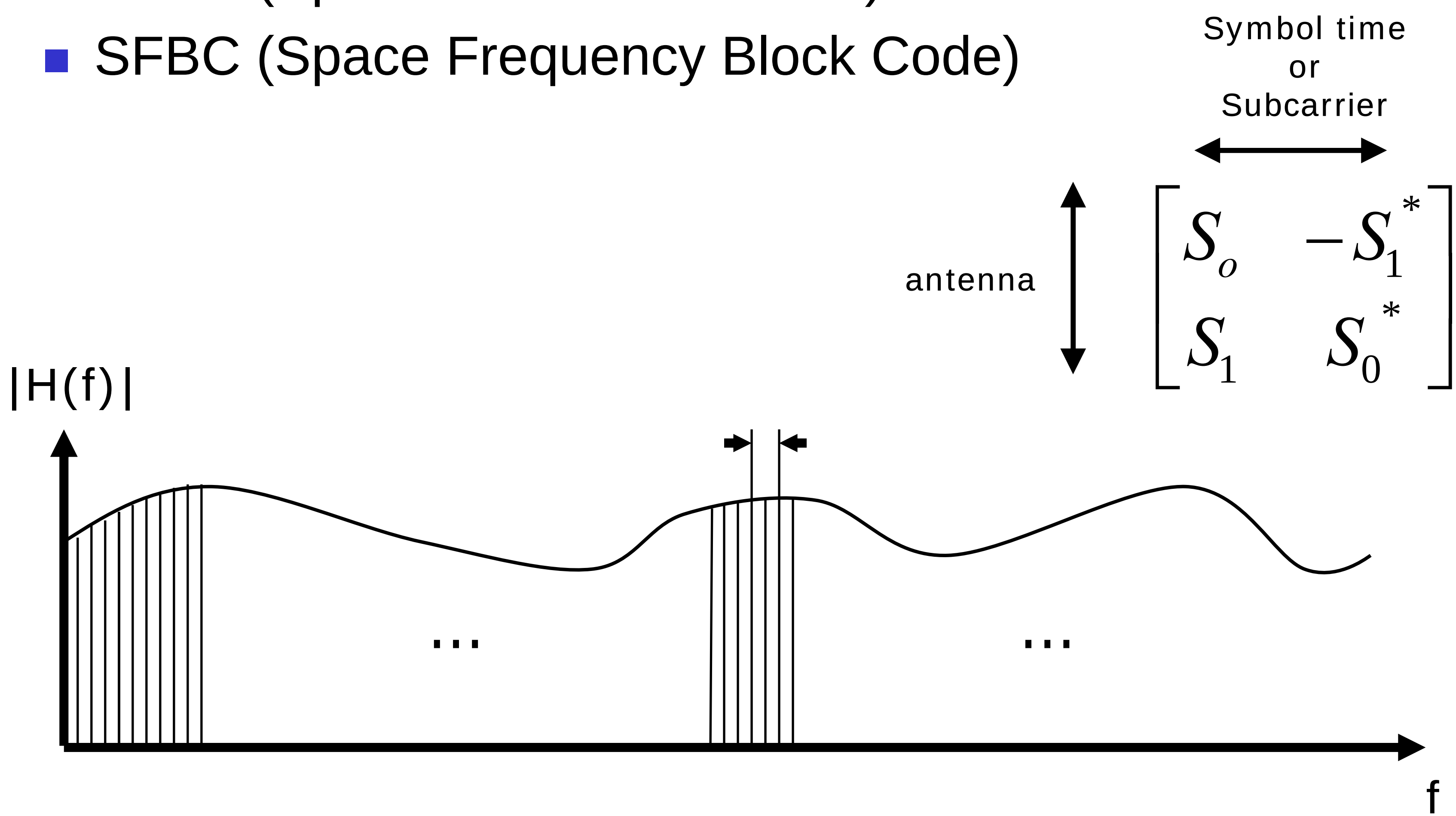


*** STC**
= STBC/SFBC
= STTD
= Alamouti Code

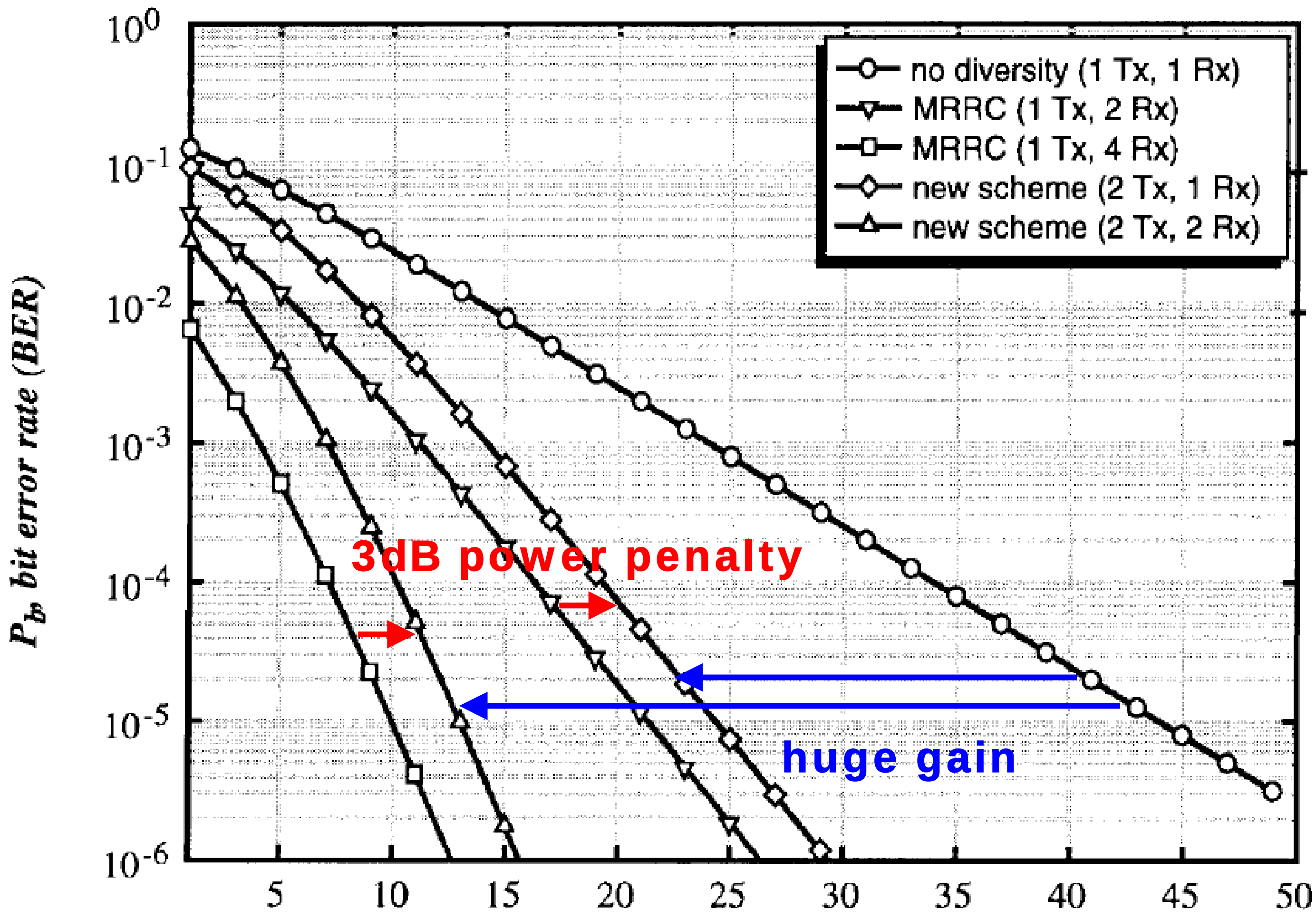
- Transmit diversity using space-time diversity coding (STC) reduces the required fade margin at receiver and improves link margin by 5-10 dB.
- Transmit diversity puts the extra antenna at the BS instead of the MS.
  - Lower-cost MS
- 3-dB power penalty compared to rx MRC

SFBC

- STBC (Space Time Block Code)
- SFBC (Space Frequency Block Code)



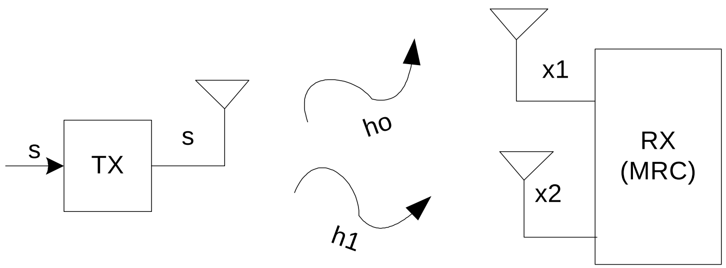
BER of MRC & STC



* Siavash M. Alamouti, "A Simple Transmit Diversity Technique for Wireless Communications", IEEE Journal on Selected Areas in Communications, vol. 16, no. 8, October 1998.

Comparisons: (Rx-)MRC, STC, TX-MRC

- RX-MRC (Receiver MRC)

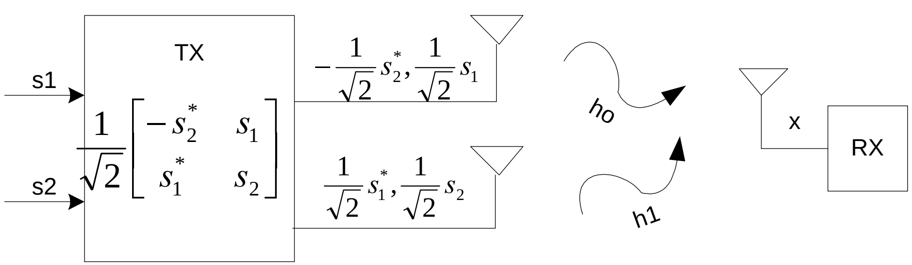


$$\begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} h_0 \\ h_1 \end{bmatrix} s + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

$$\vec{x} = \vec{h} s + \vec{n}$$

$$SNR = \frac{|h_o|^2 + |h_1|^2}{\sigma^2}$$

- STC (Space Time Code, Transmit Diversity)

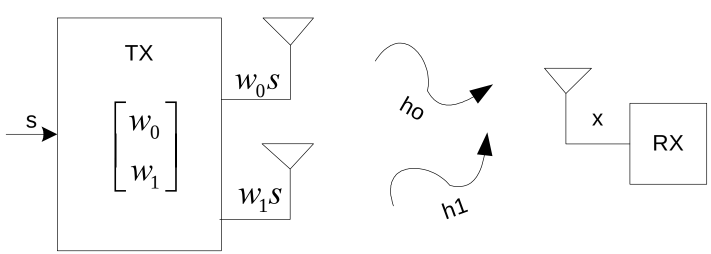


$$\begin{bmatrix} x(T_1) \\ x^*(T_2) \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} h_0 & h_1 \\ h_1^* & -h_0^* \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

$$\vec{x} = H\vec{s} + \vec{n}$$

$$SNR = \frac{|h_o|^2 + |h_1|^2}{2\sigma^2}$$

- TX-MRC (Transmit MRC)

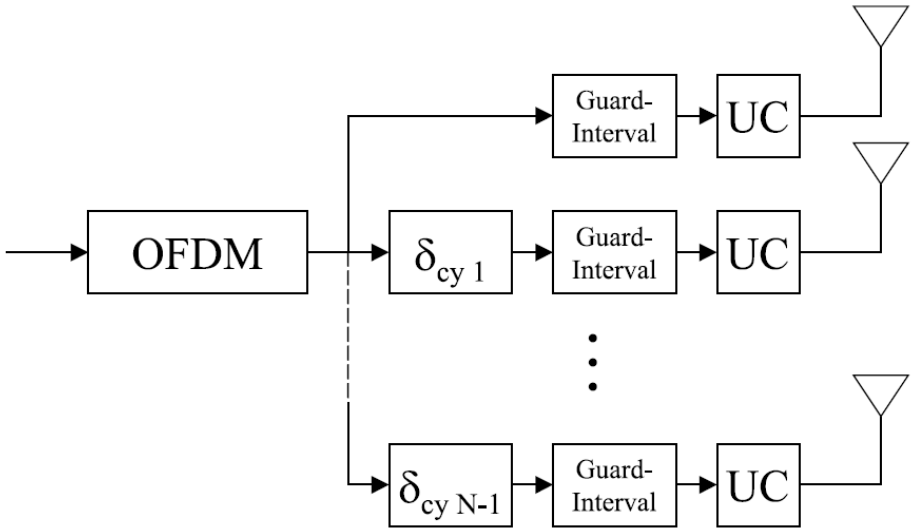


$$x = [w_o h_0 + w_1 h_1] s + n \qquad w_o = h_0^* / \sqrt{h_0^2 + h_1^2}$$

$$w_1 = h_1^* / \sqrt{h_0^2 + h_1^2}$$

$$SNR = \frac{|h_o|^2 + |h_1|^2}{\sigma^2}$$

Cyclic Delay Diversity (CDD)*



- The OFDM symbols of the CDD signal can be generated from the reference signal OFDM symbols just by applying a cyclic time shift of δ_{cy} to the reference signals' OFDM symbols and subsequent insertion of the cyclic prefix.
- CDD is independent of the existence of a cyclic prefix (guard interval) and are capable to increase the channel frequency selectivity without increasing the overall channel delay spread because these operations are done before guard interval insertion and are restricted to the OFDM symbol itself

* Armin Dammann and Stefan Kaiser, "Transmit/Receive-Antenna Diversity Techniques for OFDM Systems"

CDD – cont'd

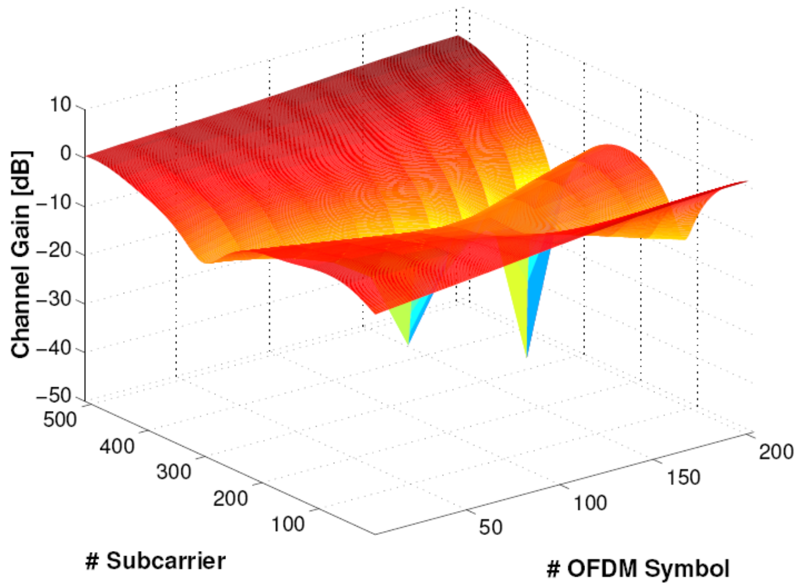


Figure 6: Indoor channel snapshot for a single antenna system

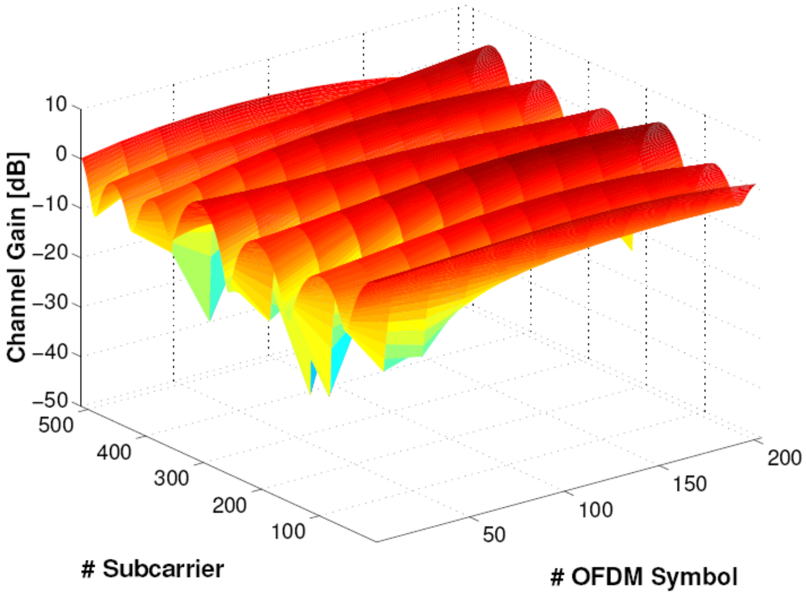


Figure 7: Indoor channel snapshot for a CDD system

- An additional transmitter antenna with CDD increases the frequency selectivity, i.e. decreases the coherence bandwidth
- A lower coherence bandwidth lead to a better error performance
- In order to achieve any diversity effects, i.e. to get constructive and destructive interference within the OFDM signal bandwidth B, the inserted (cyclic) delays δ_{cy} have to fulfill $\delta_{cy} \geq 1/B$

Several Problems in CDD

- CDD may raise synchronization ambiguities where the OFDMA signal is transmitted with different delays on the two Tx antennas, making synchronization more difficult
- CDD decreases the coherence bandwidth of the actual channel and therefore may incur channel estimation performance degradation

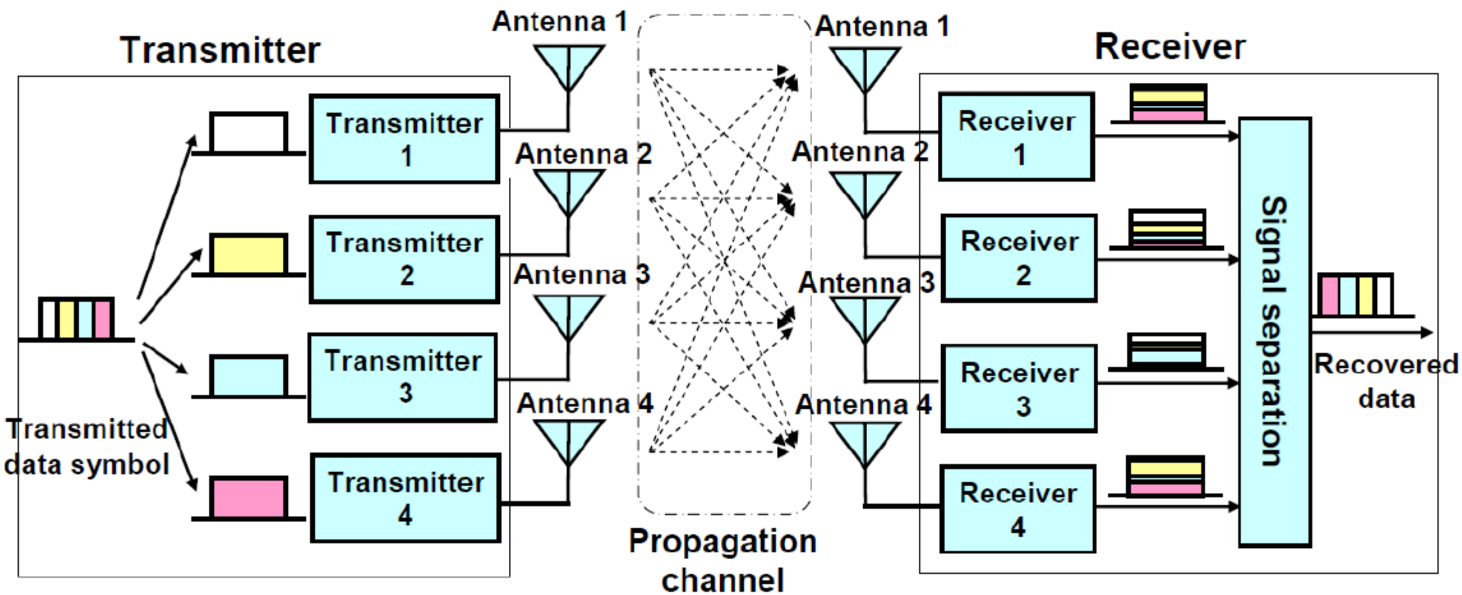
Spatial Multiplexing

MIMO Modes

- Open loop (OL)-MIMO vs. Closed loop (CL)-MIMO
- Single user (SU)-MIMO vs. Multi user (MU)-MIMO
- Vertical MIMO vs. Horizontal MIMO
- Single BS MIMO vs. Multi BS MIMO
- Codebook based beamforming vs. non-codebook based beamforming
- Diversity gain vs. Multiplexing gain
- Etc...

MIMO Spatial Multiplexing (SM)

- Multiple Input Multiple Output (MIMO)
- Multiple antennas at both transmitter and receiver
- **MIMO uses multipath to advantage** to "multiply data rate"
  - Transmits different data along different paths (simplified view)
  - MxN MIMO can multiply data rate by M or N (whichever is less) if there is enough multipath.
    - Best in urban high-multipath environment (and indoors)
    - Less effective in suburban and rural low-multipath environments



How can we get multiplexing?

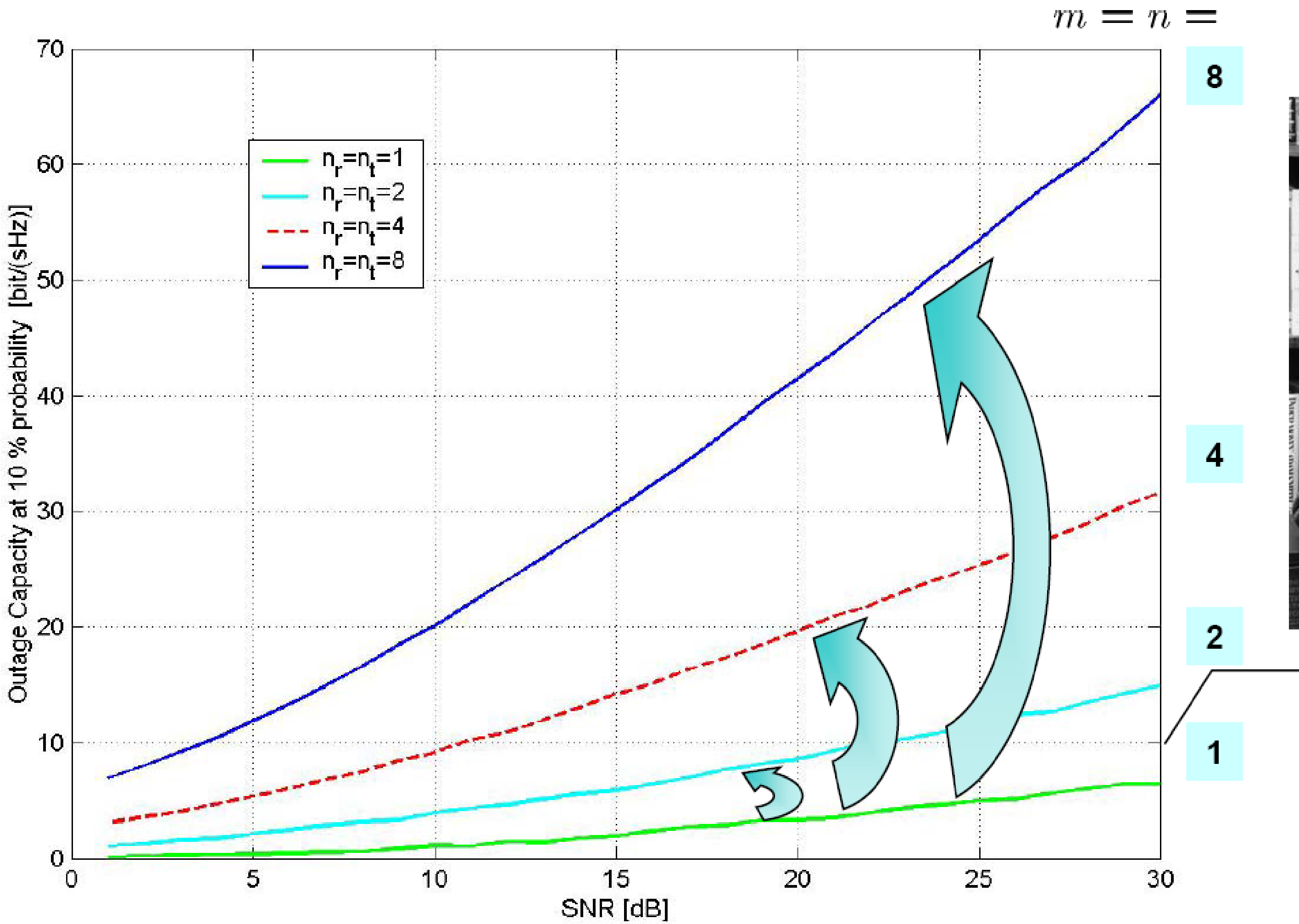
- Simple concept
  (1) Transmit “one” data in one link (1 Tx & 1 Rx antenna)
  (2) Transmit “two” data in two links far away from each other (1 Tx & 1 Rx antenna, respectively)
  (3) Transmit “two” data in one link (1 Tx & 1 Rx antenna) ??
  (4) Transmit “two” data in one link (2 Tx & 2 Rx antenna) ??

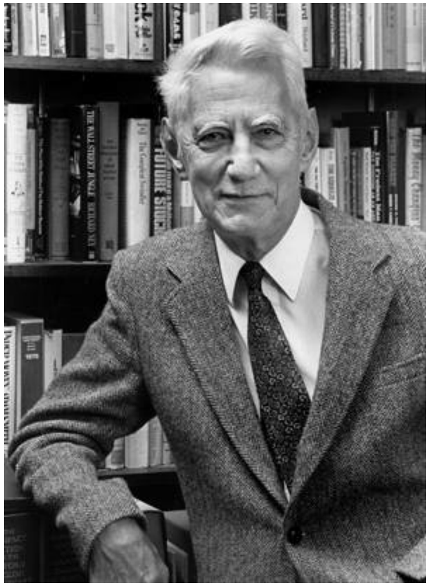
→ **(4) is just the special case of (2)!!**

- Simple linear algebra
  - Matrix (행렬)
  - Rank

- Favorable channel condition for MIMO?
  - Rich scattering for high rank
  - High SNR for reliable decoding

MIMO Capacity





Shannon Limit!

MIMO Data Rate Exercise (1)

- Example system configuration
  - System BW = 100 MHz
  - Highest Modulation = 64QAM
  - Channel Coding = {1/3, 1/2} + {repetition, puncturing}
  - MIMO order = 8 x 8

- What is the peak data rate of the example system?
  - 26 = 64 QAM → 6 bits/symbol
  - Coding Rate of 1 is possible by puncturing
  - Peak data rate = 100 x 6 x 1 x **8** = 4.8 Gbps

MIMO Data Rate Exercise (2)

- Target System: Information data rate of 1 Gbps where System BW = 100 MHz

  → requires "10 bps/Hz"

① W/O MIMO

using 1024QAM??

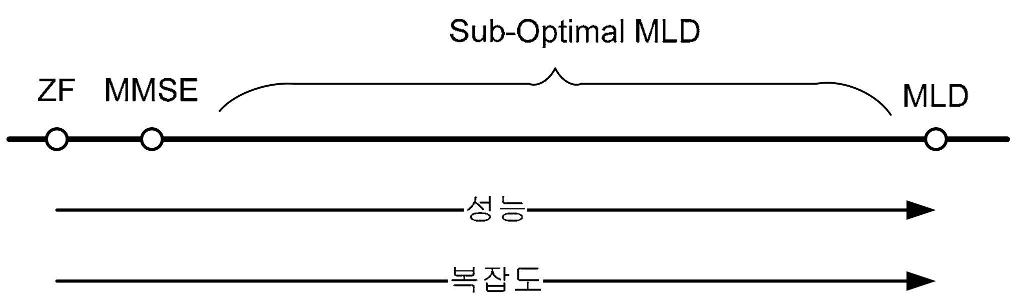
② With MIMO

using 16QAM + 4x4 MIMO = 16 bps/Hz

MIMO Implementation Issues

- Transmission power divided among multiple antennas
- Tradeoffs between data rate and diversity order
- Spaced to achieve sufficient fading decorrelation (device form-factor)
- Pilot overhead
- Feedback overhead
- Problem with conventional repeaters
- Demodulator Complexity
  - ZF (Zero Forcing)
    - Brute-force : $\mathbf{r} = \mathbf{H}\mathbf{x} + \mathbf{n}, \quad \tilde{\mathbf{x}} = \mathbf{H}^{-1}\mathbf{r} - \mathbf{H}^{-1}\mathbf{n}$
    - Noise enhancement
  - MMSE (Minimum Mean Square Error)
    - Consider noise, too
  - A lot of sub-optimal MLD
  - MLD
    - Optimal performance, but high complexity

$$\begin{bmatrix} \tilde{x}_1 \\ \tilde{x}_2 \end{bmatrix} = \arg\min_{\{x_1, x_2\}} \left\{ \left\| \begin{bmatrix} r_1 \\ r_2 \end{bmatrix} - \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \left[\text{송신기가 보낼 수 있는 모든 } \{x_1, x_2\} \text{ 조합} \right] \right\|^2 \right\}$$

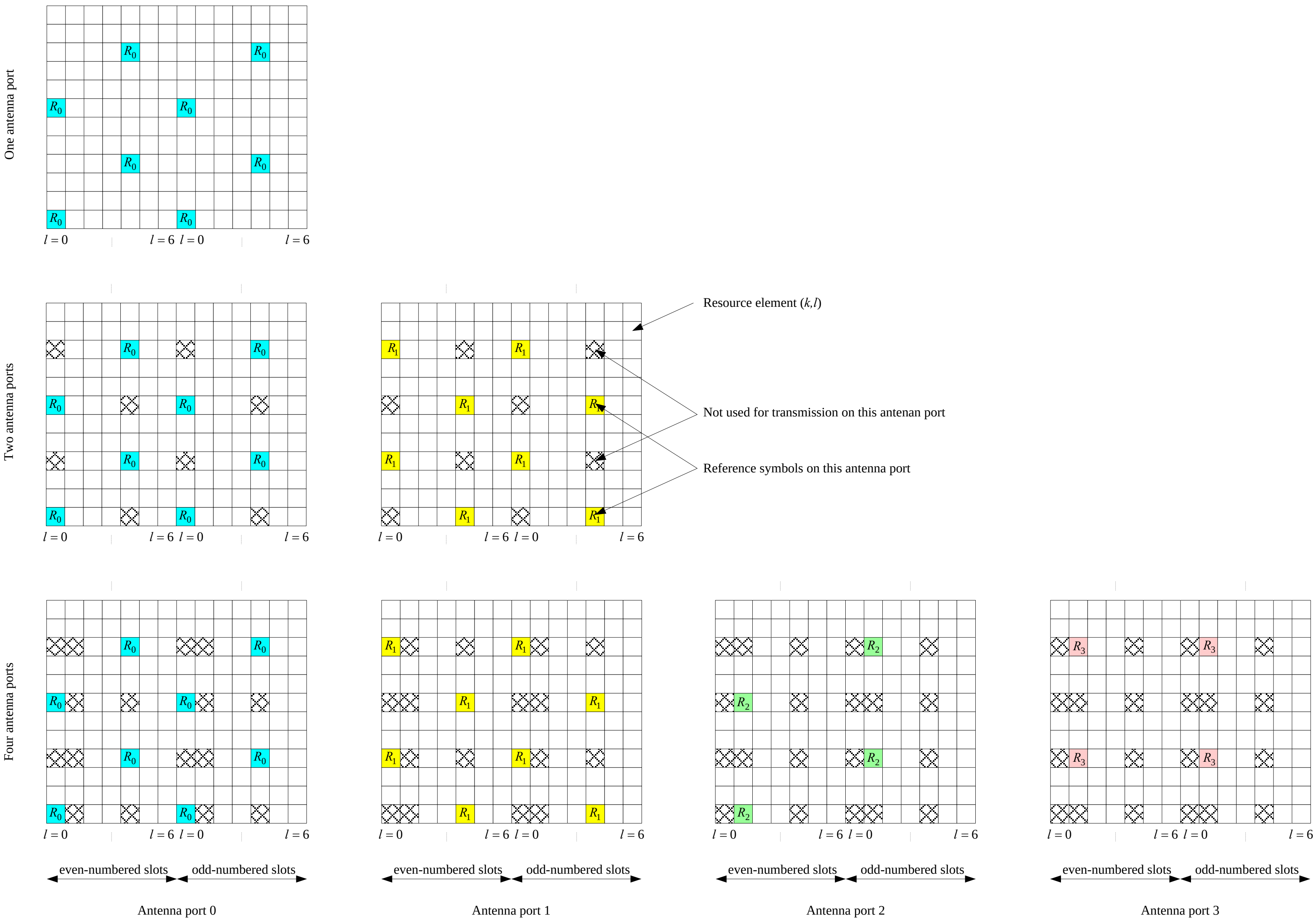


Similarity of Interference-Suppression Techniques for Various Applications

- Complexity decreasing from left to right

	Optimum	Interference Cancellation	Linear
Equalization (ISI)	Maximum likelihood sequence detection (MLSD)	Decision feedback equalization (DFE)	Zero forcing minimum mean square error (MMSE)
Multiuser	Optimum multiuser detector (MUD)	Successive/parallel interference cancellation, iterative MUD	Decorrelating, MMSE
Spatial-multiplexing Receiver	ML detector sphere decoder (near optimum)	Bell Labs Layered Spaced Time (BLAST)	Zero forcing, MMSE

LTE DL Reference Signals Mapping



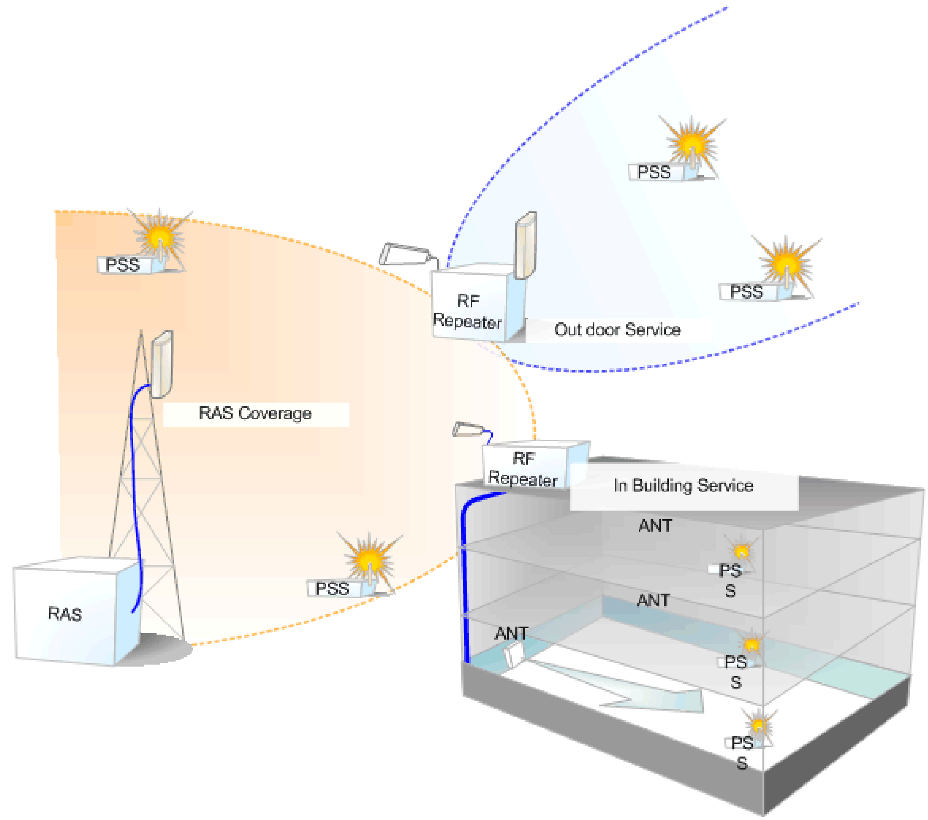
MIMO in Handset?

- Okay w/ 2x2
- What about 8x8, 12x12?

* T. Kaiser, “MIMO Deployment Benefits for LTE”, LTE 2007, May 22-24, 2007

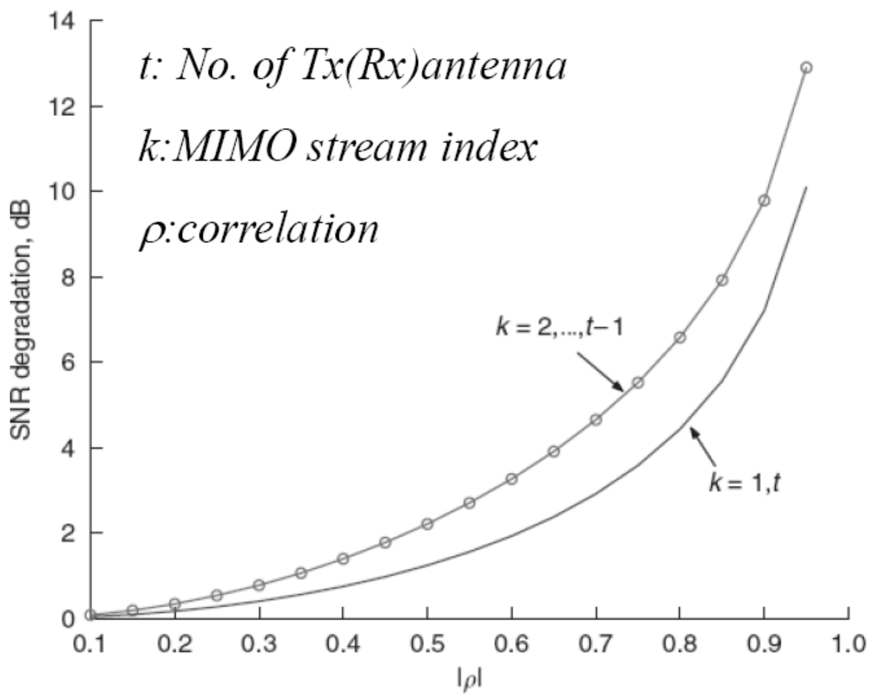
MIMO with Repeaters?

- 2x2 MIMO is expected to give about 40% capacity enhancement compared to non-MIMO system if there is not so many repeaters
- Repeater types
  - Optical Repeater
  - Microwave Repeater
  - RF Repeater
- **“2x2”** required to support SM
  “1x1” is okay for diversity
- Even with 2x2 RF repeater
  - MIMO capacity related with Channel Matrix



MIMO 성능: Antenna Correlation

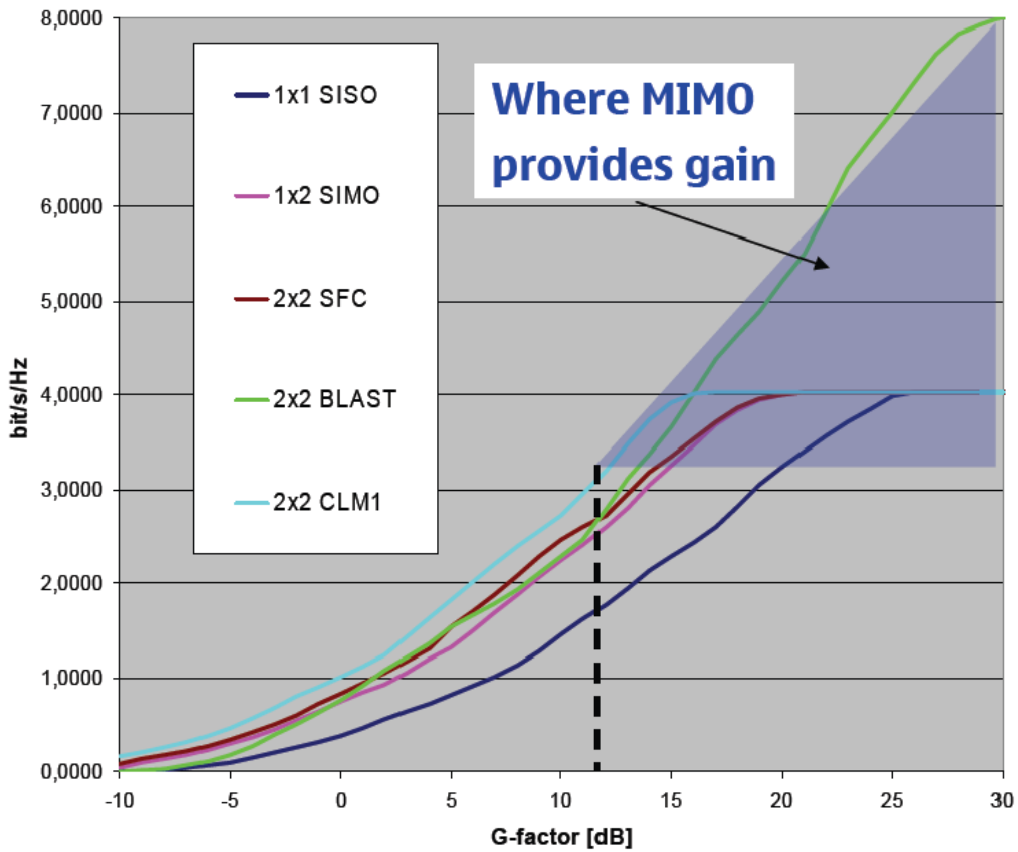
- Effect of Correlation for MIMO
  - MIMO 성능은 송수신 안테나 신호의 Correlation에 크게 좌우됨
  - 안테나별 채널이 독립이어야 함 → Correlation이 작아야 함
- Example: SNR after zero forcing detection
  - SNR degradation = $SNR_{iid} - SNR_{correlated}$



[Ref: Xu and Lau, "Performance analysis for MIMO systems using zero forcing detector over fading channels," IEE Proc.-Commun, Vol. 153, No. 1, Feb. 2006]

MIMO 성능: SINR

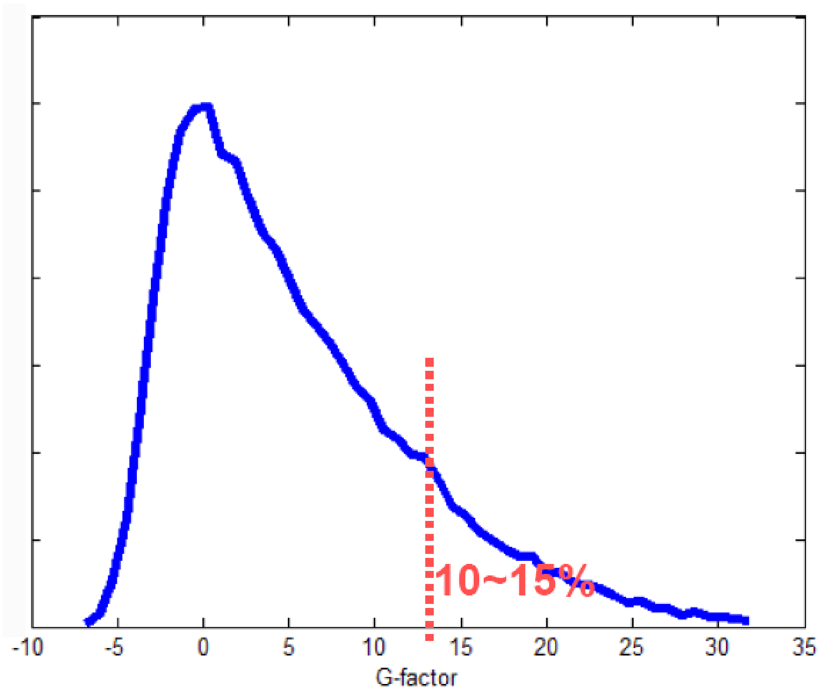
- MIMO는 high SINR에서 SIMO대비 성능 이득을 보임
- G-factor = SINR = S / (I+N)



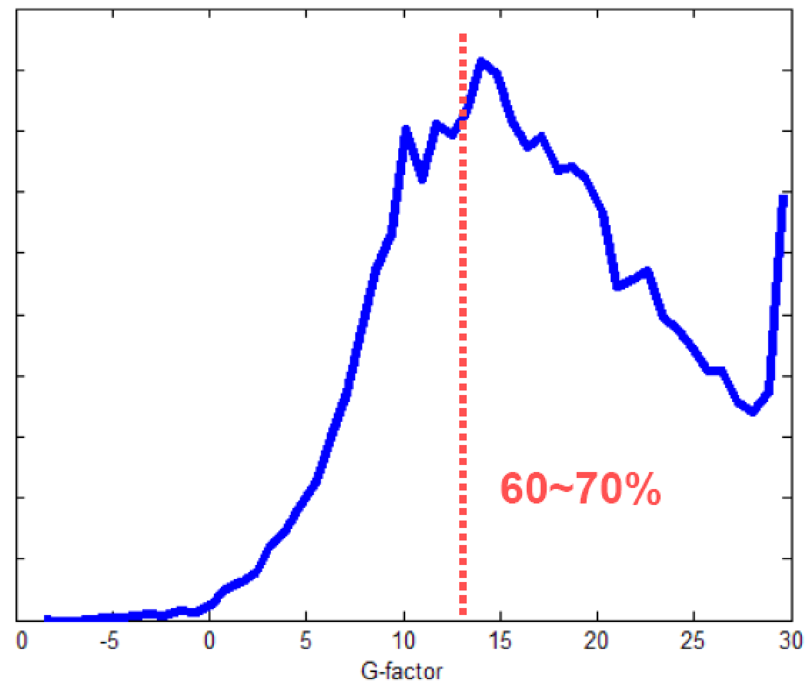
* 황근철 (삼성전자), "MIMO 기술현황", 제4회 중소기업을 위한 이동통신 기술지원 세미나, 청강문화산업대, May 2008

Typical G-factor Distribution

- Outdoor (FRF=1, cell r=800m)



- Indoor (isolated cell, 140mx80m bldg)



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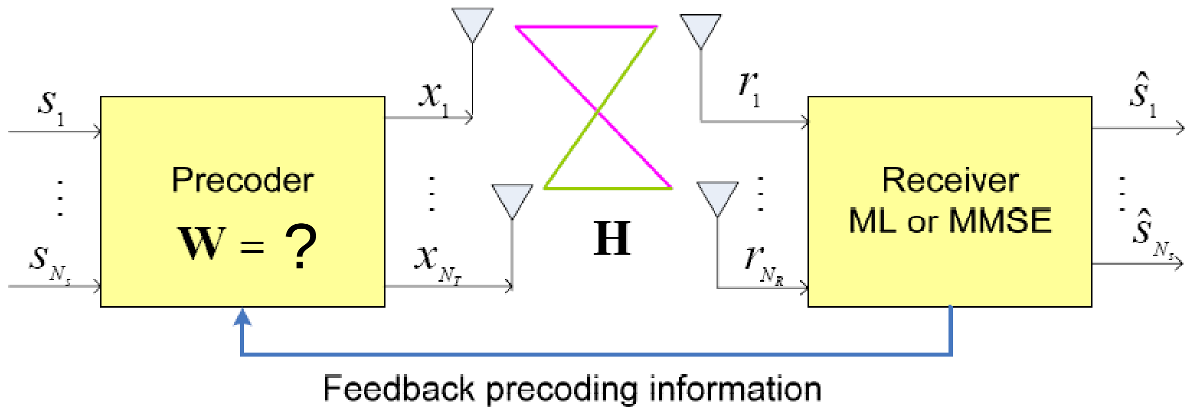
SVD MIMO as a Closed Loop MIMO

- In CL-SU-MIMO, SVD-MIMO is the optimum

  G. G. Raleigh and J. M. Cioffi, "Spatio-temporal coding for wireless communication," *IEEE Trans. Commun*., vol.46, no.3, March 1998



$$\mathbf{x} = \mathbf{W}\mathbf{s}$$

$$\mathbf{r} = \mathbf{H}\mathbf{W}\mathbf{s} + \mathbf{n}$$

Optimal choice of W: singular vectors of H matrix

Use Codebook with limited feedback

MIMO Channel Decomposition

Channel Transfer Matrix

$$\mathbf{H} = \begin{bmatrix} h_{11} & \cdots & h_{1N_T} \\ h_{21} & \cdots & h_{2N_T} \\ \vdots & \vdots & \vdots \\ h_{N_R 1} & \cdots & h_{N_R N_T} \end{bmatrix}$$

Singular Value Decomposition

$$\mathbf{H} = \mathbf{U}\mathbf{D}\mathbf{V}^H$$

$$\mathbf{D} = \begin{bmatrix} \sqrt{\lambda_1} & 0 \cdots & 0 \\ 0 & \sqrt{\lambda_2} \cdots & 0 \\ \vdots & \vdots & \vdots \\ 0 & \cdots & \sqrt{\lambda_n} \end{bmatrix}$$

Channel Correlation Matrix

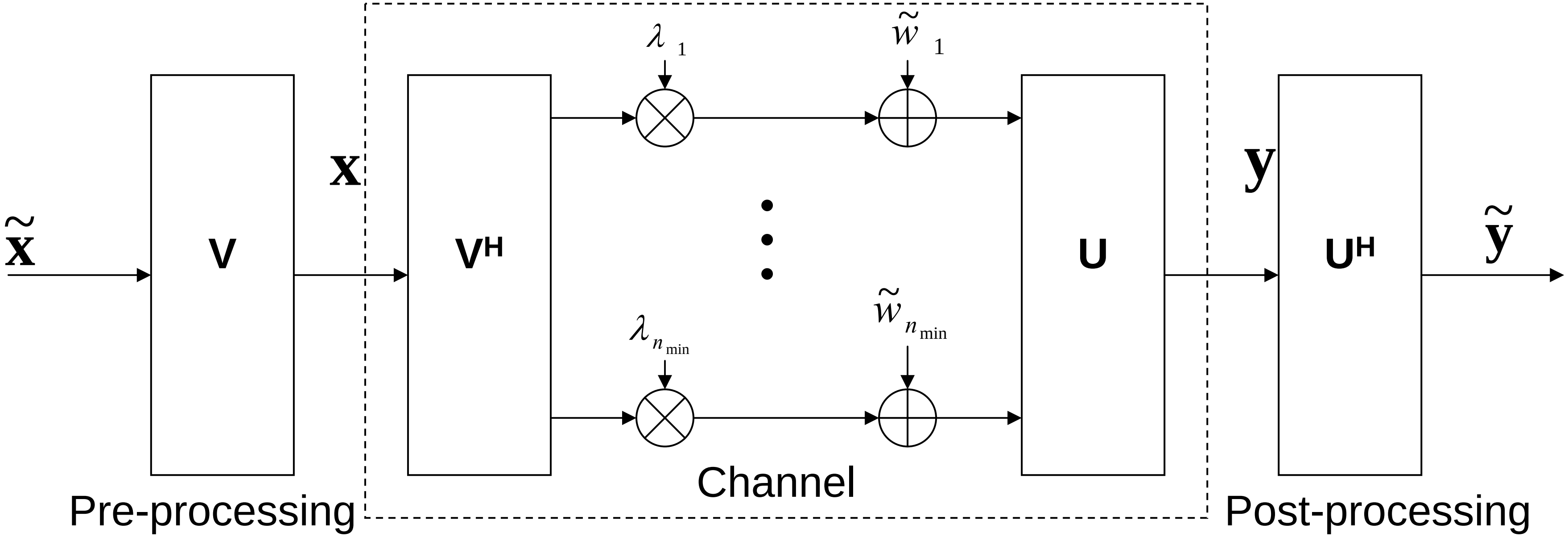
$$\mathbf{R} = \mathbf{H}\mathbf{H}^H = \begin{bmatrix} g_{11} & \cdots & g_{1N_T} \\ g_{21} & \cdots & g_{2N_T} \\ \vdots & \cdots & \vdots \\ g_{N_R 1} & \cdots & g_{N_R N_T} \end{bmatrix}, \quad g_{ij} = \sum_{k=1}^{N_T} h_{ik} h_{jk}^*$$

Eigen Value Decomposition

$$\mathbf{R} = \mathbf{V}\mathbf{\Lambda}\mathbf{\Lambda}^H = \mathbf{V}\mathbf{D}^H\mathbf{D}\mathbf{V}^H$$

$$\mathbf{D}^H\mathbf{D} = \begin{bmatrix} \lambda_1 & 0 \cdots & 0 \\ 0 & \lambda_2 \cdots & 0 \\ \vdots & \vdots & \vdots \\ 0 & \cdots & \lambda_n \end{bmatrix}$$

Deterministic MIMO System Model



With number of transmitting antenna=n_t and receiving antenna=n_r,

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{w}$$

$$\mathbf{x} \in C^{n_t}, \mathbf{y} \in C^{n_r}, \mathbf{w} \sim N(0, N_0 \mathbf{I}_{n_r})$$

Multiplexing Capability of Deterministic MIMO Channels

$$
\begin{aligned}
\tilde{\mathbf{y}} &= \mathbf{U}^{H}\mathbf{y} \\
&= \mathbf{U}^{H}(\mathbf{H}\mathbf{x} + \mathbf{w}) \\
&= \mathbf{U}^{H}(\mathbf{U}\mathbf{D}\mathbf{V}^{H}\mathbf{x} + \mathbf{w}) \\
&= \mathbf{U}^{H}(\mathbf{U}\mathbf{D}\mathbf{V}^{H}\mathbf{V}\tilde{\mathbf{x}} + \mathbf{w}) \\
&= \mathbf{D}\tilde{\mathbf{x}} + \mathbf{U}^{H}\mathbf{w}
\end{aligned}
$$

$$
\boxed{\tilde{\mathbf{y}} = \mathbf{D}\tilde{\mathbf{x}} + \tilde{\mathbf{w}}}
$$

Singular Values

- The Singular Values of the channel matrix are the key to determining how good the channel is for MIMO
- SISO: $C = BW \cdot \log(1+\rho)$
- MIMO: $C = \sum_{i=1\ldots N} BW \cdot \log\left(1+\frac{\rho}{N}\sigma_i^{\,2}(\mathbf{H})\right)$

where N is the number of independent transmitter-receiver path

$\sigma_i^{\,2}(\mathbf{H})$ is the singular values of radio channel matrix, H

- The SVs let you calculate the increase in channel capacity
- The ratio of Singular Values = Condition Number

SVD Example (Mathematics)

$\mathbf{H} = \mathbf{U}\mathbf{D}\mathbf{V}^{\mathbf{H}}$

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 2 \\ 0 & 0 & 3 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 4 & 0 & 0 & 0 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} 4 & 0 & 0 & 0 & 0 \\ 0 & 3 & 0 & 0 & 0 \\ 0 & 0 & \sqrt{5} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ \sqrt{0.2} & 0 & 0 & 0 & \sqrt{0.8} \\ 0 & 0 & 0 & 1 & 0 \\ -\sqrt{0.8} & 0 & 0 & 0 & \sqrt{0.2} \end{bmatrix}$$

$\mathbf{U}\mathbf{U}^{\mathbf{H}} = \mathbf{I}$

$$\begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 1 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$\mathbf{V}\mathbf{V}^{\mathbf{H}} = \mathbf{I}$

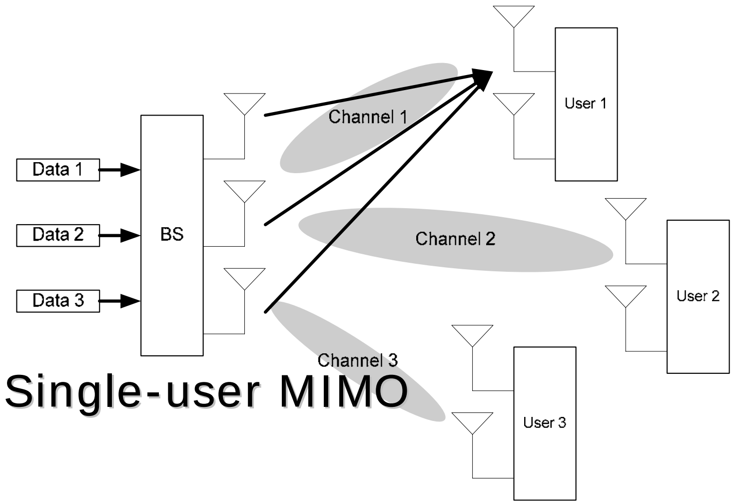
$$\begin{bmatrix} 0 & 0 & \sqrt{0.2} & 0 & -\sqrt{0.8} \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & \sqrt{0.8} & 0 & \sqrt{0.2} \end{bmatrix} \cdot \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ \sqrt{0.2} & 0 & 0 & 0 & \sqrt{0.8} \\ 0 & 0 & 0 & 1 & 0 \\ -\sqrt{0.8} & 0 & 0 & 0 & \sqrt{0.2} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

* singular value decomposition is not unique.

$$\mathbf{V}^{\mathbf{H}} = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ \sqrt{0.2} & 0 & 0 & 0 & \sqrt{0.8} \\ \sqrt{0.4} & 0 & 0 & \sqrt{0.5} & -\sqrt{0.1} \\ -\sqrt{0.4} & 0 & 0 & \sqrt{0.5} & \sqrt{0.1} \end{bmatrix}$$

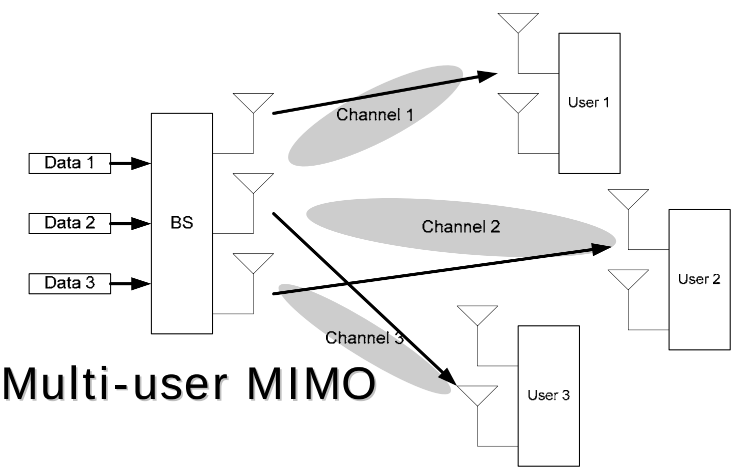
SU-MIMO & MU-MIMO

- Single-user MIMO schemes
  - All streams to one user
  - Stream-by-stream SIC
  - Spatial domain multiuser diversity is NOT available



Single-user MIMO

- Multi-user MIMO schemes
  - Multistreams to multiple users
  - Spatial domain multiuser diversity
  - Larger diversity gain than single-user MIMO
  - Stream-by-stream SIC is NOT available



Multi-user MIMO

MU-MIMO in theory

- Unlike SU-MIMO which is the point-to-point multiple-antenna channels, MU-MIMO is the multiple-antenna broadcast channels.
- The multiuser capacity of multiple-antenna broadcast channels depends heavily on whether the transmitter knows the channel coefficients to each user.
  - For example, in a Gaussian broadcast channel with M transmit antennas and n single-antenna users, the sum rate capacity scales like $M \log \log n$ for large n if perfect channel state information (CSI) is available at the transmitter, yet only logarithmically with M if it is not.
- The MU-MIMO with perfect CSI at the transmitter is well known capacity achieving dirty paper coding (DPC) [7].
- On the other hand, other techniques such as random beamforming (RBF) [8] and opportunistic beamforming [9] have been studied as the sub-optimum scheme where there is only partial or very little side information available at the transmitter.

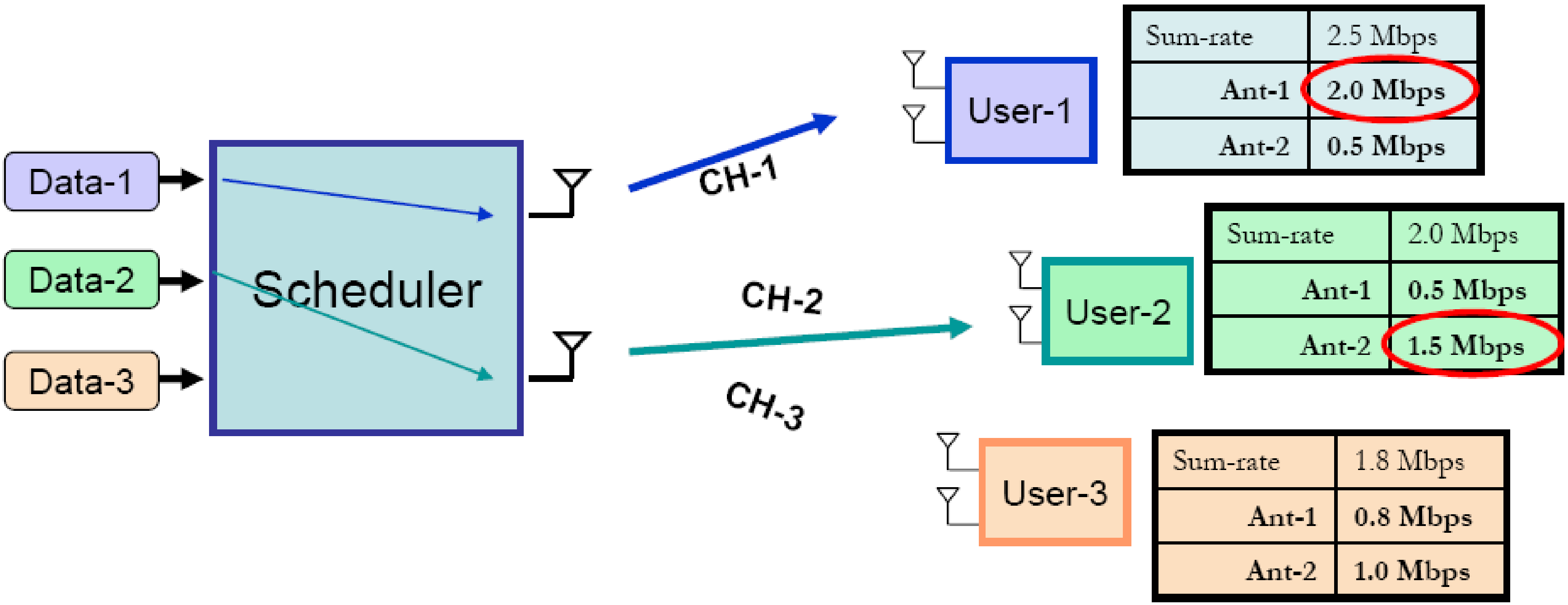
[7] M. H. M. Costa, "Writing on dirty paper," *IEEE Trans. Inform. Theory*, vol.IT-29, no.3, May 1983

[8] M. Sharif and B. Hassibi, "On the capacity of MIMO broadcast channels with partial side information," *IEEE Trans. Inform. Theory*, vol.51, no.2, Feb. 2005

[9] P. Viswanath, D. N. C. Tse, and R. Laroia, "Opportunistic beamforming using dumb antennas," *IEEE Trans. Inform. Theory*, vol.48, no.6, June 2002

MU-MIMO

- Allocate each antenna resource to different user
- Scheduler selects a user with the highest rate per antenna
- Increase system throughput!



Served rate = 3.5 Mbps

Multi-User MIMO Example: PU2RC

- 단말의 codebook 선택 방식
  - For unitary matrix V_i, $i \in \{1, ..., G\}$
  - Calculate SINR for stream m, $m \in \{1, ..., M\}$

Unitary matrix	V_1	V_2	...	V_G
Stream 1 Stream 2 : Stream M	$SINR_{1,1}$ $SINR_{1,2}$: $SINR_{1,M}$	$SINR_{2,1}$ $SINR_{2,2}$: $SINR_{2,M}$	...	$SINR_{G,1}$ $SINR_{G,2}$: $SINR_{G,M}$
Sum Rate	R_1	R_2	...	R_G

- Find the unitary matrix which gives the max sum rate
- Feedback the unitary matrix and the associated SINRs

* 삼성전자

Multi-User MIMO Example: PU2RC

- 기지국의 사용자 선택 방식 (1/2)
  - Collect all unitary matrices and SINRs

	User 1	User 2	User 3	User 4	User 5
Stream 1	$SINR_{1,1}$	$SINR_{2,1}$	$SINR_{3,1}$	$SINR_{4,1}$	$SINR_{5,1}$
Stream 2	$SINR_{1,2}$	$SINR_{2,2}$	$SINR_{3,2}$	$SINR_{4,2}$	$SINR_{5,2}$
Stream 3	$SINR_{1,3}$	$SINR_{2,3}$	$SINR_{3,3}$	$SINR_{4,3}$	$SINR_{5,3}$
Stream 4	$SINR_{1,4}$	$SINR_{2,4}$	$SINR_{3,4}$	$SINR_{4,4}$	$SINR_{5,4}$
Unitary matrix	V_2	V_1	V_1	V_2	V_1

  - Sort the table w.r.t unitary matrices

	User 2	User 3	User 5	User 1	User 4
Stream 1	$SINR_{1,1}$	$SINR_{2,1}$	$SINR_{3,1}$	$SINR_{4,1}$	$SINR_{5,1}$
Stream 2	$SINR_{1,2}$	$SINR_{2,2}$	$SINR_{3,2}$	$SINR_{4,2}$	$SINR_{5,2}$
Stream 3	$SINR_{1,3}$	$SINR_{2,3}$	$SINR_{3,3}$	$SINR_{4,3}$	$SINR_{5,3}$
Stream 4	$SINR_{1,4}$	$SINR_{2,4}$	$SINR_{3,4}$	$SINR_{4,4}$	$SINR_{5,4}$
Unitary matrix	all V_1			all V_2	

* 삼성전자

Multi-User MIMO Example: PU2RC

- 기지국의 사용자 선택 방식 (2/2)
  - Calculate a sum rate for each unitary matrix

	User 2	User 3	User 5	Max	Select
Stream 1	$SINR_{2,1}$	$SINR_{3,1}$	$SINR_{5,1}$	$SINR_{3,1}$	User 3
Stream 2	$SINR_{2,2}$	$SINR_{3,2}$	$SINR_{5,2}$	$SINR_{2,2}$	User 2
Stream 3	$SINR_{2,3}$	$SINR_{3,3}$	$SINR_{5,3}$	$SINR_{5,3}$	User 5
Stream 4	$SINR_{2,4}$	$SINR_{3,4}$	$SINR_{5,4}$	$SINR_{3,4}$	User 3
Unitary	all V_1			Sum Rate	C_1

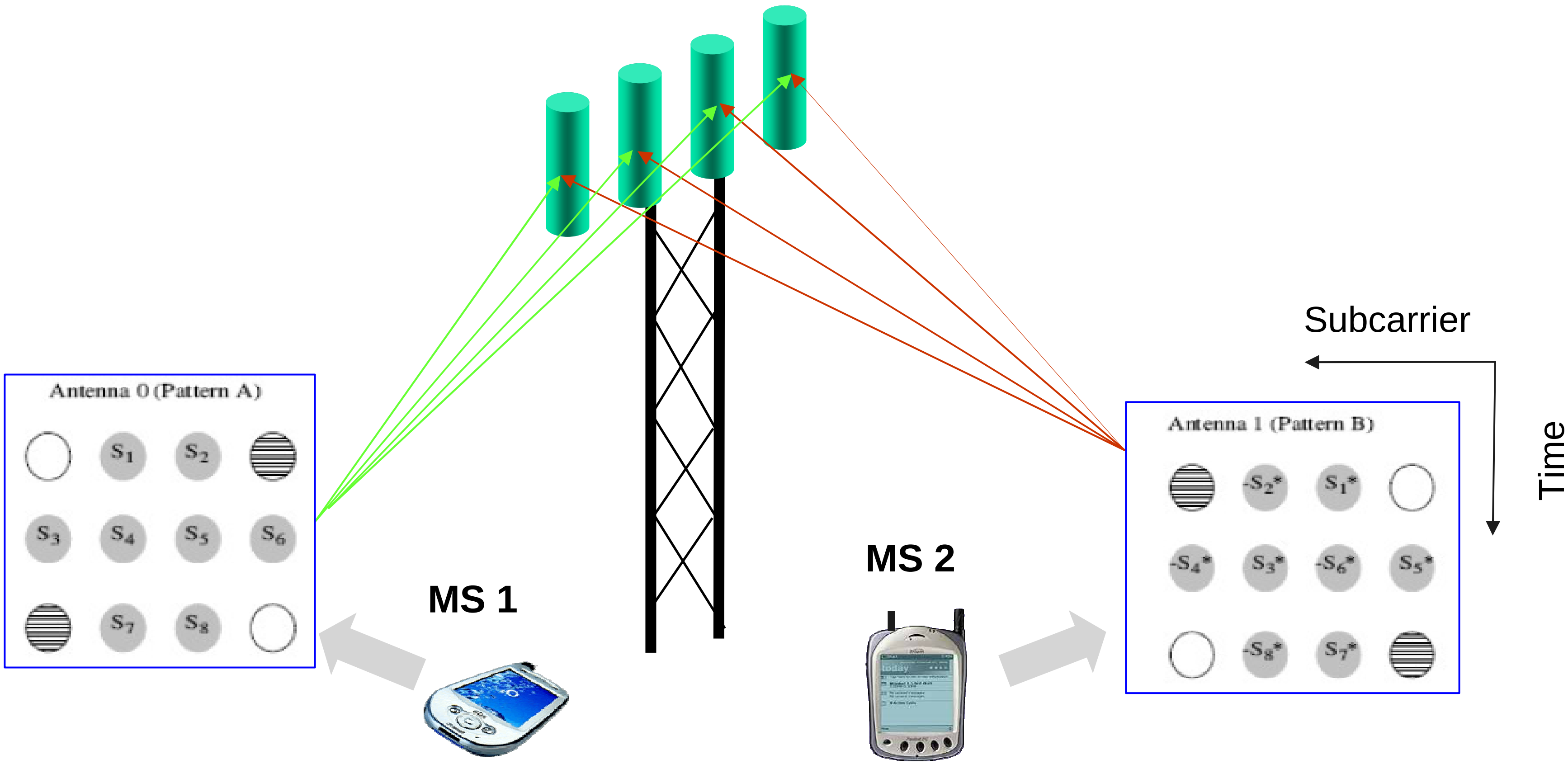
User 1	User 4	Max	Select
$SINR_{1,1}$	$SINR_{4,1}$	$SINR_{4,1}$	User 4
$SINR_{1,2}$	$SINR_{4,2}$	$SINR_{1,2}$	User 1
$SINR_{1,3}$	$SINR_{4,3}$	$SINR_{1,3}$	User 1
$SINR_{1,4}$	$SINR_{4,4}$	$SINR_{4,4}$	User 4
all V_2		Sum Rate	C_2

  - Fine the unitary matrix corresponding to the max sum-rate
  - Deterministic multiuser beamforming
    - Use unitary matrix V_1 if $C_1 > C_2$
    - Selected user for each stream →

Stream 1	User 3
Stream 2	User 2
Stream 3	User 5
Stream 4	User 3

UL Collaborative MIMO SM

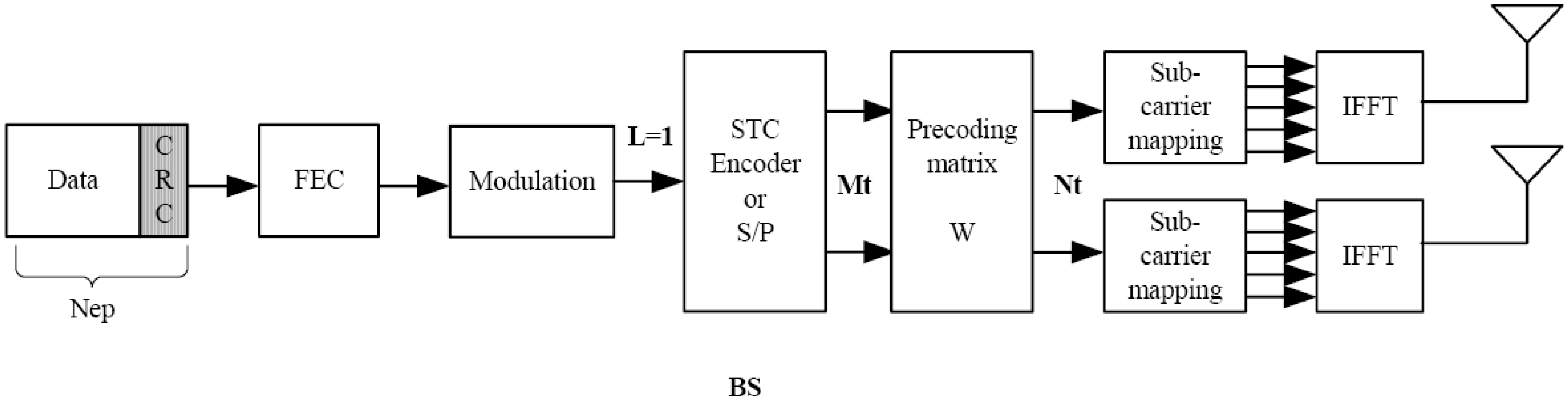
- Example in the uplink of IEEE 802.16e



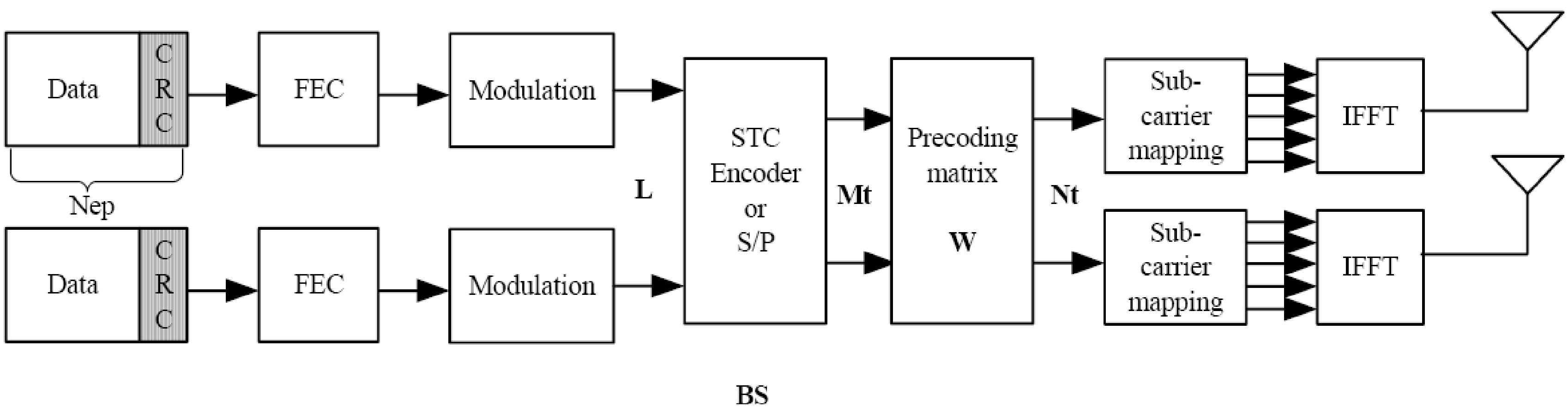
MSs spatially uncorrelated
Without 3dB power penalty

Vertical/Horizontal MIMO

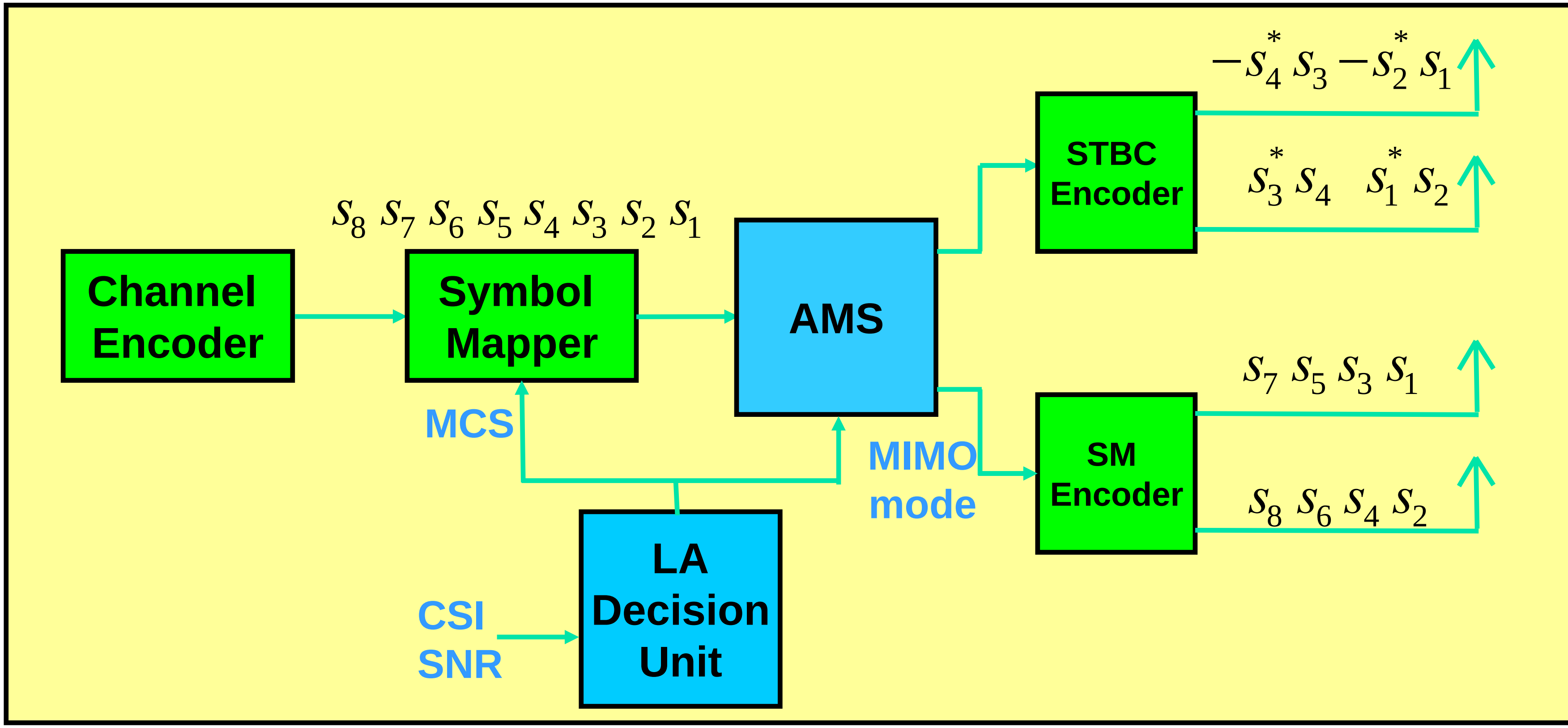
- Vertical Encoded 2x2 MIMO System



- Horizontal Encoded 2x2 MIMO System

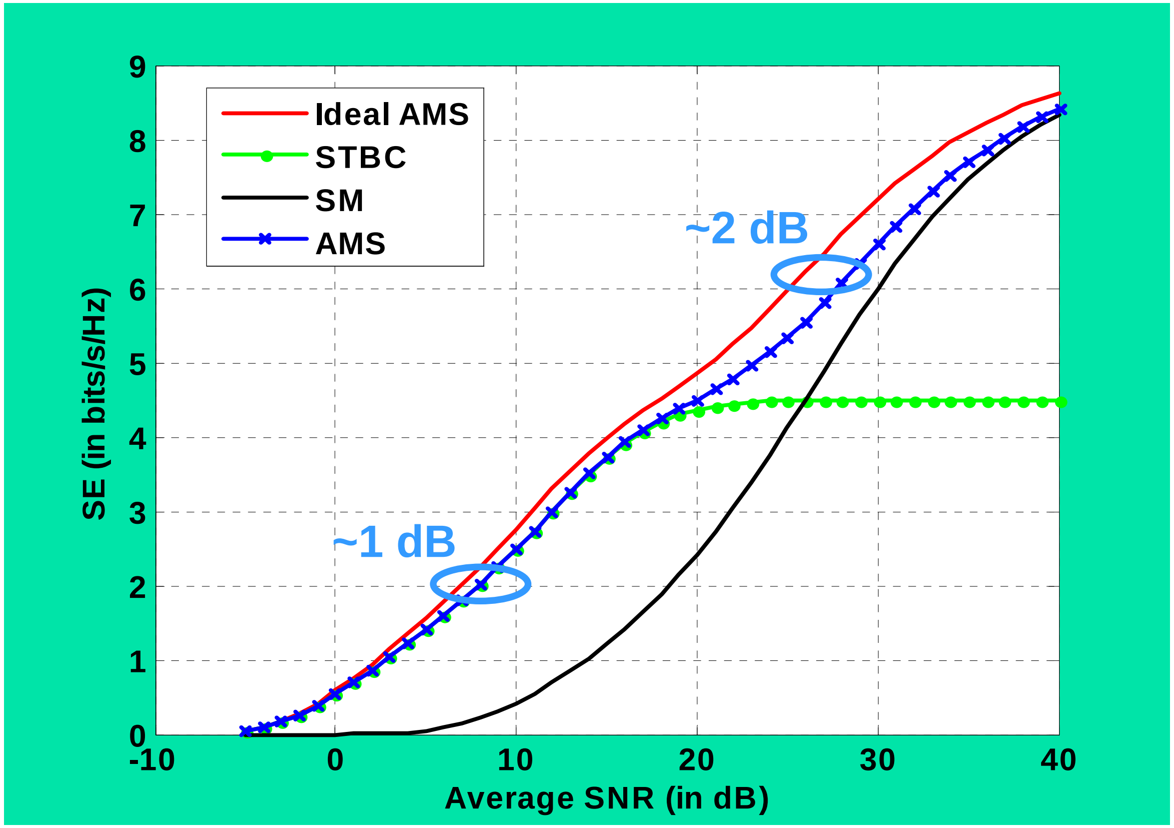


DL Adaptive MIMO Switching (AMS)



MCS:	Modulation and Coding Scheme
LA:	Link Adaptation
CSI:	Channel State Information
SNR:	Signal-to-Noise Ratio

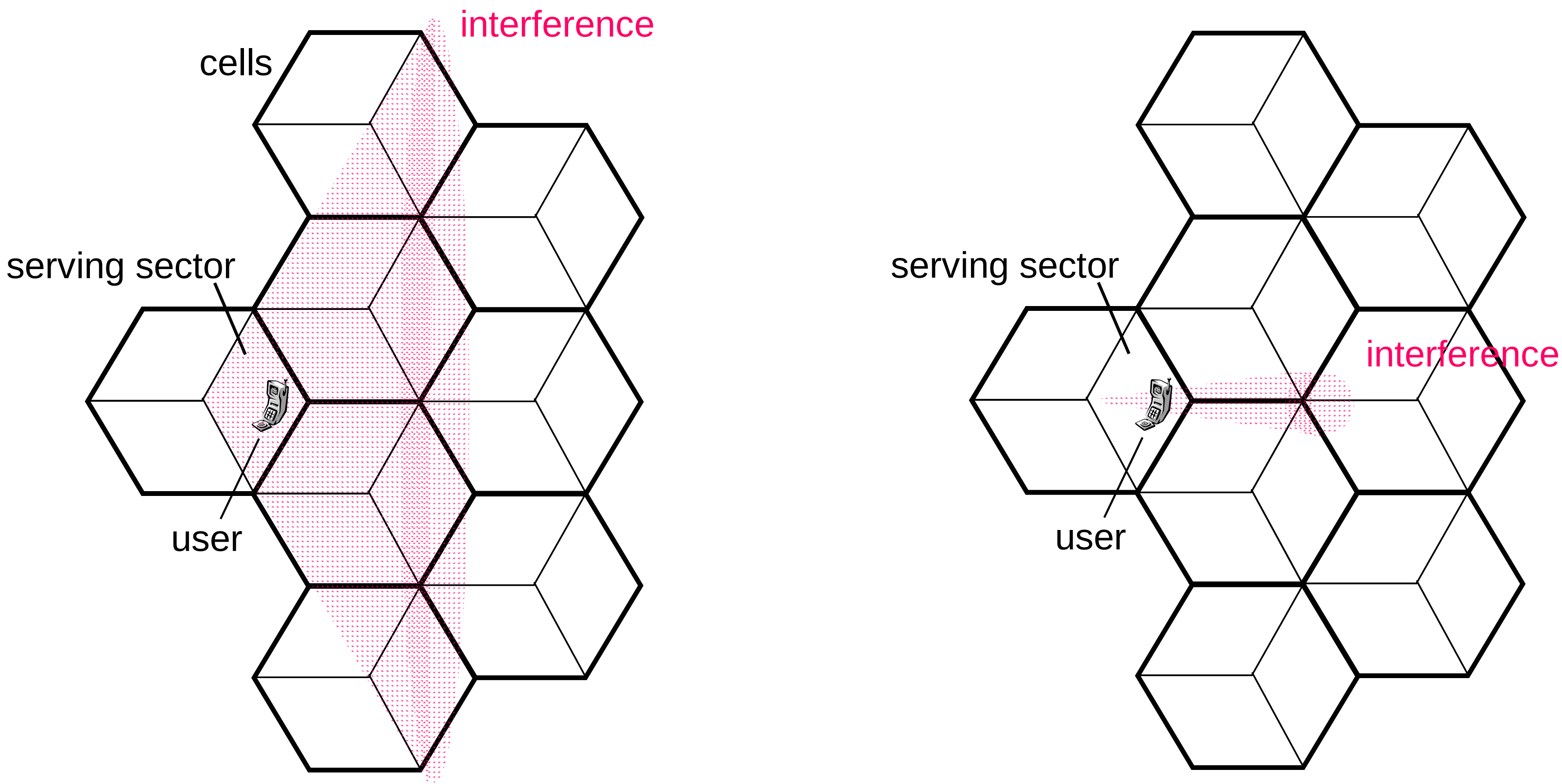
Performance of AMS



AMS overcomes the deficiencies of STBC and SM and leads to spectral efficiency very close to the ideal one at both low and high SNR regions

Beamforming

BF Starting Point

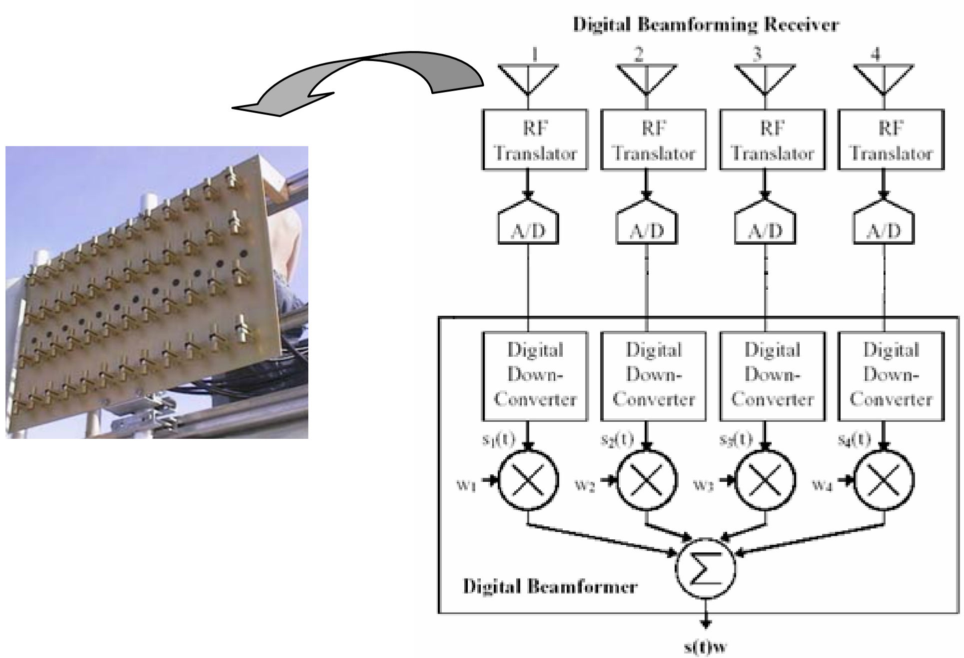


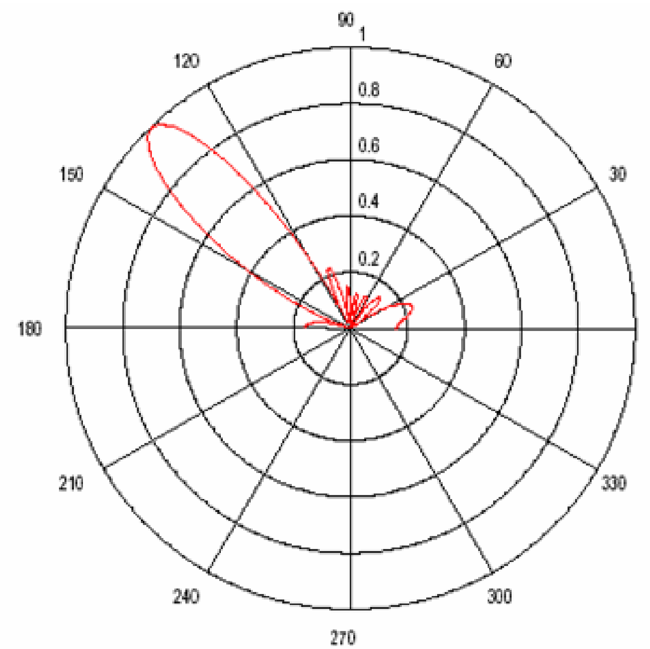
Form directional beam to reduce interference

- → Received signal power boosted for desired user
- → Nulling for other users
- → Fully adaptive

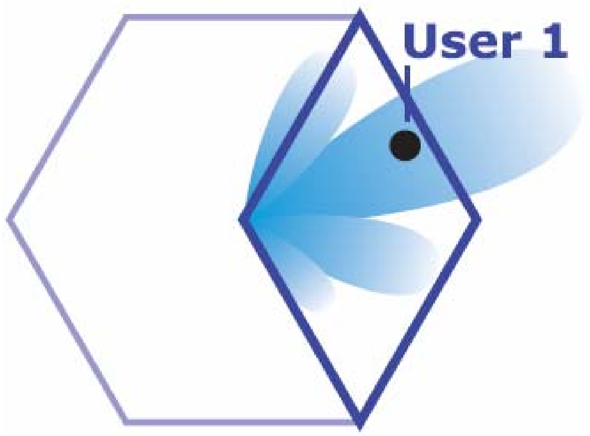
Beamforming & AAS

- Several small wide-beamwidth antennas form large directional array with narrow beamwidth
  - Higher antenna gain improves range
- Narrow beam reduces interference to and from other sectors and cells
  - Nulls in antenna pattern can be directed toward interferers
  - Improves channel capacity & spectral efficiency
- Base station only (Tx and Rx)

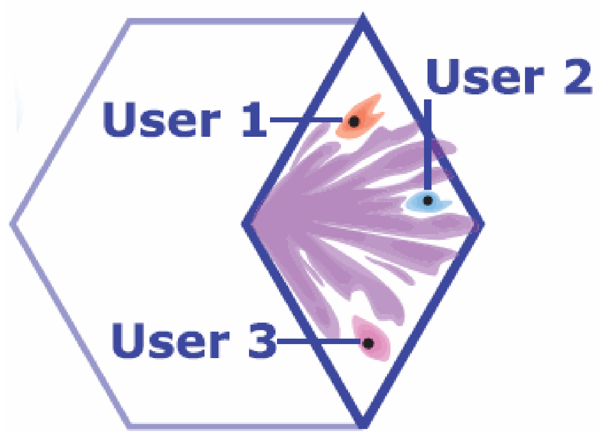




BF and AAS*



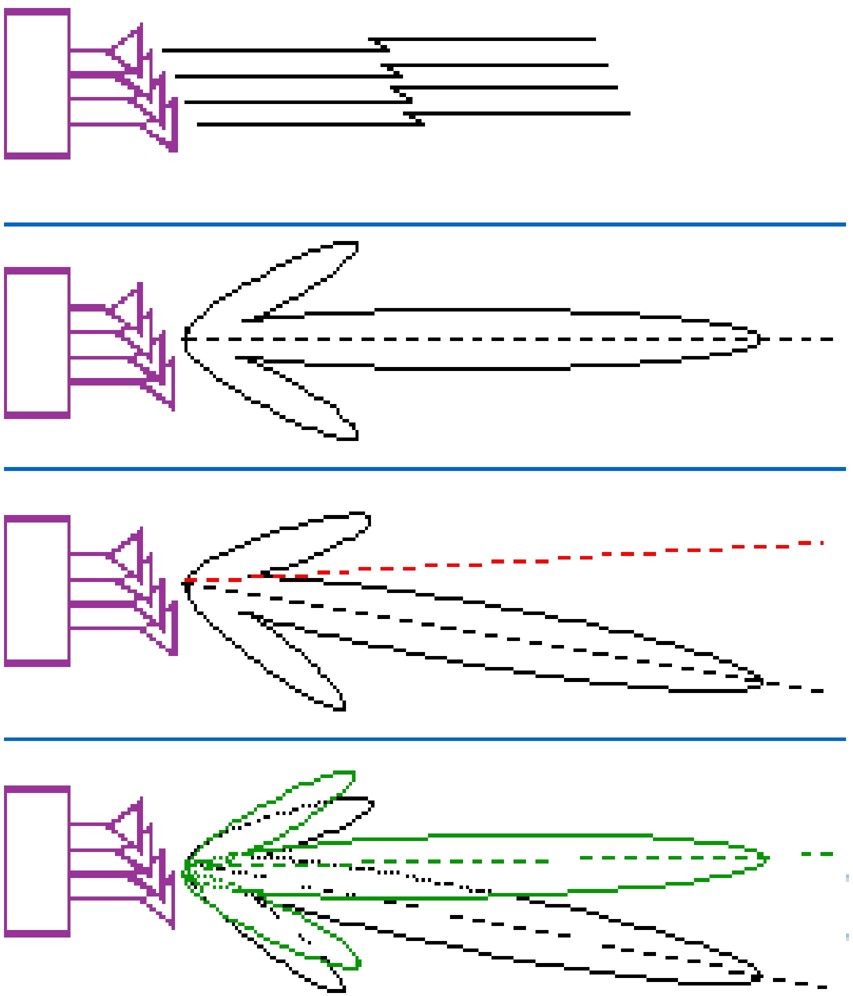
- Simple beam forming



- Fully adaptive antenna system

* ArrayComm, "Wireless isn't broadband without us", ArrayComm, 2004

Multi Antenna System



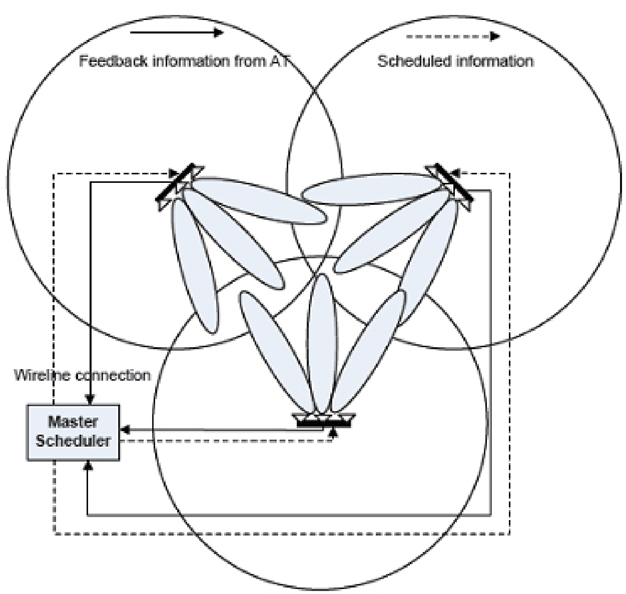
- Spatial Diversity
  - Gain due to multiple fading paths
  - Reduces fading margin
  - Gain depends upon scattering environment
- Coherent Gain
  - Improves link budget
  - Focuses radiation = passive I.C.
  - Gain = 10*log(N_ant)
- Interference Mitigation
  - Active interference cancellation
  - Enhances capacity
  - Increases per-user data rate
- **Spatial Multiplexing**
  - Single user = enhanced throughput
  - Multiple users = **SDMA**

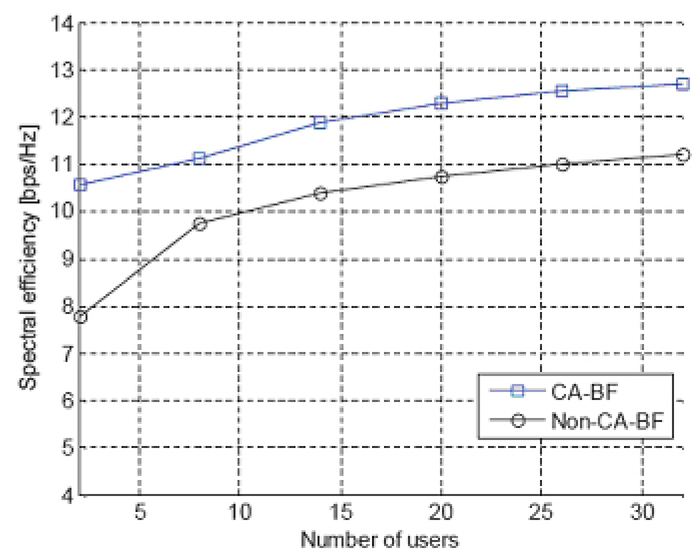
MU-MIMO and SDMA?

- “OL-SU-MIMO SM” (where different antennas clearly transmit independent different symbols, i.e., symbols are multiplexed in physical antenna domain) and “SDMA” (where different antennas work together to make spatially separate multiple signatures for multiple symbol delivery) look different from each other
- However, “MU-MIMO” and “SDMA” can be regarded as the same
- The difference could be
  - MU-MIMO ‘typically’ with codebook-based precoding/beamforming
  - SDMA ‘typically’ with non-codebook-based precoding/beamforming

Collision Avoidance Beamforming

- Actively studied in 3GPP2
- Scheduling technology which minimizes the collision b/w beams from adjacent cells
  - Adjacent cells should be coordinated through high speed network
  - MS needs to send feedback the estimated precoder of major interfering cell as well as the optimum precoder of serving cell
  - BS decides the beamforming based on the precoder feedback info
- Improve cell edge throughput & avg cell throughput
- One kind of COMP (Co-Operative Multi-Point transmission and reception) schemes





* 김동희 (삼성전자 통신연구소 표준연구랩, 3GPP2 TSG-C WG3 부의장), TTA Standard Weekly

MIMO Application in LTE

MIMO Processing in LTE

- Key Features
  - Supports 2 and 4 Tx antennas
    Min requirement: 2 TX/RX antenna @ BS, 2 RX antenna @ MS
  - Supports SU-MIMO and MU-MIMO
  - Codebook based closed loop MIMO processing
- Layer Mapping and Precoding
  - Tx diversity
  - Beamforming
  - Spatial Multiplexing

LTE MIMO Scheme

	DL MIMO		UL MIMO
SU-MIMO	Codebook based precoding	CDD based precoding	Not supported
	Up to 2 codewords transmission		
MU-MIMO	Single layer per UE		Supported
Transmit Diversity	SFBC/SFBC+FSTD for PDSCH/PDCCH/BCH		Tx antenna selection
	Transparent TD for Synchronization Signal (i.e. PVS or TSTD)		

SFBC+FSTD

- When the pilot density is same for data transmitted on four antennas

$$A = \begin{bmatrix} s_1 & -s_2^* & 0 & 0 \\ s_2 & s_1^* & 0 & 0 \\ 0 & 0 & s_3 & -s_4^* \\ 0 & 0 & s_4 & s_3^* \end{bmatrix}$$

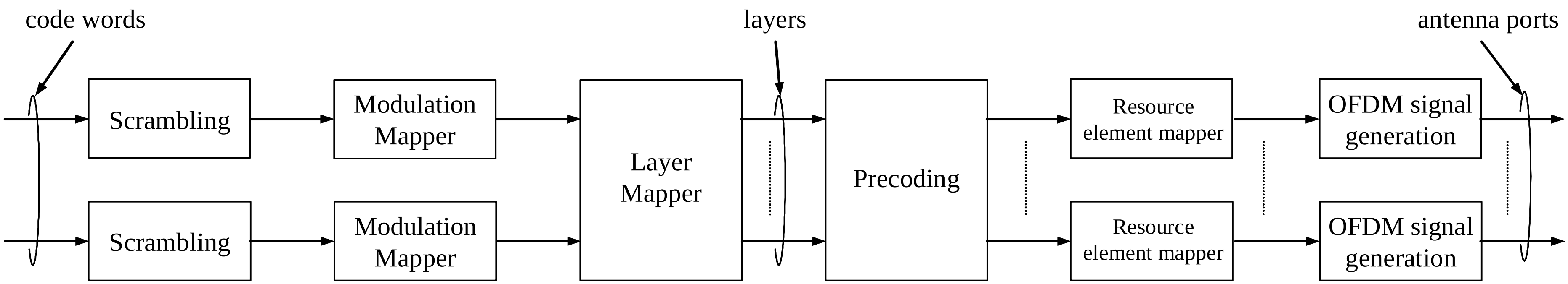
- When the pilot density for data transmitted on different antennas is not same, e.g. pilot density on group 1 (antenna 1 and 2) is not same with that on group 2 (antenna 3 and 4)

$$A = \begin{bmatrix} s_1 & -s_2^* & 0 & 0 \\ 0 & 0 & s_3 & -s_4^* \\ s_2 & s_1^* & 0 & 0 \\ 0 & 0 & s_4 & s_3^* \end{bmatrix}$$

- When the pilot density is all different for antenna 1, 2, 3 and 4

$$A = \begin{bmatrix} s_1 & 0 & s_3 & 0 \\ 0 & -s_2^* & 0 & -s_4^* \\ s_2 & 0 & s_4 & 0 \\ 0 & s_1^* & 0 & s_3^* \end{bmatrix}$$

DL Physical Channel Processing



- scrambling of coded bits in each of the code words to be transmitted on a physical channel
- modulation of scrambled bits to generate complex-valued modulation symbols
- mapping of the complex-valued modulation symbols onto one or several transmission layers
- precoding of the complex-valued modulation symbols on each layer for transmission on the antenna ports
- mapping of complex-valued modulation symbols for each antenna port to resource elements
- generation of complex-valued time-domain OFDM signal for each antenna port

* 3GPP TS 36.211, Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation, V8.6.0, March 2009

Layer Mapping

- The complex-valued modulation symbols for each of the code words to be transmitted are mapped onto one or several layers.
- Complex-valued modulation symbols $d^{(q)}(0),\ldots,d^{(q)}(M_{\text{symb}}^{(q)}-1)$ for code word q shall be mapped onto the layers $x(i)=\left[x^{(0)}(i) \quad \ldots \quad x^{(\upsilon-1)}(i)\right]^T$,

  $i=0,1,\ldots,M_{\text{symb}}^{\text{layer}}-1$.

  where υ is the number of layers

  $M_{\text{symb}}^{\text{layer}}$ is the number of modulation symbols per layer

- Layer mapping for transmission on a single antenna port

  $x^{(0)}(i)=d^{(0)}(i)$ with $M_{\text{symb}}^{\text{layer}}=M_{\text{symb}}^{(0)}$

Layer Mapping for SM

Table 6.3.3.2-1: Codeword-to-layer mapping for spatial multiplexing

Number of layers	Number of code words	Codeword-to-layer mapping $i = 0,1,\ldots,M_{\text{symb}}^{\text{layer}} - 1$	
1	1	$x^{(0)}(i) = d^{(0)}(i)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)}$
2	2	$x^{(0)}(i) = d^{(0)}(i)$ $x^{(1)}(i) = d^{(1)}(i)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)} = M_{\text{symb}}^{(1)}$
2	1	$x^{(0)}(i) = d^{(0)}(2i)$ $x^{(1)}(i) = d^{(0)}(2i+1)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)} / 2$
3	2	$x^{(0)}(i) = d^{(0)}(i)$ $x^{(1)}(i) = d^{(1)}(2i)$ $x^{(2)}(i) = d^{(1)}(2i+1)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)} = M_{\text{symb}}^{(1)} / 2$
4	2	$x^{(0)}(i) = d^{(0)}(2i)$ $x^{(1)}(i) = d^{(0)}(2i+1)$ $x^{(2)}(i) = d^{(1)}(2i)$ $x^{(3)}(i) = d^{(1)}(2i+1)$	$M_{\text{symb}}^{\text{layer}} = M_{\text{symb}}^{(0)} / 2 = M_{\text{symb}}^{(1)} / 2$

Layer Mapping for Tx Diversity

Table 6.3.3.3-1: Codeword-to-layer mapping for transmit diversity

Number of layers	Number of code words	Codeword-to-layer mapping $i = 0,1,\ldots,M_{symb}^{layer} - 1$	
2	1	$x^{(0)}(i) = d^{(0)}(2i)$ $x^{(1)}(i) = d^{(0)}(2i+1)$	$M_{symb}^{layer} = M_{symb}^{(0)}/2$
4	1	$x^{(0)}(i) = d^{(0)}(4i)$ $x^{(1)}(i) = d^{(0)}(4i+1)$ $x^{(2)}(i) = d^{(0)}(4i+2)$ $x^{(3)}(i) = d^{(0)}(4i+3)$	$M_{symb}^{layer} = M_{symb}^{(0)}/4$

Precoding

- The precoder takes as input a block of vectors $x(i)=\left[x^{(0)}(i) \quad \ldots \quad x^{(\upsilon-1)}(i)\right]^T$, $i=0,1,\ldots,M_{\text{symb}}^{\text{layer}}-1$ from the layer mapping and generates a block of vectors $y(i)=\left[\ldots \quad y^{(p)}(i) \quad \ldots\right]^T$, $i=0,1,\ldots,M_{\text{symb}}^{\text{ap}}-1$ to be mapped onto resources on each of the antenna ports where $y^{(p)}(i)$ represents the signal for antenna port p.

- Precoding for transmission on a single antenna port

$$y^{(p)}(i)=x^{(0)}(i)$$

Precoding without CDD

$$\begin{bmatrix} y^{(0)}(i) \\ \vdots \\ y^{(P-1)}(i) \end{bmatrix} = W(i) \begin{bmatrix} x^{(0)}(i) \\ \vdots \\ x^{(\upsilon-1)}(i) \end{bmatrix}$$

Precoding for large-delay CDD

$$\begin{bmatrix} y^{(0)}(i) \\ \vdots \\ y^{(P-1)}(i) \end{bmatrix} = W(i)D(i)U \begin{bmatrix} x^{(0)}(i) \\ \vdots \\ x^{(\upsilon-1)}(i) \end{bmatrix}$$

Table 6.3.4.2.2-1: Large-delay cyclic delay diversity

Number of layers υ	U	$D(i)$
1	$[1]$	$[1]$
2	$\frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & e^{-j2\pi/2} \end{bmatrix}$	$\begin{bmatrix} 1 & 0 \\ 0 & e^{-j2\pi i/2} \end{bmatrix}$
3	$\frac{1}{\sqrt{3}}\begin{bmatrix} 1 & 1 & 1 \\ 1 & e^{-j2\pi/3} & e^{-j4\pi/3} \\ 1 & e^{-j4\pi/3} & e^{-j8\pi/3} \end{bmatrix}$	$\begin{bmatrix} 1 & 0 & 0 \\ 0 & e^{-j2\pi i/3} & 0 \\ 0 & 0 & e^{-j4\pi i/3} \end{bmatrix}$
4	$\frac{1}{2}\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & e^{-j2\pi/4} & e^{-j4\pi/4} & e^{-j6\pi/4} \\ 1 & e^{-j4\pi/4} & e^{-j8\pi/4} & e^{-j12\pi/4} \\ 1 & e^{-j6\pi/4} & e^{-j12\pi/4} & e^{-j18\pi/4} \end{bmatrix}$	$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & e^{-j2\pi i/4} & 0 & 0 \\ 0 & 0 & e^{-j4\pi i/4} & 0 \\ 0 & 0 & 0 & e^{-j6\pi i/4} \end{bmatrix}$

Codebook for Precoding – 2 ports

- For transmission on two antenna ports, $p \in \{0,1\}$, the precoding matrix $W(i)$ shall be selected from Table 6.3.4.2.3-1 or a subset thereof.

Table 6.3.4.2.3-1: Codebook for transmission on antenna ports $\{0,1\}$.

Codebook index	Number of layers υ	
	1	2
0	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$	$\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}$
1	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$
2	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$	$\frac{1}{2}\begin{bmatrix}1 & 1\\j & -j\end{bmatrix}$
3	$\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$	-

Codebook for Precoding – 4 ports

- The quantity $W_n^{\{s\}}$ denotes the matrix defined by the columns given by the set $\{s\}$ from the expression $W_n = I - 2u_n u_n^H / u_n^H u_n$ where I is the 4x4 identity matrix and the vector u_n is given by Table 6.3.4.2.3-2.

Table 6.3.4.2.3-2: Codebook for transmission on antenna ports $\{0,1,2,3\}$.

Codebook index	u_n	Number of layers υ			
		1	2	3	4
0	$u_0 = \begin{bmatrix}1 & -1 & -1 & -1\end{bmatrix}^T$	$W_0^{\{1\}}$	$W_0^{\{14\}}/\sqrt{2}$	$W_0^{\{124\}}/\sqrt{3}$	$W_0^{\{1234\}}/2$
1	$u_1 = \begin{bmatrix}1 & -j & 1 & j\end{bmatrix}^T$	$W_1^{\{1\}}$	$W_1^{\{12\}}/\sqrt{2}$	$W_1^{\{123\}}/\sqrt{3}$	$W_1^{\{1234\}}/2$
2	$u_2 = \begin{bmatrix}1 & 1 & -1 & 1\end{bmatrix}^T$	$W_2^{\{1\}}$	$W_2^{\{12\}}/\sqrt{2}$	$W_2^{\{123\}}/\sqrt{3}$	$W_2^{\{3214\}}/2$
3	$u_3 = \begin{bmatrix}1 & j & 1 & -j\end{bmatrix}^T$	$W_3^{\{1\}}$	$W_3^{\{12\}}/\sqrt{2}$	$W_3^{\{123\}}/\sqrt{3}$	$W_3^{\{3214\}}/2$
4	$u_4 = \begin{bmatrix}1 & (-1-j)/\sqrt{2} & -j & (1-j)/\sqrt{2}\end{bmatrix}^T$	$W_4^{\{1\}}$	$W_4^{\{14\}}/\sqrt{2}$	$W_4^{\{124\}}/\sqrt{3}$	$W_4^{\{1234\}}/2$
5	$u_5 = \begin{bmatrix}1 & (1-j)/\sqrt{2} & j & (-1-j)/\sqrt{2}\end{bmatrix}^T$	$W_5^{\{1\}}$	$W_5^{\{14\}}/\sqrt{2}$	$W_5^{\{124\}}/\sqrt{3}$	$W_5^{\{1234\}}/2$
6	$u_6 = \begin{bmatrix}1 & (1+j)/\sqrt{2} & -j & (-1+j)/\sqrt{2}\end{bmatrix}^T$	$W_6^{\{1\}}$	$W_6^{\{13\}}/\sqrt{2}$	$W_6^{\{134\}}/\sqrt{3}$	$W_6^{\{1324\}}/2$
7	$u_7 = \begin{bmatrix}1 & (-1+j)/\sqrt{2} & j & (1+j)/\sqrt{2}\end{bmatrix}^T$	$W_7^{\{1\}}$	$W_7^{\{13\}}/\sqrt{2}$	$W_7^{\{134\}}/\sqrt{3}$	$W_7^{\{1324\}}/2$
8	$u_8 = \begin{bmatrix}1 & -1 & 1 & 1\end{bmatrix}^T$	$W_8^{\{1\}}$	$W_8^{\{12\}}/\sqrt{2}$	$W_8^{\{124\}}/\sqrt{3}$	$W_8^{\{1234\}}/2$
9	$u_9 = \begin{bmatrix}1 & -j & -1 & -j\end{bmatrix}^T$	$W_9^{\{1\}}$	$W_9^{\{14\}}/\sqrt{2}$	$W_9^{\{134\}}/\sqrt{3}$	$W_9^{\{1234\}}/2$
10	$u_{10} = \begin{bmatrix}1 & 1 & 1 & -1\end{bmatrix}^T$	$W_{10}^{\{1\}}$	$W_{10}^{\{13\}}/\sqrt{2}$	$W_{10}^{\{123\}}/\sqrt{3}$	$W_{10}^{\{1324\}}/2$
11	$u_{11} = \begin{bmatrix}1 & j & -1 & j\end{bmatrix}^T$	$W_{11}^{\{1\}}$	$W_{11}^{\{13\}}/\sqrt{2}$	$W_{11}^{\{134\}}/\sqrt{3}$	$W_{11}^{\{1324\}}/2$
12	$u_{12} = \begin{bmatrix}1 & -1 & -1 & 1\end{bmatrix}^T$	$W_{12}^{\{1\}}$	$W_{12}^{\{12\}}/\sqrt{2}$	$W_{12}^{\{123\}}/\sqrt{3}$	$W_{12}^{\{1234\}}/2$
13	$u_{13} = \begin{bmatrix}1 & -1 & 1 & -1\end{bmatrix}^T$	$W_{13}^{\{1\}}$	$W_{13}^{\{13\}}/\sqrt{2}$	$W_{13}^{\{123\}}/\sqrt{3}$	$W_{13}^{\{1324\}}/2$
14	$u_{14} = \begin{bmatrix}1 & 1 & -1 & -1\end{bmatrix}^T$	$W_{14}^{\{1\}}$	$W_{14}^{\{13\}}/\sqrt{2}$	$W_{14}^{\{123\}}/\sqrt{3}$	$W_{14}^{\{3214\}}/2$
15	$u_{15} = \begin{bmatrix}1 & 1 & 1 & 1\end{bmatrix}^T$	$W_{15}^{\{1\}}$	$W_{15}^{\{12\}}/\sqrt{2}$	$W_{15}^{\{123\}}/\sqrt{3}$	$W_{15}^{\{1234\}}/2$

Codebook for Transmit Diversity

$$\begin{bmatrix} y^{(0)}(2i) \\ y^{(1)}(2i) \\ y^{(0)}(2i+1) \\ y^{(1)}(2i+1) \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 0 & j & 0 \\ 0 & -1 & 0 & j \\ 0 & 1 & 0 & j \\ 1 & 0 & -j & 0 \end{bmatrix} \begin{bmatrix} \mathrm{Re}\left(x^{(0)}(i)\right) \\ \mathrm{Re}\left(x^{(1)}(i)\right) \\ \mathrm{Im}\left(x^{(0)}(i)\right) \\ \mathrm{Im}\left(x^{(1)}(i)\right) \end{bmatrix}$$

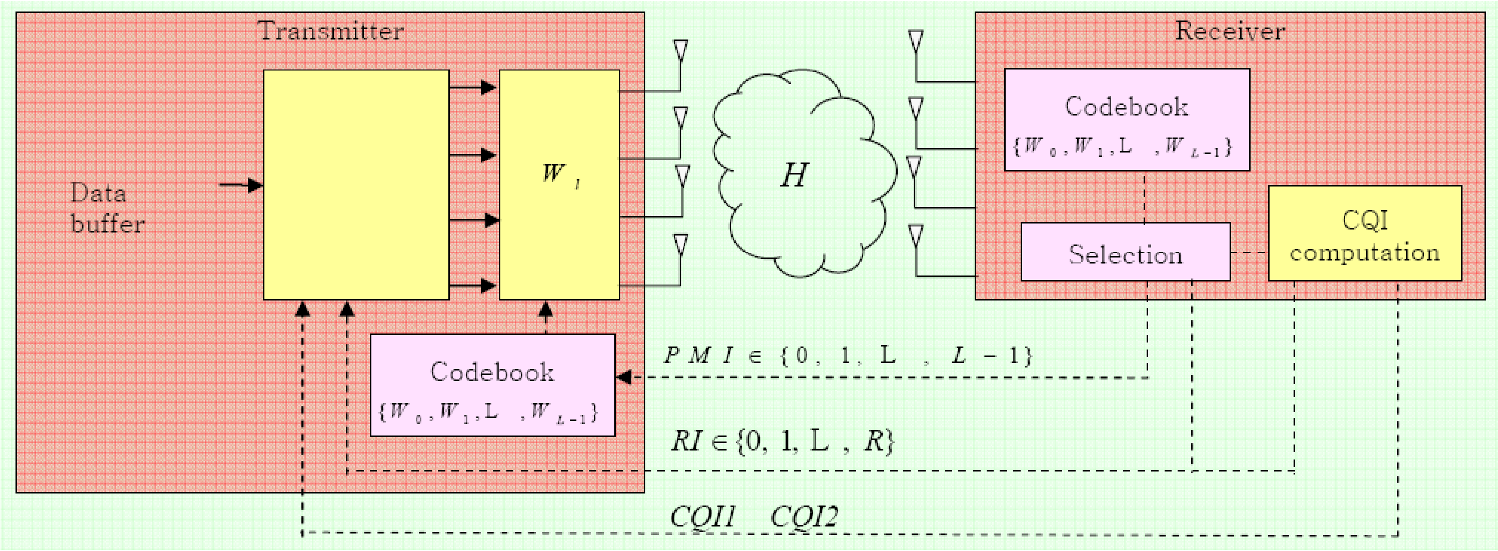
$$\begin{bmatrix} y^{(0)}(4i) \\ y^{(1)}(4i) \\ y^{(2)}(4i) \\ y^{(3)}(4i) \\ y^{(0)}(4i+1) \\ y^{(1)}(4i+1) \\ y^{(2)}(4i+1) \\ y^{(3)}(4i+1) \\ y^{(0)}(4i+2) \\ y^{(1)}(4i+2) \\ y^{(2)}(4i+2) \\ y^{(3)}(4i+2) \\ y^{(0)}(4i+3) \\ y^{(1)}(4i+3) \\ y^{(2)}(4i+3) \\ y^{(3)}(4i+3) \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} 1 & 0 & 0 & 0 & j & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & j & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & j & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & -j & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & j & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 & 0 & 0 & 0 & j \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & j \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & -j & 0 \end{bmatrix} \begin{bmatrix} \mathrm{Re}\left(x^{(0)}(i)\right) \\ \mathrm{Re}\left(x^{(1)}(i)\right) \\ \mathrm{Re}\left(x^{(2)}(i)\right) \\ \mathrm{Re}\left(x^{(3)}(i)\right) \\ \mathrm{Im}\left(x^{(0)}(i)\right) \\ \mathrm{Im}\left(x^{(1)}(i)\right) \\ \mathrm{Im}\left(x^{(2)}(i)\right) \\ \mathrm{Im}\left(x^{(3)}(i)\right) \end{bmatrix}$$

RI, PMI, CQI

- Rank Indication (RI)
  - Info about the channel rank or, expressed differently, the number of layers that should, preferably, be used for Dl transmission to the UE
- Precoder Matrix Indication (PMI)
  - Provides a precoder matrix that should, preferably, used for DL transmission
  - The reported precoder matrix should be determined assuming the number of layers indicated by RI
  - PMI is reported only in CL mode. In OL mode, the network instead selects the precoder matrix to use according to a pre-defined rule.
  - Network has 2 choices:
    - The network may follow the recommendation from UE, in which case it only has to confirm with 1 bit indicator in DL scheduling assignment.
    - The network may select a different precoder. Then the precoder information needs to be explicitly included in DL scheduling assignment.
- Channel Quality Indication (CQI)
  - A set of pre-defined MCS combinations

Channel-Status Reports

- Illustration of PMI Selection, CQI and RI Reporting (example)



- *wideband reports* reflects the status over the entire cell BW
  per-subband reports reflects the status over each subband where one subband size is ranging from 2 RBs to 8 RBs
- *periodic reports* is normally delivered using PUCCH
  aperiodic reports or *trigger-based reports* is always delivered using PUSCH

Sounding RS

- Reference for channel quality information
  - Channel quality measurement for frequency/time aware scheduling
  - Channel quality measurement for link adaptation
  - Channel quality measurement for power control
  - Channel quality measurement for MIMO, BF
- Sequence generation

  $r^{\mathrm{SRS}}(n) = r_{u,v}^{(\alpha)}(n)$ which is defined by cyclic shift α of a base sequence $\bar{r}_{u,v}(n)$

- SRS can be used for *non-codebook-based beamforming* together with *user-specific reference signals*

Summary

MIMO is already in the Market - IEEE 802.11n

[2007 IT 히트상품] 노트북PC - LG전자 `산타로사 R500`

[디지털타임스 2007-06-27 06:09:55]

무선랜 135Mbps 속도 고성능

LG전자는 인텔 차세대 모바일 센트리노 산타로사 플랫폼 론칭에 맞춰 산타로사 노트북PC를 대거 출시했다. 고성능과 차별화 된 디자인을 겸비한 산타로사 노트북PC 5종을 출시했으며 디자인과 성능을 앞세워 프리미엄 시장 공략에 나서고 있다.

15.4인치 R500은 인텔 코어2 듀오 프로세서, 모바일 칩셋과 선택 사양인 최신 무선랜, 터보 메모리로 구성되며, 고효율과 빠른 무선 인터넷 환경을 제공하는 것이 특징이다. 인텔 코어2듀오 프로세서 T7500(2.2㎓) CPU, 2GB 듀얼 채널 메모리, 터보 메모리를 적용한 160GB HDD, 최신 3D 그래픽 `엔비디아 지포스 8600M GS 256MB'메모리를 탑재했다.

Power of MIMO

삼성전자 4G 이동통신 시대 이끈다

2006-09-01

- 삼성전자 세계최초로 4G기술 공개시연 성공
- 삼성 와이브로에 이어 4G표준 이끈다

삼성전자는 31일 제주 신라호텔에서 열린 삼성 4G 포럼 2006에서 정지시 1Gbps급 이동시 100Mbps급 전송속도로 끊김없이 데이터를 송수신하는 4G 시범시연에 성공했다.

⋮

특히 삼성전자는 최고 전송률을 자랑하는 '8X8 MIMO(Multi Input Multi Output 다중안테나) 기술'을 이용해 세계 최초로 3.5Gbps 전송속도 실험결과를 발표하였다. 기존 무선랜은 1개의 전파를 1개의 경로를 따라 전달되기 때문에 장애물에 의해 신호가 약해졌던 것에 비해 삼성전자의 '8X8 MIMO 기술'은 각각 8개의 송신 및 수신 안테나로 모든 신호를 동시에 내보내고 받아내기 때문에 3.5Gbps나 되는 대용량 데이터 전송이 가능하다. 4G로 정의된 전송속도가 정지시 1Gbps급인 것을 감안할 때 삼성전자는 일반 4G속도의 3.5배에 달하는 기술을 선보인 것이다.

ETRI, 세계 최초 3.6Gbps 4G 무선전송시스템 개발

이동통신 2007/10/12 11:15

- CDMA, WiBro, 지상파DMB이어 또 한번 세계 최고 기술력 선보여
- 이동통신 선진국에 비해 최소 1년 먼저 원천기술 확보

ㅇ ETRI는 2007년 10월 11일, 4G 이동통신(IMT-Advanced)의 정지 및 저속(3km/h) 이동시 최소 요구 규격인 1Gbps보다 3배 이상 빠른 3.6Gbps 전송속도를 구현하는 저속이동용 무선전송시스템(이하 NoLA)을 세계 최초로 개발하여 시연회를 개최

- 현재 약 100Mbps 속도의 광랜으로 영화 한 편을 1분 정도 만에 다운로드 받을 수 있는데 비해 이번에 개발된 기술은 단 수 초만에 가능하고, 5기가바이트 급 백과사전과 HD급 동영상 등을 다운로드 받을 때 적게는 수십분이 걸리는데 비해 개발된 기술은 약 10여초 이내에 다운로드가 가능

ㅇ 이번에 개발된 기술은 유럽과 미국, 일본을 중심으로 1Gbps 정도의 시스템이 개발되어 있는 정도이며, 국제전기통신연합(ITU)의 차세대 무선 전송의 핵심기술로 경쟁이 치열한 분야일 뿐만 아니라 실시간 구현하기까지 많은 어려움이 산재되어 불가능에 가까운 기술이었음

- 그러나 ETRI는 이러한 여러 난제를 ▲여덟 개의 다중 안테나를 사용한 미모(MIMO) 기술 ▲ Multi-Rate LDPC 부호기 기술 ▲ Multi-Gigabit LDPC 복호기 설계 및 구현 기술 ▲ Multi-Gigabps급 Throughput(처리량) 제공 무선제어 기술 등 네 가지 핵심 기술을 바탕으로 개발하였으며, 현재까지 선진국에 비해 최소 1년 이상 최대 3년 앞선 원천기술을 확보하게 됨

Multiple Antenna Technology

Array Gain	Spatial Diversity Gain
• Increase in average SNR ($SNR_1 + \ldots + SNR_{MR}$) • Available at Tx & Rx through coherent combining • Requires channel knowledge • Beamforming techniques including smart antennas	• Benefits from indep. fading paths (space/time/frequency/etc) • Reduces variability (variance of power) • To overcome the effects of fading • Minimize Pe (conservative approach)
Multiplexing Gain	**Interference Reduction**
• Offers linear increase in capacity by transmitting independent data streams from different antennas • Critical to achieve high spectral efficiency Maximize transmission rate (optimistic approach) • Use rich scattering/fading to your advantage	• Exploits the difference of spatial signatures of the user and CCIs • Allows aggressive freq. reuse plan • Space-time signal processing can cancel or reduce the interference, and boost signal power and reduce signal amplitude variability

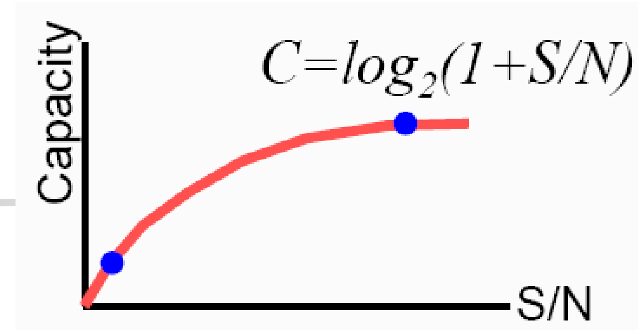
* 이미현 (삼성전자), “WiBro를 위한 MIMO 기술”, TTA 표준 기술 교육, Sep. 2008

MIMO vs. AAS

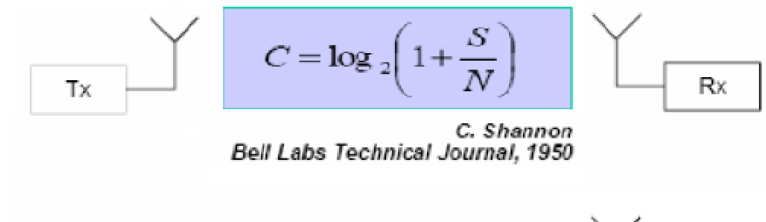
	MIMO	AAS
Requirement	■Largely separated TX antennas	■Closely spaced Tx antennas ■Relatively static condition
Pros	■No requirement on channel conditions (mobile, static, flat, FSF etc) ■Versatile structure (OL, CL in i.i.d or correlated channels) ■No complicated calibration needed (OL) ■Signaling scheme less complicated ■Linear capacity increase with the number of antennas at no cost in BW and transmit power ■No feedback overhead even in FDD (OL) ■Includes the beamforming as a special form (single stream precoding)	■Adaptive beamforming on the best frequency bin to maximize throughput ■Interference reduction capability ■Range extension advantage ■Less complexity and power at SS ■Multi-user diversity gain
Cons	■More complexity at SS in general ($N_R \geq N_T$) ■Not suitable at very low SINR region	■Sensitive to channel time variation ■Signaling overhead (e.g AAS preamble, sounding) ■Complicated calibration required

* 이미현 (삼성전자), “WiBro를 위한 MIMO 기술”, TTA 표준 기술 교육, Sep. 2008

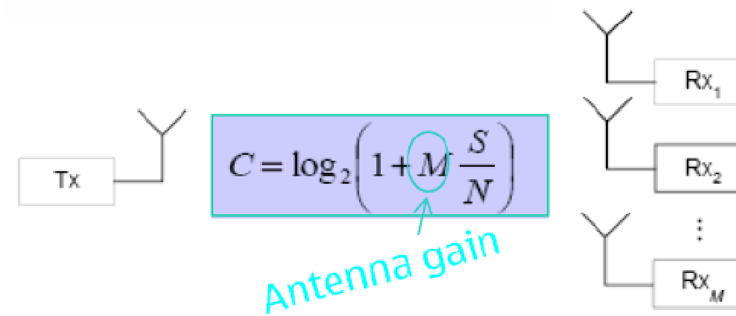
MIMO Summary



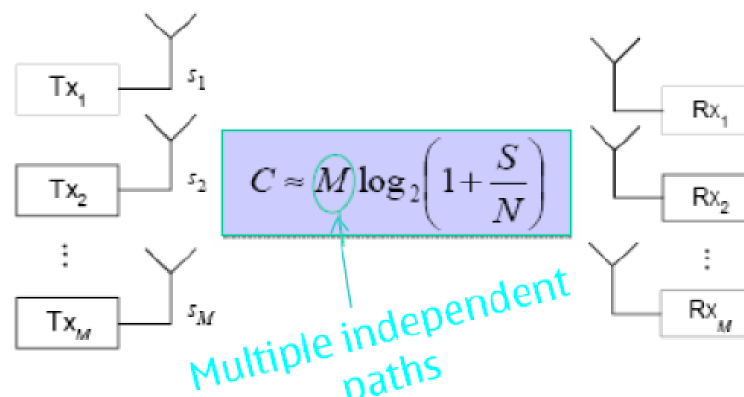
- SISO
  - Capacity = log(1+SNR)



- SIMO
  - SNR이득: x 수신안테나수
  - Diversity이득

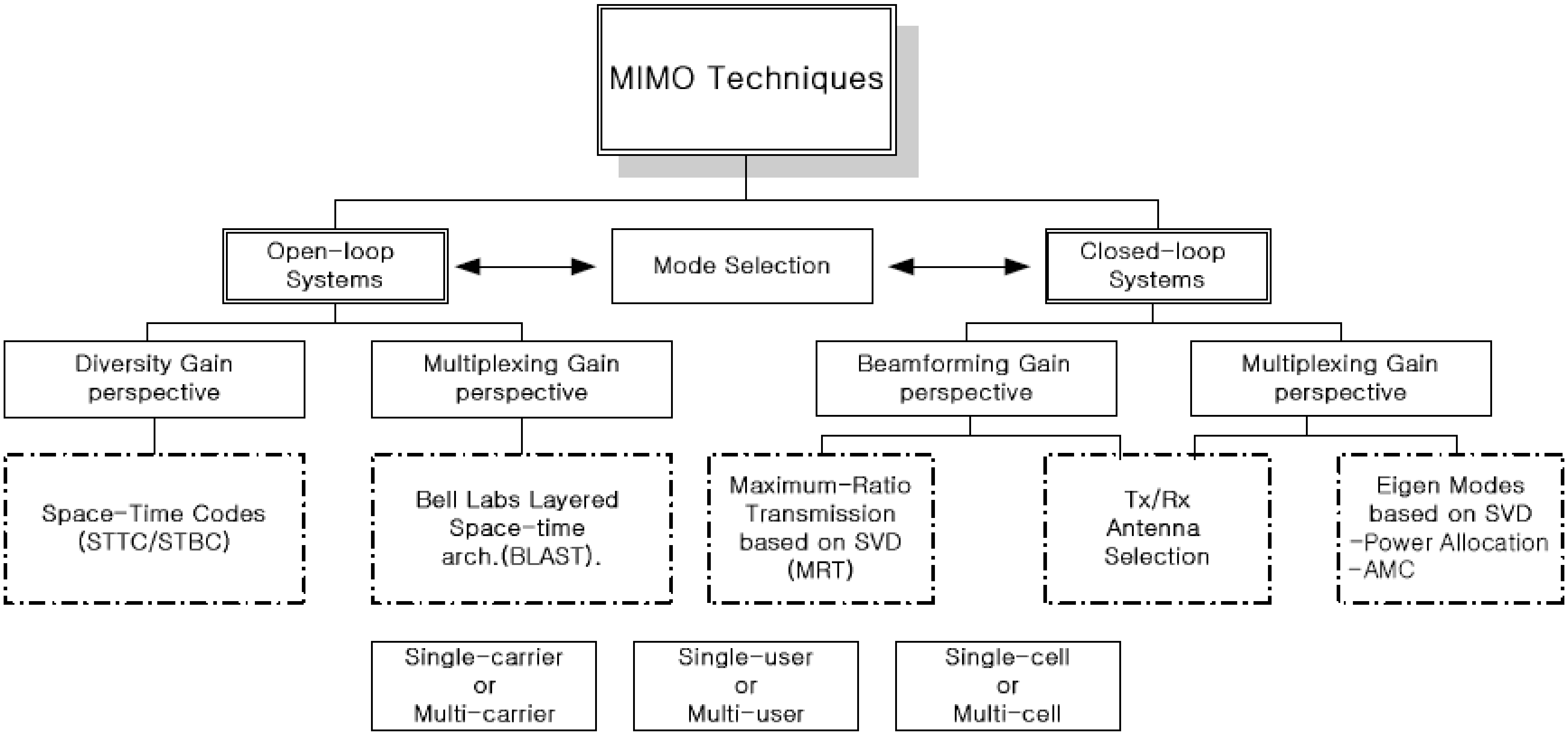


- MIMO
  - 용량증가: x min(Ntx, Nrx)



* 황근철 (삼성전자), “MIMO 기술현황”, 제4회 중소기업을 위한 이동통신 기술지원 세미나, 청강문화산업대, May 2008

MIMO techniques



Key Messages

- MIMO = Diversity + SM + ...
- MIMO SM (OL/CL) is NOT very difficult to understand
- MIMO is one of the KEY ENABLERS for broadband wireless system
- MIMO has CHALLENGES to be overcome

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