WiBro를 위한 MIMO 기술

2007. 6. 22

이미현 책임연구원

mihyun.mac.lee@samsung.com

Samsung Electronics

Outline

- **Multiple Antenna Technology**
  - **Space Diversity**
  - **Spatial Multiplexing**
  - **Beamforming**
- **MIMO in IEEE802.16e**
  - **Matrix A, B, C**
  - **Antenna Grouping/Selection**
  - **MIMO Precoding**
- **AAS(Adaptive Antenna System) in IEEE802.16e**
  - **AAS System Design**
  - **AAS System Operation**

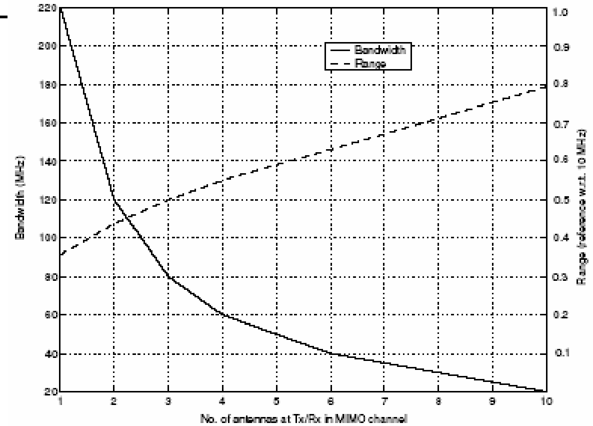
Multiple Antenna Technology

- *Gains of Multiple Antenna*
- *Multiple Antenna Structure*
- *Codebook-based Precoding*

Why MIMO?

For 4G Ultra Broadband Wireless, e.g., 1 Gbps data rate

- SISO can NOT achieve high spectral efficiency
  - Limitation on high power transmission (≤ 1 watt)
  - Peak receive SNR limit due to limitation on linear LNA (≤ 30-35 dB)
  - Average receive SINR lies in the range of 10-20 dB at best → 4-6 bps/Hz (2-4 bps/Hz typically)
  - Using high gain directional antennas in LOS channels (up to 9 bps/Hz) prohibit mobility

SISO	MIMO
▪ 250 MHz needed (4 bps/Hz) ▪ Scarce under 6 GHz (needed for NLOS op) ▪ Range reduction unavoidable (factor of 3 smaller than 10 MHz transmission with *n=3*) ▪ Considering cellular operation, 250 MHz per link may be too much	

Ref. Paulraj et al, Proc. IEEE, Feb. 2004

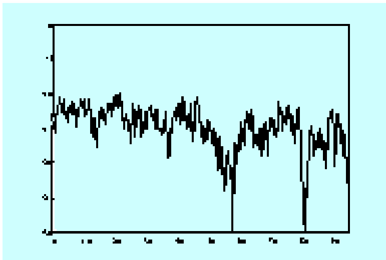
Why MIMO?

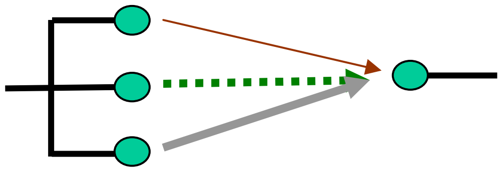
Target

High data rate	→	• Channel Capacity (C)
Quality	→	• Minimize the Probability of Error (Pe)
Real-life Issues	→	• Minimize the complexity/cost of implementation of the proposed system • Minimize the transmission power required (translate into SNR) • Minimize the Bandwidth used

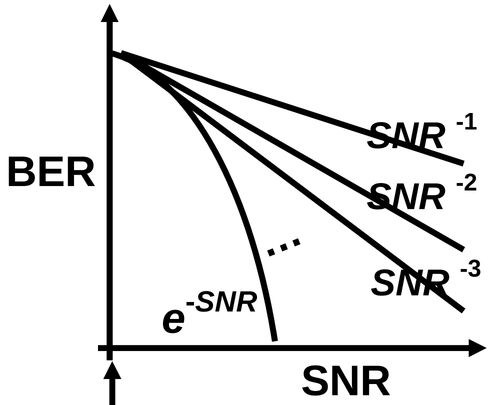
Gains of Multiple Antenna

- *Spatial Diversity:* **Link Reliability**

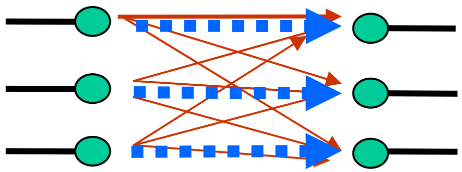




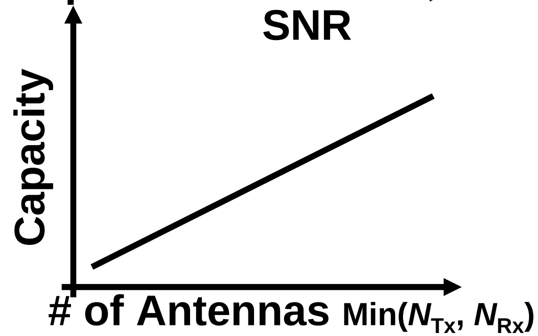
Diversity



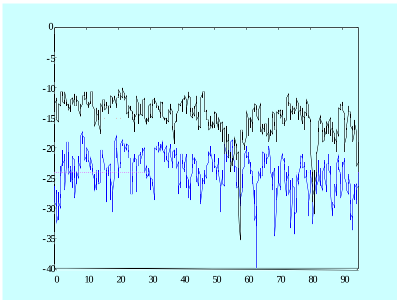
- *Spatial Multiplexing:* **Data Rate**

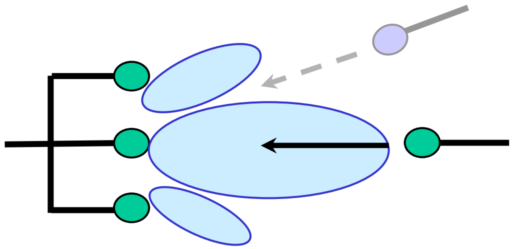


Multiplexing

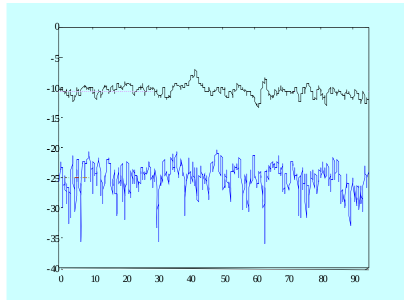


- *Beamforming:* **SINR, SDMA**





Beam forming

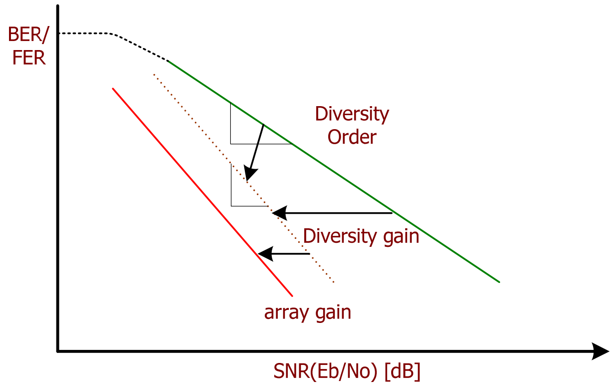


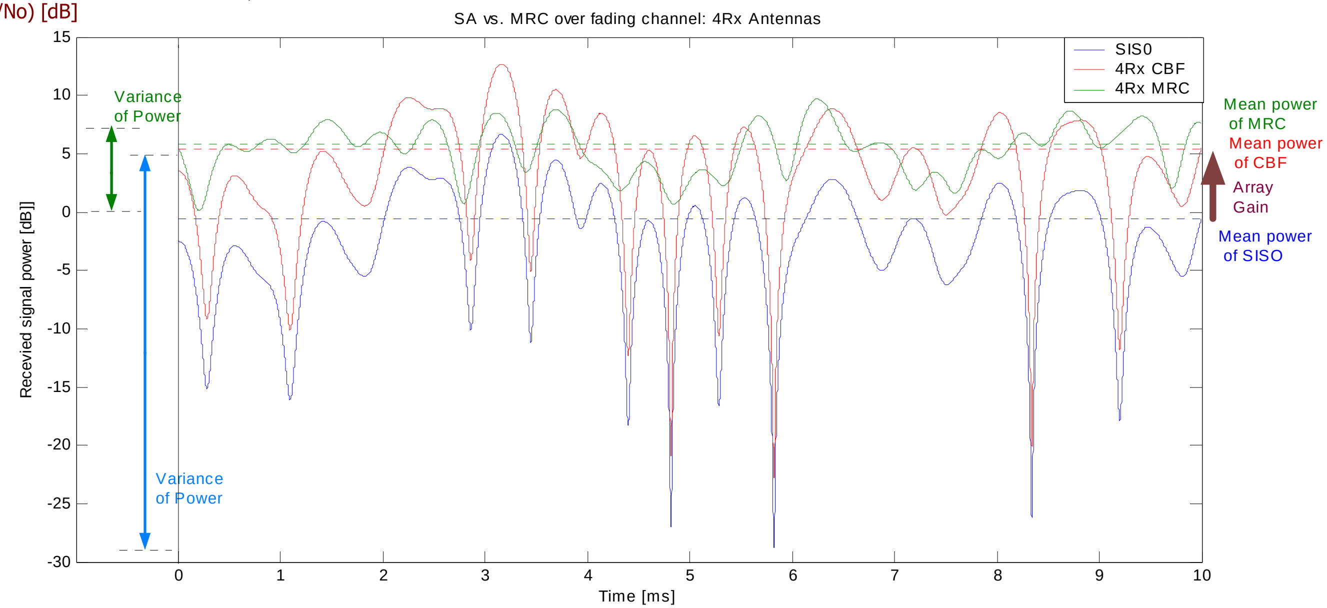
Gains of Multiple Antenna

Array Gain	Spatial Diversity Gain
• Increase in average SNR (SNR_1 +…+ SNR_{M_R}) • 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

Array Gain

- Gain linearly increase to # of antennas





Spatial Diversity (1/4)

- Spatial diversity Gain
  - Transmit diversity
  - Receive diversity
  - Space-time signal processing techniques

- For an (N_R, N_T) system
  - The total number of signal paths is $N_T N_R$
  - The maximal diversity gain d_{max} is the total number of independent signal paths that exist between the transmitter and receiver

$$1 \leq d \leq d_{max} = N_T N_R$$

  - A diversity gain d implies that in the high SNR region, P_e decays at a rate of SNR^{-d} as apposed to SNR^{-1} for a SISO system (d: slope of BER curve in log-log domain)

Spatial Diversity (2/4)

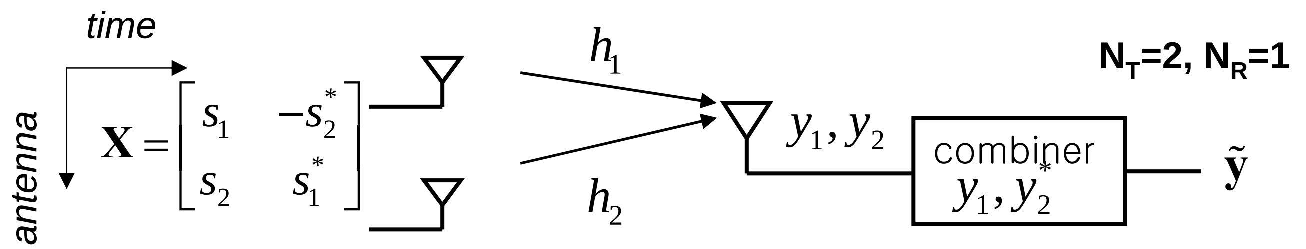
- **Transmit Diversity:** Multiple Antennas at Transmitter
  - Delay diversity (e.g. Cyclic Delay Diversity)
  - Antenna hopping
    - FSTD (Frequency Switched Transmit Diversity)
    - TSTD (Time Switched Transmit Diversity)
  - MRT (Maximum Ratio Transmit)
  - TxAA (Transmit Antenna Array)

Spatial Diversity (3/4)

- Receiver Diversity: Multiple Antennas at Receiver
  - Selection diversity: choose received signal with the largest received power, SNR, etc
  - Switched diversity: choose alternate antenna if signal falls below a certain threshold
  - Linear combining: linearly combine a weighted replica of all received signals (MRC, EGC)

Spatial Diversity (4/4)

- Sophisticated Space-Time Signal Processing Techniques
  - STBC/SFBC, SFTC
- Space-Time Block Codes (STBC)
  - Achieve full transmit diversity (full rank)
  - Simple linear processing at receivers
  - N_T TX antennas; K encoded symbols; L channel uses (delay)
  - Diversity order = rank, Rate = $r_s = K/L$
  - Channel assumed to remain constant over two symbol time and frequency flat



$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \Rightarrow \tilde{\mathbf{y}} = \begin{bmatrix} \tilde{y}_1 \\ \tilde{y}_2 \end{bmatrix} = \begin{bmatrix} |h_1|^2 + |h_2|^2 & 0 \\ 0 & |h_1|^2 + |h_2|^2 \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \mathbf{H}^H \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix}$$

Spatial Multiplexing (1/3)

- MIMO Channel

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

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

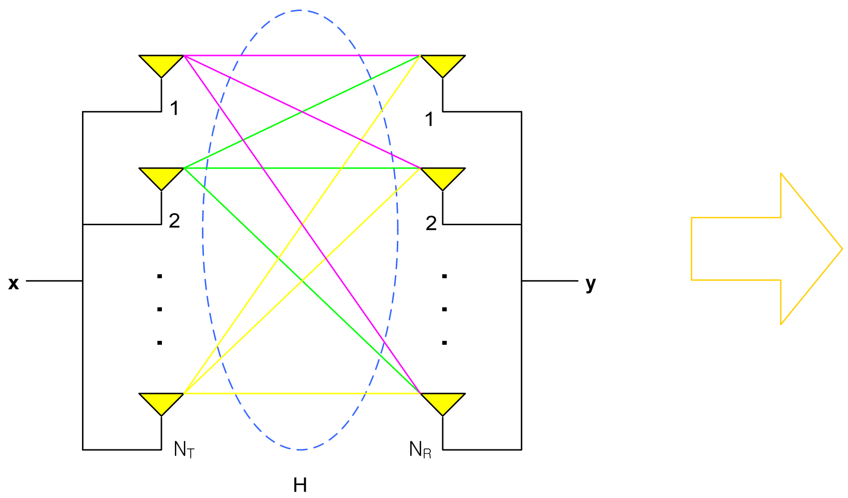
Eigen Value Decomposition

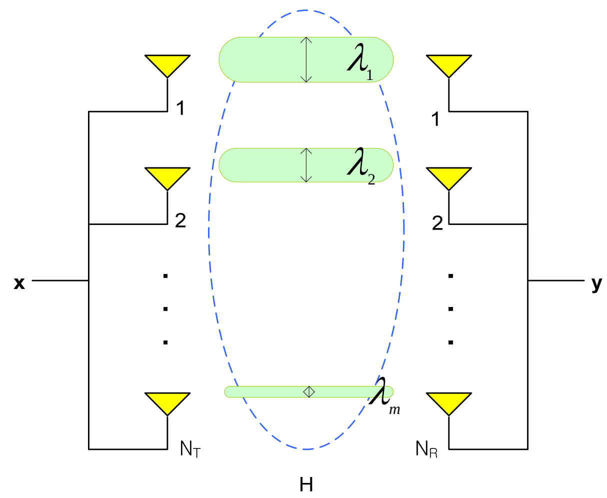
$$\mathbf{R} = \mathbf{V}\mathbf{\Lambda}\mathbf{\Lambda}^H = \mathbf{V}\mathbf{D}^H\mathbf{D}\mathbf{V}^H$$

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

Spatial Multiplexing (2/3)

- Allows even higher data rates by transmitting parallel data streams in the same frequency spectrum
  - (N_T, N_R) MIMO channel opens up $m=\min(N_T, N_R)$ independent SISO channels between the transmitter and the receiver
  - Viewing the MIMO received vector in a different but equivalent way
  - So, intuitively, send a maximum of m different information symbols over the channel at any given time

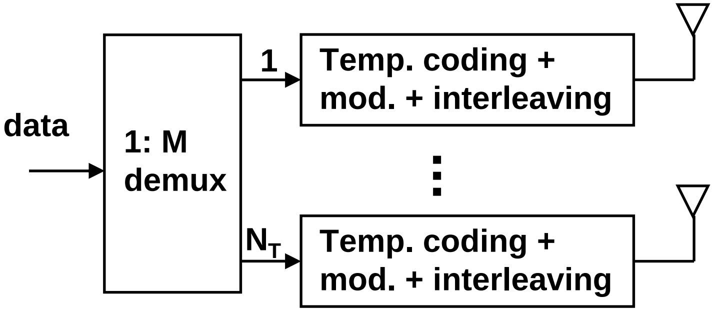




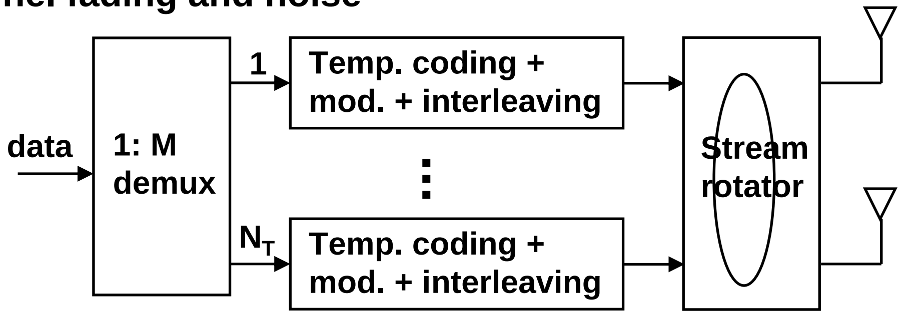
Spatial Multiplexing (3/3)

Goal: To send independent stream of data through different transmit antennas ($r_s = N_T$) and decode the signal vector successfully

Impairments: Multi-stream interference, channel fading and noise

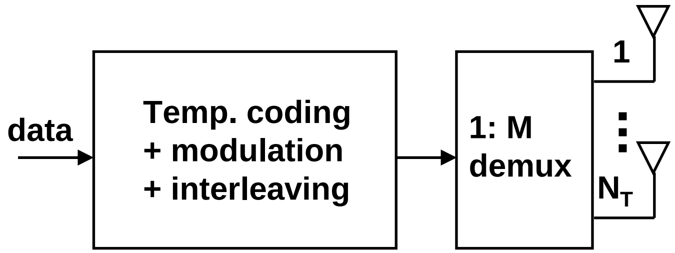


Horizontal Encoding (HE) : div. order = N_T; sub-optimal; easy to decode



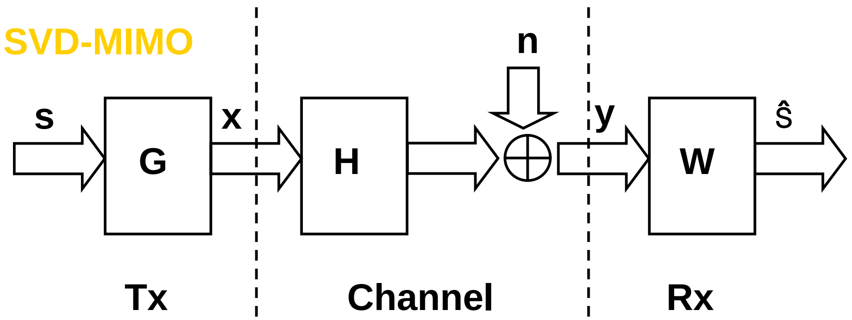
Diagonal Encoding (DE) :

- can achieve full diversity (MN_T)
- complexity close to HE
- D-BLAST has initial wasted ST block (Foschini '96)



Vertical Encoding (VE) : div. order = $N_T N_R$; optimal; require joint decoding of streams

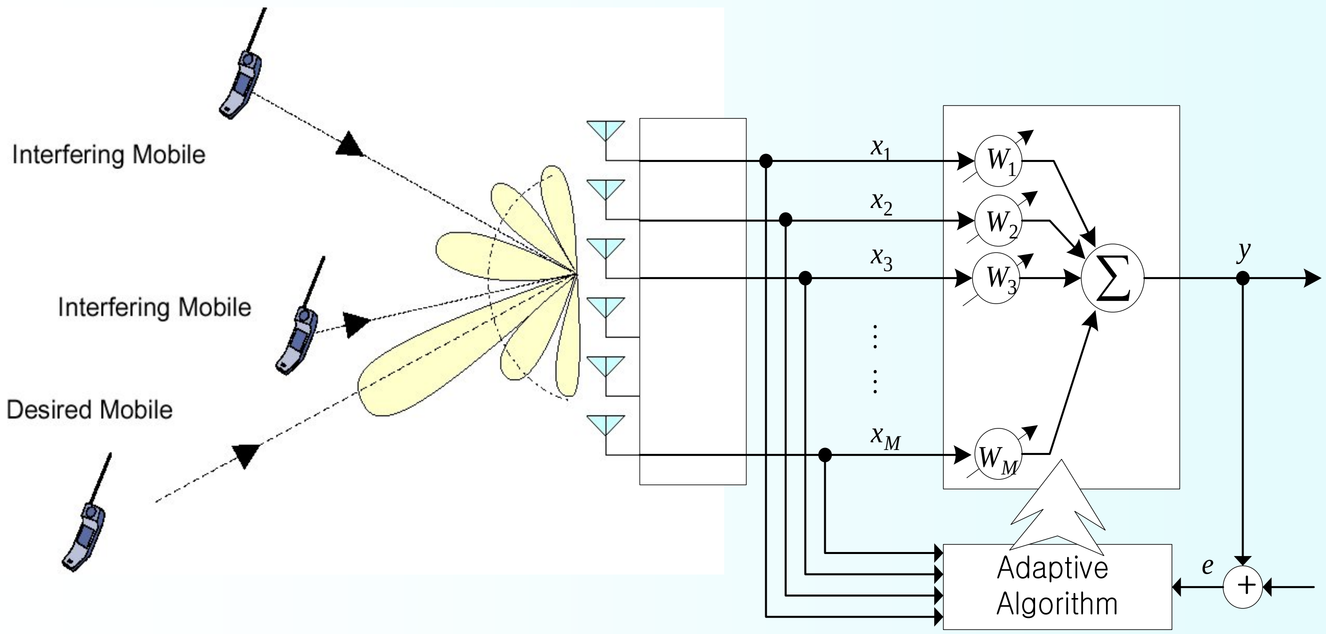
SVD-MIMO



$\mathbf{G} = \mathbf{V}\mathbf{D}^{1/2}$ $\qquad$ $\mathbf{H} = \mathbf{U}\Sigma\mathbf{V}^*$

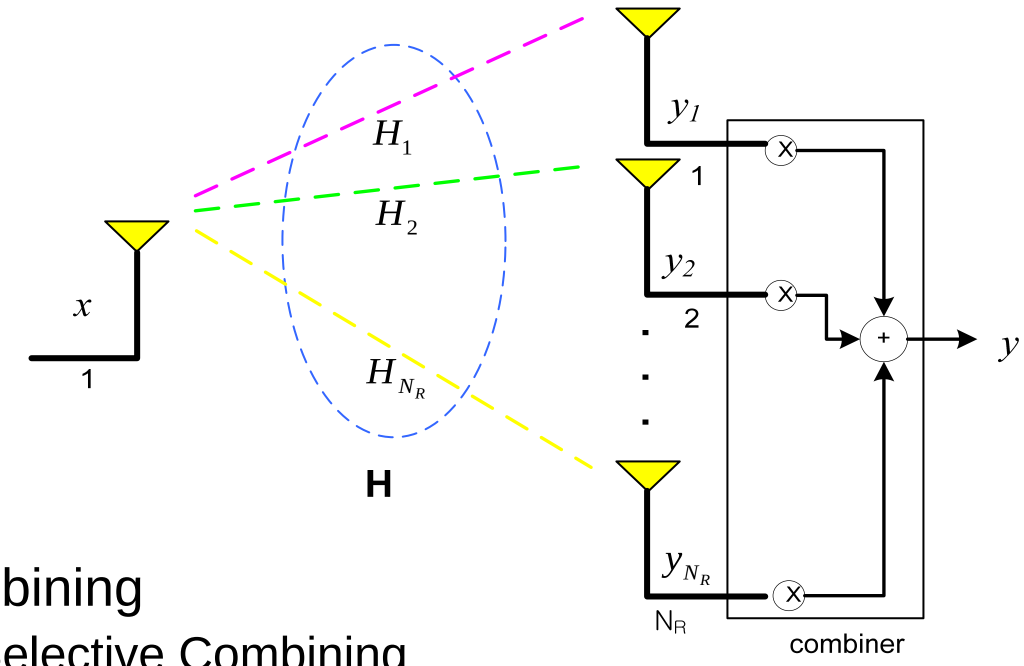
Beamforming

Adaptive Antenna Array System



SIMO

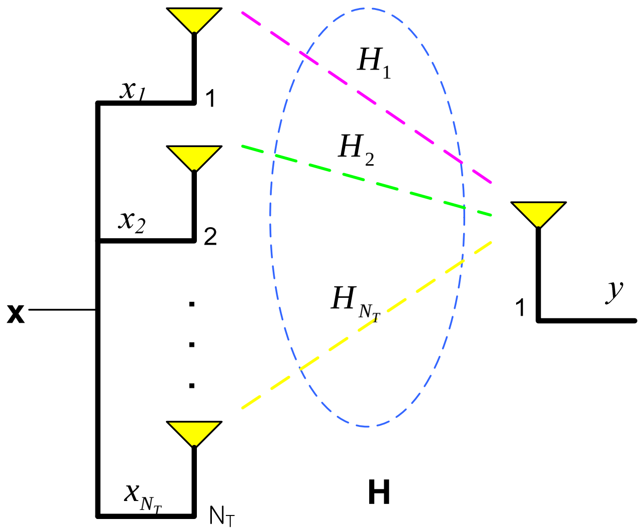
- A single transmit antenna and N_R receive antennas



- Combining
  - Selective Combining
  - Maximal Ratio Combining
  - Equal Gain Combining

MISO (1)

- N_T transmit antennas and a single receive antenna
  - Array gain : mean power ↑
  - Diversity gain : variance of power ↓

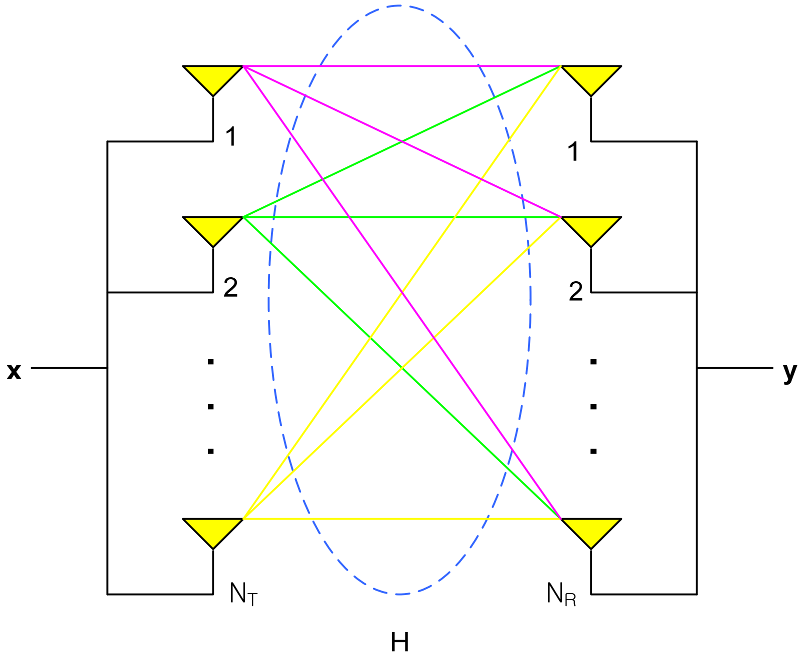


MISO (2)

Beamforming	Diversity
▪ Power gain: Increases SINR level with focused beam toward the target ▪ Array gain + interference nulling (if any) ▪ Multipath mitigation ▪ Not effective in rich scattering environment (offers much lower capacity than SM) ▪ Requires CSI ▪ Fixed beamforming vs. Adaptive beamforming ▪ Algorithms: Max SNR, Max SINR, LCMV, DoA based ▪ To improve the range of existing data rates	▪ Utilizes independent signal paths ▪ Diversity gain ▪ More effective in heavy scattering environment ▪ Average SNR improves ▪ Variability of received signal greatly reduced ▪ Not effective in less fading situation (performance degradation due to correlation among branches) ▪ Combining Algorithms: SC, EGC, MRC ▪ Available in time, frequency, space, polarization etc.

MIMO (1)

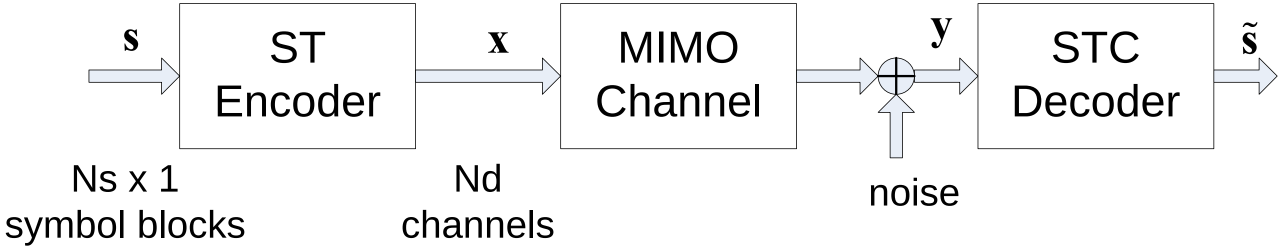
- N_T transmit antennas and N_R receive antennas
  - Diversity gain ~ $N_T N_R$
  - Rate ~ N_T
  - Capacity ~ $\min(N_T, N_R)$



$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_{N_R} \end{bmatrix} = \begin{bmatrix} h_{11} & \cdots & h_{1N_T} \\ h_{21} & \cdots & h_{2N_T} \\ \vdots & \vdots & \vdots \\ h_{N_R 1} & \cdots & h_{N_R N_T} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_{N_T} \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_{N_R} \end{bmatrix}$$

MIMO (2)

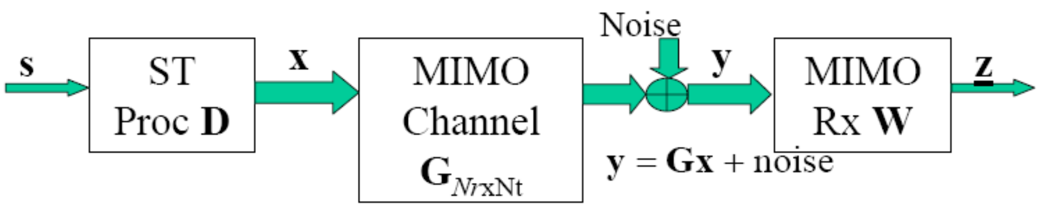
- Performance-oriented MIMO
  - Transmission rate $R_b = (N_s / N_d)\log_2 M$
  - Diversity gain

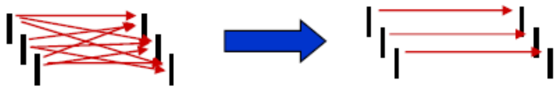


  - Implementation issues
    - Transmission power divided among multiple antennas
    - Tradeoffs between data rate and diversity order
    - Spaced to achieve sufficient fading decorrelation

MIMO (3)

- Data-rate-oriented MIMO
  - With perfect channel estimates at TX and RX, decomposes to M independent channels, M=min(N_T, N_R)
  - M-fold capacity increase over SISO system
  - Demodulation complexity





$$\mathbf{z} = \mathbf{WGDs} + \mathbf{Wn}$$

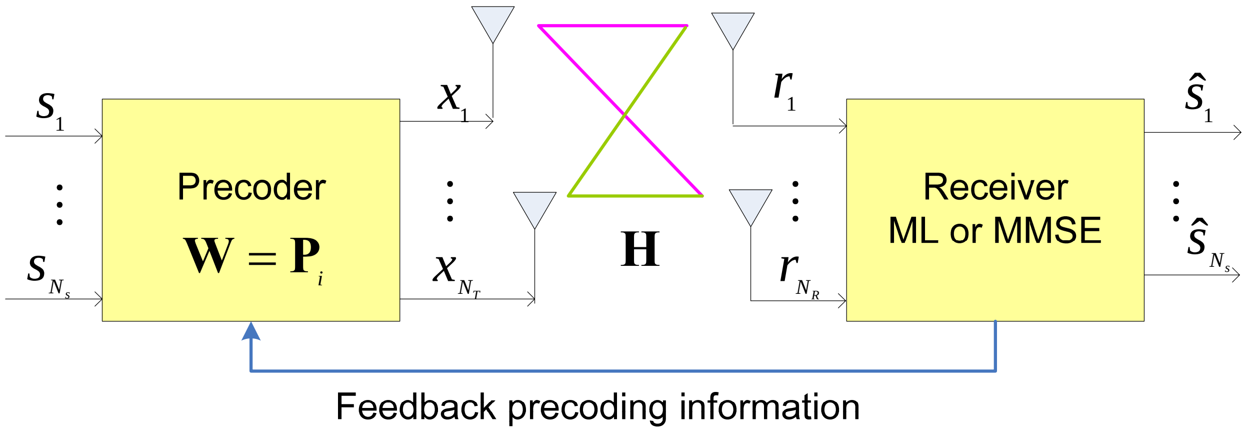
$$\mathbf{WGD} = \begin{bmatrix} s_1 & 0 & \cdots & 0 \\ 0 & s_P & & \vdots \\ \vdots & & \ddots & \\ 0 & \cdots & & 0 \end{bmatrix}$$

MIMO Precoding (1/5)

- Precoding
  - Beamforming
  - Limited Feedback for Spatial multiplexing
- Pre-coded Multiple Tx antennas
  - SDM: Spatial multiplexing of multiple streams to the same user
  - SDMA: Spatial multiplexing of multiple streams to different users
  - Transmit Beamforming
- Tradeoff
  - System performance & capacity
  - feedback overhead & system complexity

MMO Precoding (2/5)

- Nt by Nr MIMO Precoding, Ns streams



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

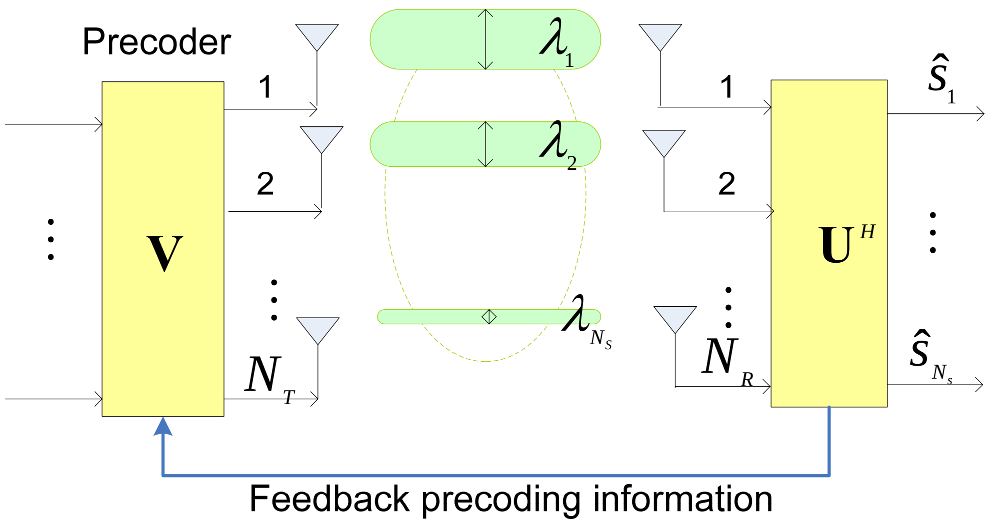
$$\mathbf{r} = \mathbf{H}\mathbf{W}\mathbf{s} + \mathbf{n}$$

Optimal choice of W: singular vectors of H matrix

Use Codebook with limited feedback

MIMO Precoding (3/5)

- SVD based MIMO Precoding



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

$$\mathbf{U}^H\mathbf{Y} = \mathbf{U}^H\mathbf{H}(\mathbf{V}\mathbf{X}) = \mathbf{U}^H(\mathbf{U}\mathbf{D}\mathbf{V}^H)(\mathbf{V}\mathbf{X})$$
$$= (\mathbf{U}^H\mathbf{U})\mathbf{D}(\mathbf{V}^H\mathbf{V})\mathbf{X} = \mathbf{D}\mathbf{X}$$

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

MIMO Precoding (3/5)

- **Code Book-based Precoding**
  - Unitary Codebook
    - Subspace-packing problem in Granssmann manifold
    - DFT matrix
  - Non-unitary Codebook
  - Zero-Forcing Beamforming

MIMO Precoding (5/5)

- Limited Feedback
  - PARC(Per-Antenna Rate Control)
    - Transmitter adjusts antenna rates independently depending on Receiver feedback and spatial channel realization
    - Receiver consists of MMSE linear transformation followed by interference cancellation based on decoded bits
  - Selective PARC
    - Adaptively selects several antennas form which to transmit
      - Select the best mode, and further selects the best subset of antennas for the chosen mode
  - PU2RC (Per-User Unitary and Rate Control)
    - Multi-user MIMO
    - Feedback both Beamforming vectors and the corresponding channel information

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

Current STC Matrix in IEEE802.16e

- *MIMO Method & Operation*
- *MIMO in Downlink*
- *MIMO in Uplink*
- *MIMO Precoding*

MIMO System

- Antenna Configuration
  - Up to 4 Tx Antennas for DL
  - Up to 2 Tx Antennas for UL
- Data Channel Reliability Enhancement
  - Open-loop Transmit Diversity
  - Per-Antenna Pilot Signals
- Per User Data Rate Enhancement
  - Spatial Multiplexing of Coded Symbol (Vertical Encoding)
  - Per-spatial Mode Rate Control (Horizontal Encoding)
  - Pre-coding with Index Feed-back or Channel Sounding
- Multi-user MIMO Scheduling
  - Periodic Channel Sounding Signals
- Wide-band TDD OFDMA System
  - Band-narrow Orthogonal Signal Design in Freq. Domain

MIMO Operation

- DL MIMO
  - Transmit diversity
  - Hybrid diversity
  - Spatial multiplexing
  - Transmit Beamforming
  - Adaptive Antenna system
- UL MIMO
  - Transmit diversity
  - Spatial multiplexing
  - Collaborative spatial mutiplexing
- MIMO Precoding
  - Short term precoding
  - Long term precoding
  - Codebook based precoding

DL MIMO Transmissions

	Matrix A **TD (Transmit Diversity)**	**Matrix B** **Hybrid (TD + SM)**	**Matrix C** **SM (Spatial Multiplexing)**
2 Tx	$A = \begin{bmatrix} S_i & -S^*_{i+1} \\ S_{i+1} & S^*_i \end{bmatrix}$	$C = \frac{1}{\sqrt{1+r^2}} \begin{pmatrix} S_i + jr \cdot S_{i+3} & r \cdot S_{i+1} + S_{i+2} \\ S_{i+1} - r \cdot S_{i+2} & jr \cdot S_i + S_{i+3} \end{pmatrix}$	$B = \begin{bmatrix} S_i \\ S_{i+1} \end{bmatrix}$
3 Tx	$A_1 = \begin{bmatrix} \tilde{S}_1 & -\tilde{S}_2^* & 0 & 0 \\ \tilde{S}_2 & \tilde{S}_1^* & \tilde{S}_3 & -\tilde{S}_4^* \\ 0 & 0 & \tilde{S}_4 & \tilde{S}_3^* \end{bmatrix}$	$B_1 = \begin{bmatrix} \sqrt{\frac{3}{4}} & 0 & 0 \\ 0 & \sqrt{\frac{3}{4}} & 0 \\ 0 & 0 & \sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} \tilde{S}_1 & -\tilde{S}_2^* & \tilde{S}_5 & -\tilde{S}_6^* \\ \tilde{S}_2 & \tilde{S}_1^* & \tilde{S}_6 & \tilde{S}_5^* \\ \tilde{S}_7 & -\tilde{S}_8^* & \tilde{S}_3 & -\tilde{S}_4^* \end{bmatrix}$	$C = \begin{bmatrix} S_1 \\ S_2 \\ S_3 \end{bmatrix}$
4 Tx	$A = \begin{bmatrix} s_1 & -s_2^* & 0 & 0 \\ s_2 & s_1^* & 0 & 0 \\ 0 & 0 & s_3 & -s_4^* \\ 0 & 0 & s_4 & s_3^* \end{bmatrix}$	$B = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_2 & s_1^* & s_6 & -s_8^* \\ s_3 & -s_4^* & s_7 & s_5^* \\ s_4 & s_3^* & s_8 & s_6^* \end{bmatrix}$	$C = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix}$

DL MIMO Techniques (1)

DL (Nt=Tx ant.)			2 Tx.	3 Tx.	4 Tx.	Comments
Open Loop	**Transmit Diversity (TD)**		Matrix A	Matrix A FDFR	Matrix A w/ AC	Spatial rate (Ns) = 1
	Hybrid Diversity (HD)			Matrix B FDFR	Matrix B w/ AC	Ns = 2, Num_layer ≤ 2 Rate control possible (VE or HE)
	Spatial Multiplex (SM)		Matrix C	Matrix C	Matrix C	Ns = Nt, Num_layer ≤Ns Rate control possible (VE or HE)
Tx Beam forming	**SDM/SDMA**		Effective SISO or Matrix A, B, C			Using channel reciprocity
Closed Loop	**AG**	**TD**	X	3 cases	3 cases	Ns =1, AG index feedback
		HD	X	3 cases	6 cases	Ns =2, AG index feedback
	AS		Rate 1	rate 1, 2	Rate 1, 2, 3	Ns < Nt, AS index feedback
	Precoding		rate 1, 2	Rate 1,2,3	rate 1, 2, 3, 4	Codebook based precoding (3 and 6 bit codewords defined) Grassmanian BF
AAS			Effective SISO			Use AAS preamble, dedicated pilot, sounding

DL MIMO Techniques (2)

- Open-Loop MIMO

항목	장점	단점
3 Tx FDFR STC/ AC	Diversity 이득 3을 달성	LLR 계산에서 복잡도 증가
4 Tx Diversity with AC	FDFR에 비하여 복잡도 낮음	FDFR에 비해 약간의 성능 열화 존재
2 Tx FDFR Hybrid	High order modulation에서 약간의 coding 이득	복잡도 높음
3 Tx FDFR Hybrid	Diversity 이득 존재	-LLR 계산에서 복잡도 증가
4 Tx Hybrid with AC	FDFR에 비하여 복잡도 낮음	FDFR에 비해 약간의 성능 열화 존재

DL MIMO Techniques (3)

- Closed-Loop MIMO

항목	기술 특징	장점	단점
Antenna Grouping	3 Tx 이상에서 matrix A 또는 B에 적용될 수 있음	-High mobility 환경에서 성능 열화 없음	성능이득이 low mobility 환경에서 AS 대비 적음
Antenna Selection	3 Tx 이상에서 matrix C 에 적용될 수 있음	-단말의 계산량 적음 -Low mobility 환경에서 성능이득이 AG 대비 상대적으로 큼	High mobility 에서 성능 열화 있음
Precoding	Quantized SVD 계열 Single/multiple stream Grassmanian BF	-채널이 full rank 가 아닌 경우 성능 이득이 큼 (long term link quality 관점)	-피드백 양에 따라 성능 이득 변화가 큼 -단말에서 피드백해야 할 양이 많음 -단말에서 codebook 선택을 위한 계산량이 많음

Indication of DL MIMO Operation

Indication of MIMO Operation

STC_Zone_IE

Zone information
- Permutation
- OFDMA symbol offset
- # of antennas
- MIMO mode
- Pilot pattern

DL_MAP_IE()s

Burst information
- Burst allocation
- MIMO mode
- # of layers
- MCS level per layer

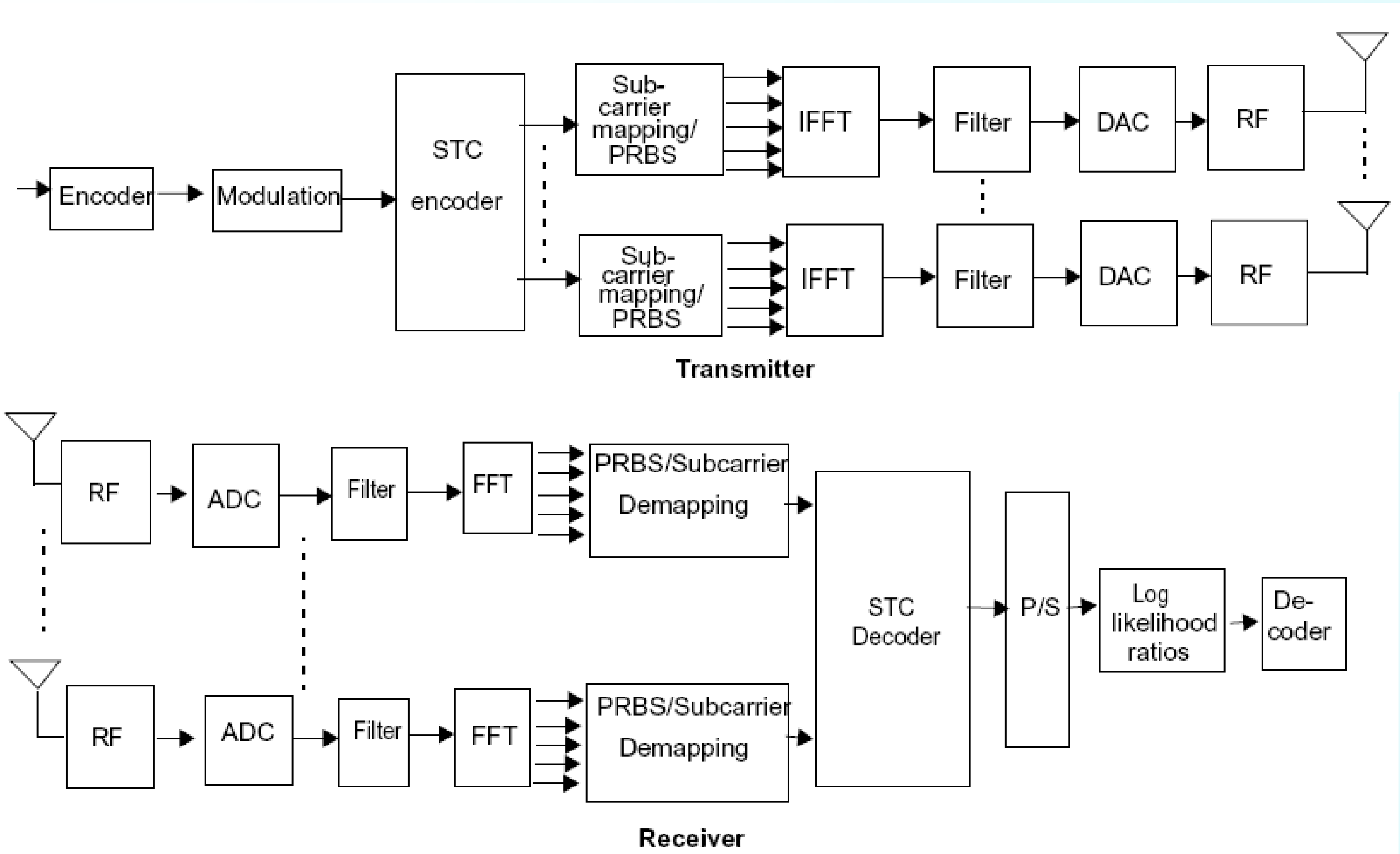
Several bursts can be grouped one IE

- Burst Indicator

- MIMO_Basic_IE()
- MIMO_Enhanced_IE()
- HARQ MAP_IE()
- MAP_IE()
- CL MIMO DL Enhanced IE()

STC in DL

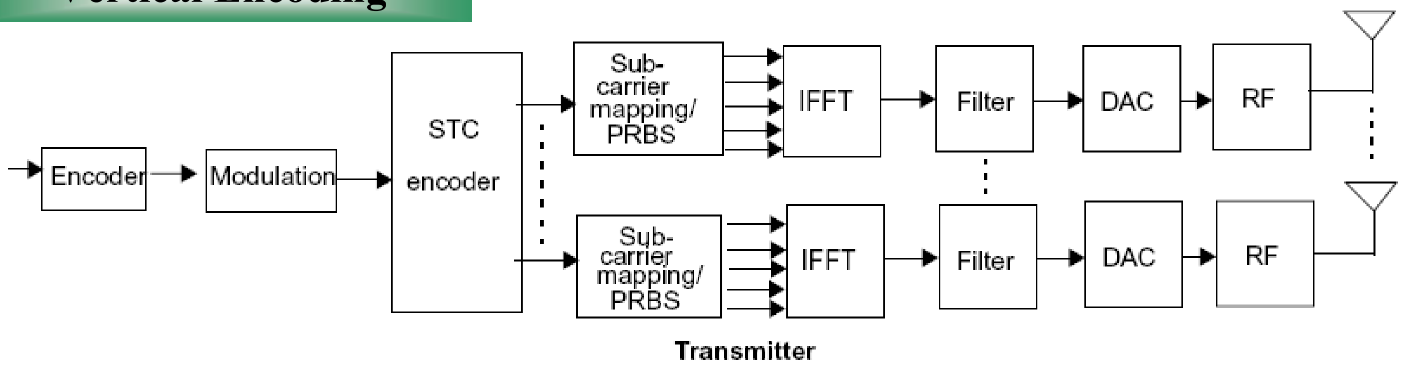
Matrix A



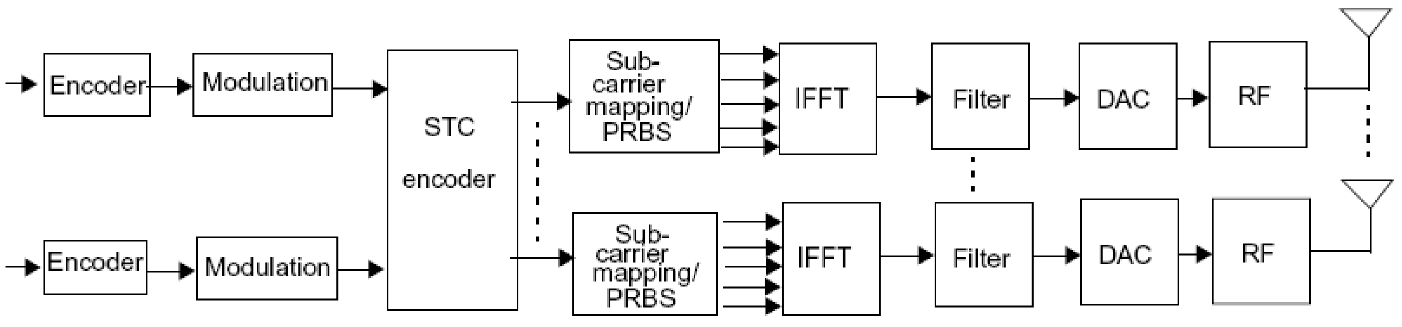
STC in DL

Matrix B

Vertical Encoding



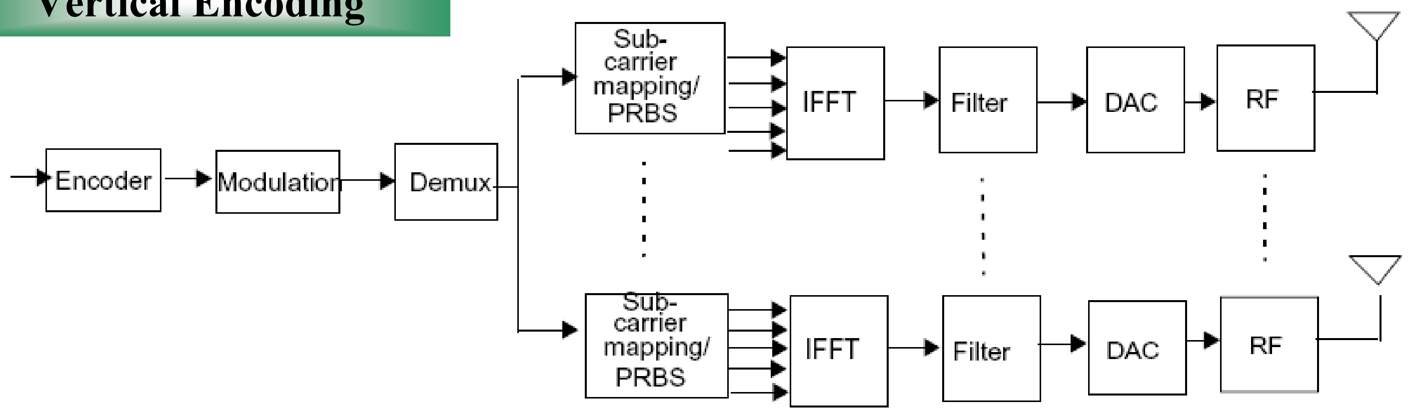
Horizontal Encoding



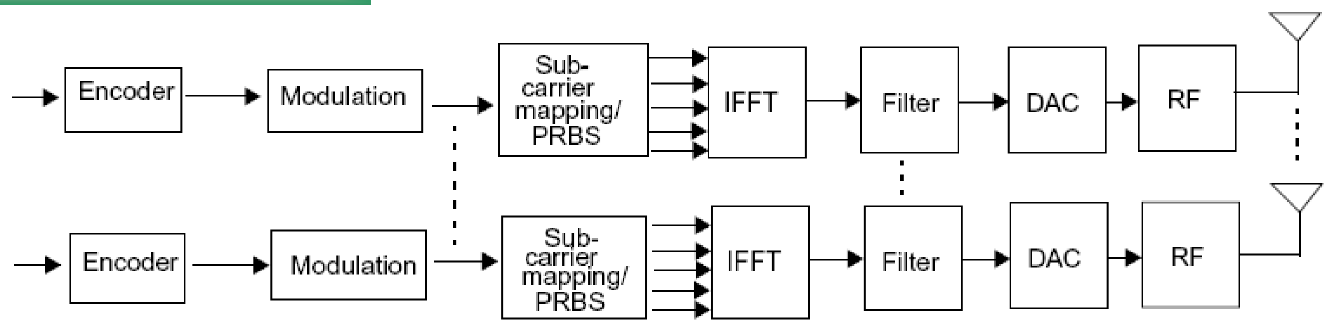
STC in DL

Matrix C

Vertical Encoding



Horizontal Encoding



Full Diversity Full Rate

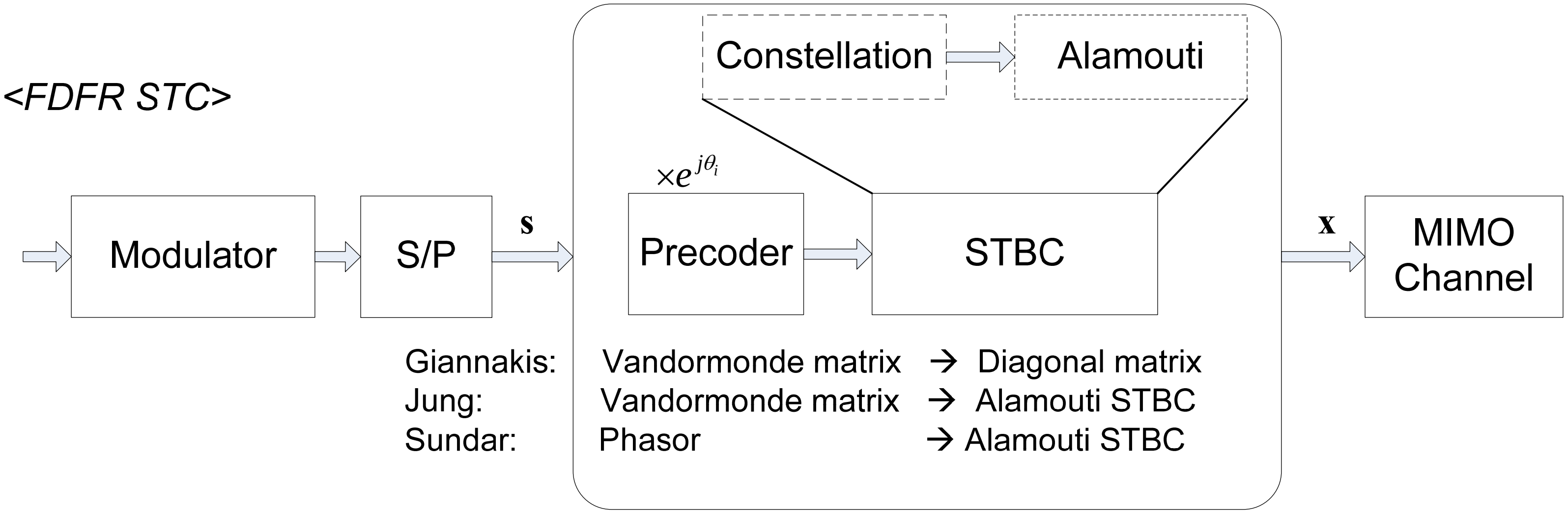
Full Diversity Full Rate

- **Alamouti, 1998**
  - FDFR orthogonal code for 2 Tx antennas
- **Tarokh, 1999**
  - Proved that FDFR orthogonal code only exists for 2 Tx antennas
- **Jafarkhani, 2001**
  - Proposed FR Quasi-orthogonal code
- **Giannakis, 2002/2003**
  - Proposed FDFR code using constellation rotating code
- **Jung, 2003**
  - Improved coding gain using concatenated Alamouti code
- **Sundar**
  - Proposed FDFR using phase rotator
  - Low complexity by linear decoding

Full Diversity Full Rate

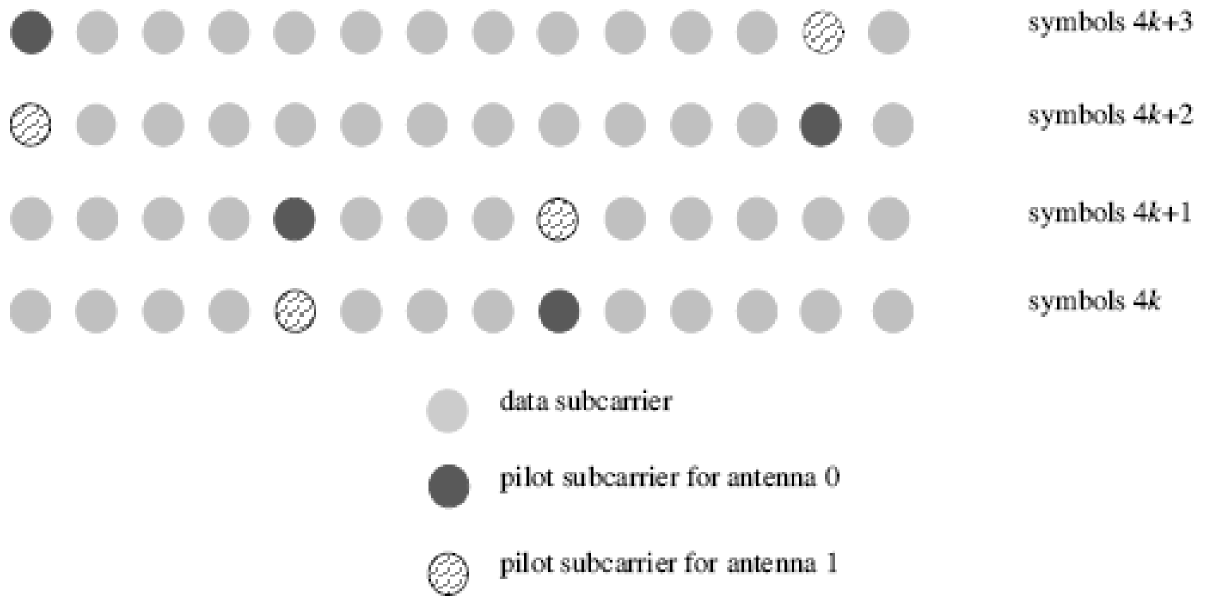
- FDFR

<FDFR STC>



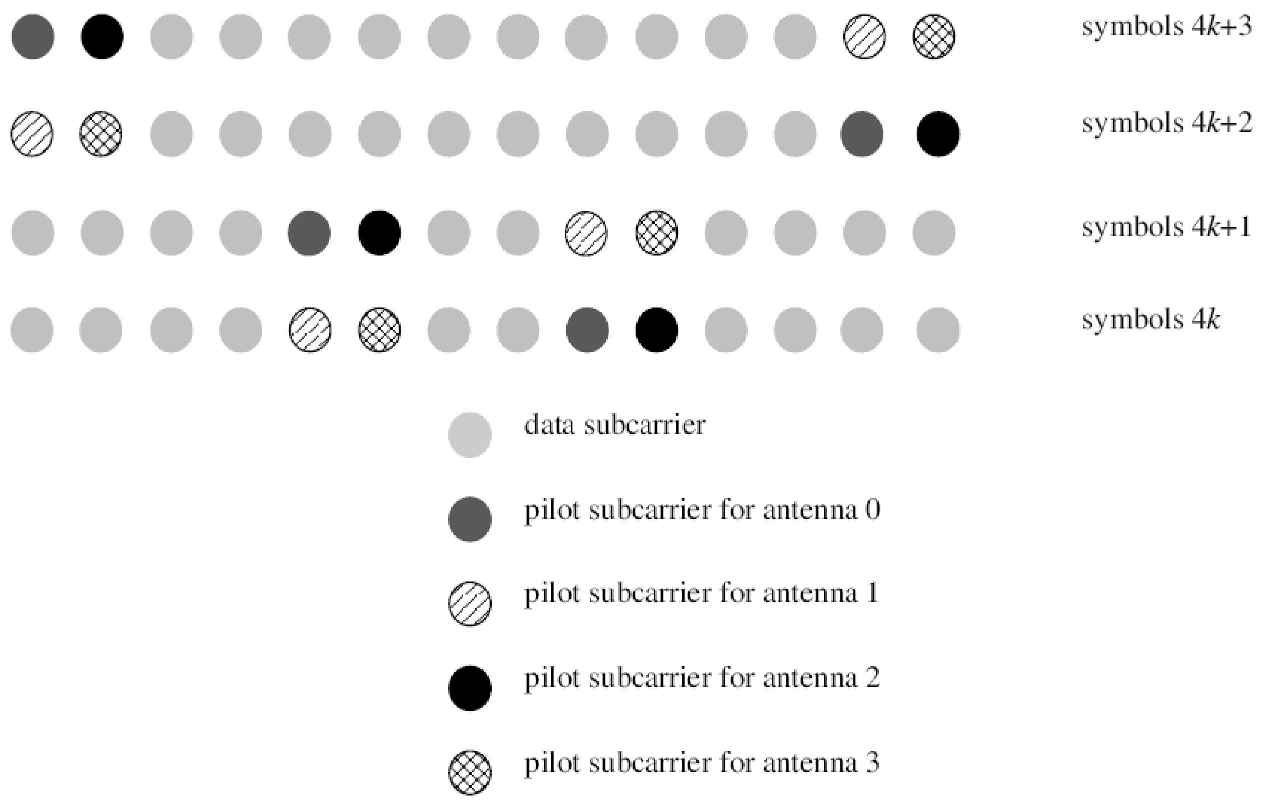
DL STC in PUSC (1/2)

- Cluster Structure using 2 Tx



DL STC in PUSC (2/2)

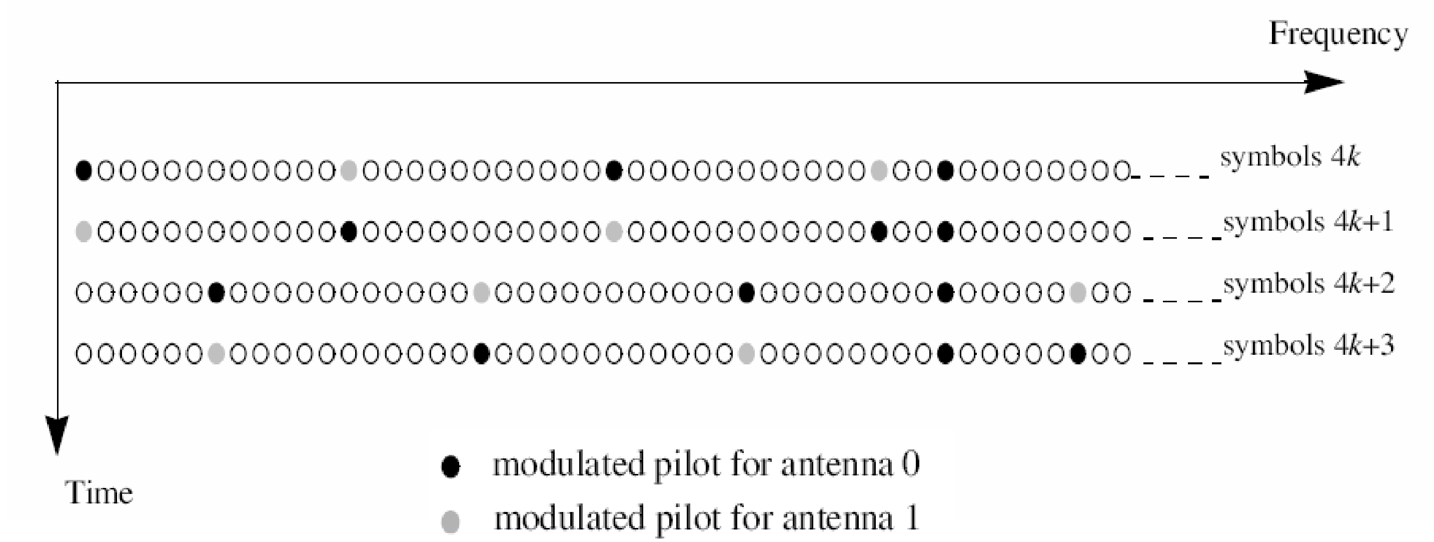
- Cluster Structure using 4 Tx



DL STC in FUSC (1/2)

- Pilot pattern for 2 Txs

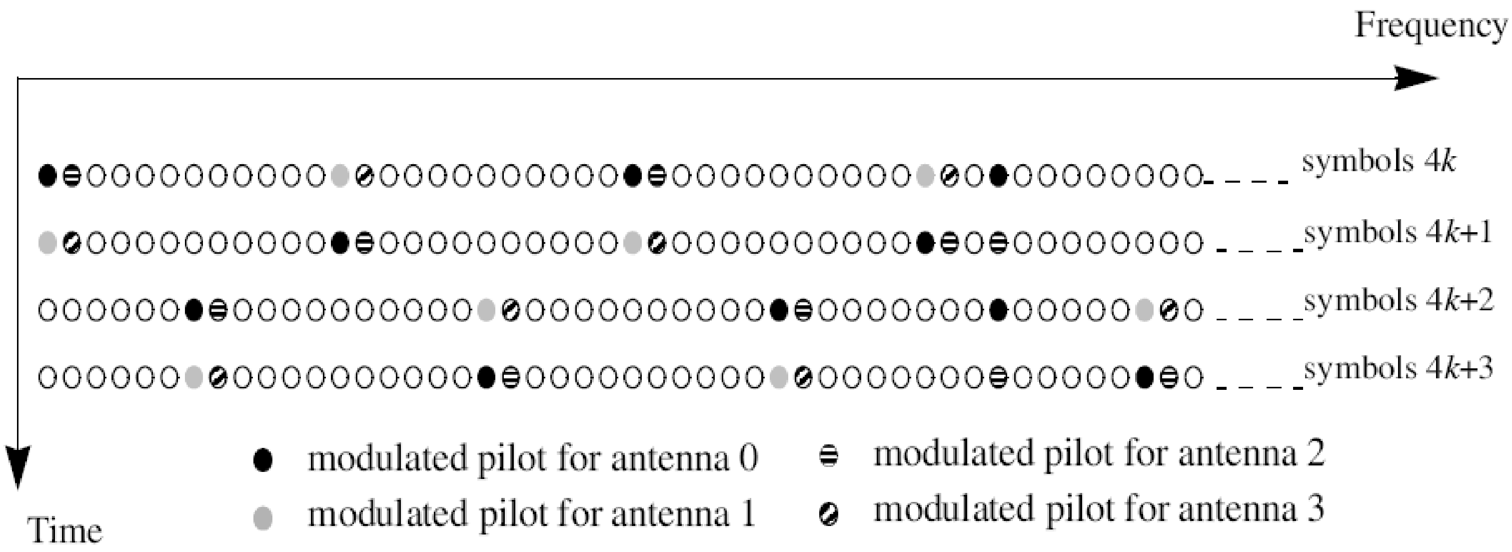
	Even symbols	Odd symbols
Antenna 0	VariableSet#0, ConstantSet#0	Variable#1, ConstantSet#0
Antenna 1	VariableSet#1, ConstantSet#1	VariableSet#0, ConstantSet#1



DL STC in FUSC (2/2)

- Pilot patterns for 4 Tx

	Even symbols	Odd symbols
Antenna 0	VariableSet#0, ConstantSet#0	Variable#1
Antenna 1	VariableSet#1, ConstantSet#1	VariableSet#0
Antenna 2	VariableSet#0+1	Variable#1+1, ConstantSet#0
Antenna 3	VariableSet#1+1	VariableSet#0+1, ConstantSet#1

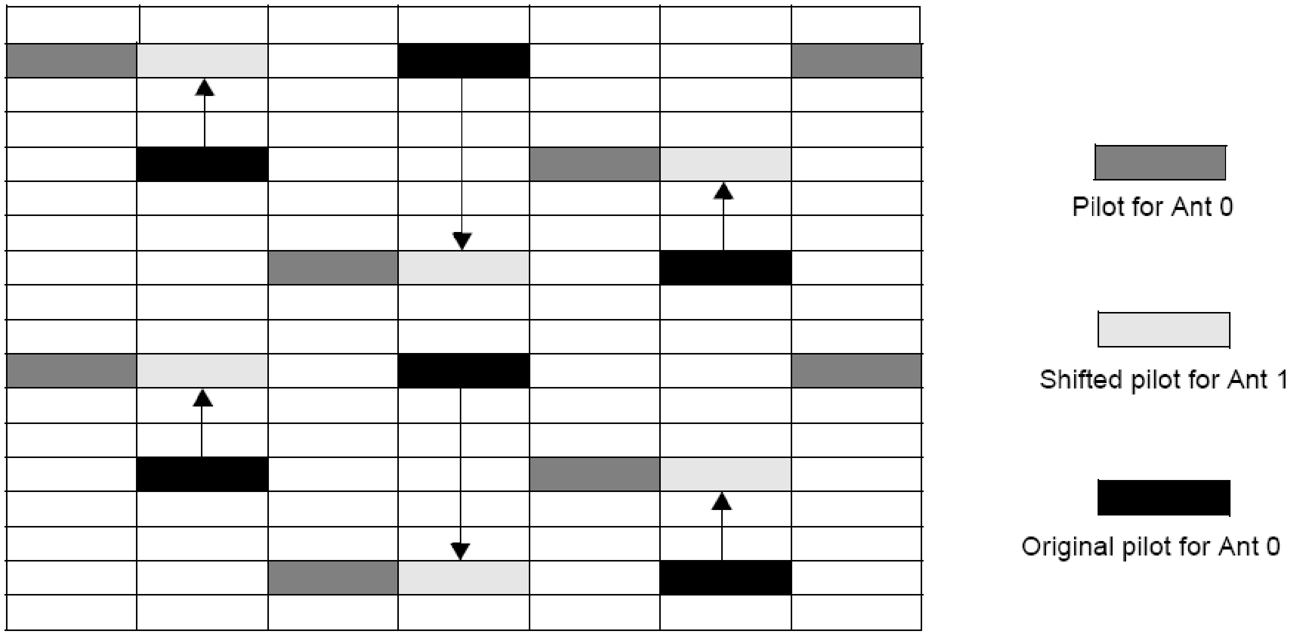


DL STC in AMC and OFUSC (1/3)

- Pilot Patterns for 2 Tx

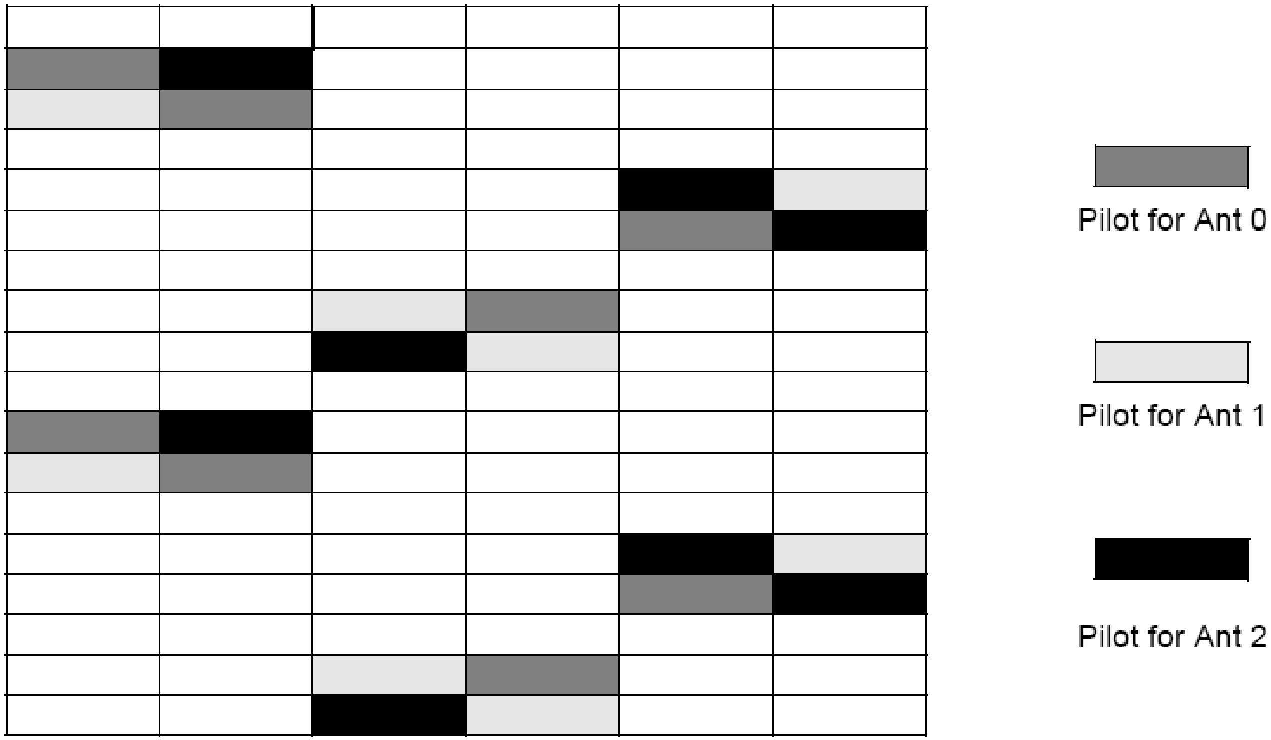
	Even symbols	Odd symbols
Antenna 0	9k + 3[m mod 3]+1	x
Antenna 1	x	9k + 3[(m-1) mod 3]+1

m=symbol index



DL STC in AMC and OFUSC(2/3)

- Pilot Patterns for 3 Tx



0	2	1	0	2	1
1	0	2	1	0	2

DL STC in AMC and OFUSC (3/3)

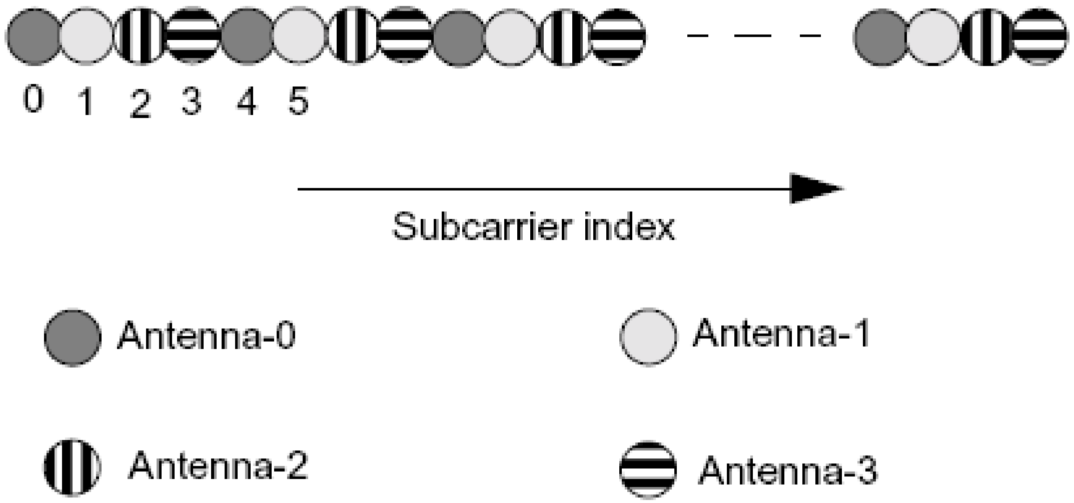
- Pilot Patterns for 4 Tx

	Even symbols	Odd symbols
Antenna 0	9k + 3[m mod 3]+1	x
Antenna 1	x	9k + 3[(m-1) mod 3]+1
Antenna 2	9k + 3[m mod 3]+2	
Antenna 3	x	9k + 3[(m-1) mod 3]+2

0	2	1	3	1	3
1	3	0	2	0	2

Air Interface Details

- MIMO Mid-amble
  - DL Channel Estimation per Antenna
  - Orthogonality by Freq. Decimation
  - Up to 4 Transmit Antenna Support
  - Optimized Sequences for PAPR Reduction



Current STC Matrix for 2Tx

- STC Mapping using 2 Tx

$$\mathbf{s}_1 = s_0, s_1, \cdots, s_{47}$$

$$\mathbf{s}_2 = s_{48}, s_{49}, \cdots, s_{95}$$

Matrix A	Antenna 0		Antenna 1	
Subcarrier index	Even symbol	Odd symbol	Even symbol	Odd symbol
0	S0	- S24*	S24	S0*
1	S1	- S25*	S25	S1*
2	S2	- S26*	S26	S2*
3	S3	- S27*	S27	S3*
4	S4	- S28*	s28	S4*

Matrix B (VE)	Antenna 0		Antenna 1	
Subcarrier index	Even symbol	Odd symbol	Even symbol	Odd symbol
0	S0	S48	S1	S49
1	S2	S49	S3	S51
2	S4	S50	S5	S53
3	S6	S51	S7	S55
4	S8	S52	S9	S57

Current STC Matrix for 3Tx

- Transmission format A uses Matrix A (rate = 1)

$$A = \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & 0 & 0 \\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_3 & -\tilde{s}_4^* \\ 0 & 0 & \tilde{s}_4 & \tilde{s}_s^* \end{bmatrix}$$

- Transmission format B uses Matrix B (rate = 2)

$$B = \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & \tilde{s}_5 & -\tilde{s}_6^* \\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_6 & \tilde{s}_5^* \\ \tilde{s}_7 & \tilde{s}_8 & \tilde{s}_3 & \tilde{s}_4 \end{bmatrix}$$

$$\tilde{s}_1 = s_{1I} + js_{3Q};\ \tilde{s}_2 = s_{2I} + js_{4Q};$$

$$\tilde{s}_3 = s_{3I} + js_{1Q};\ \tilde{s}_4 = s_{4I} + js_{2Q}; \tilde{s}_5 = s_{5I} + js_{7Q}$$

$$\text{where} \quad s_i = s_{iI} + js_{iQ}, s_i = x_i e^{j\theta}$$

- Transmission format C uses Matrix C (rate = 3)

$$C = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \end{bmatrix}$$

Current STC Matrix for 3Tx Rate 1

Subcarrier

$$\overbrace{\qquad\qquad}^{f_1}\overbrace{\qquad\qquad}^{f_2}$$

$$A = \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & 0 & 0 \\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_3 & -\tilde{s}_4^* \\ 0 & 0 & \tilde{s}_4 & \tilde{s}_3^* \end{bmatrix}$$

1 2 1 2

OFDM symbol

$$\tilde{s}_1 = s_{1I} + js_{3Q}$$

$$\tilde{s}_2 = s_{2I} + js_{4Q}$$

$$\tilde{s}_3 = s_{3I} + js_{1Q}$$

$$\tilde{s}_4 = s_{4I} + js_{2Q}$$

Here,

x_i are the QAM symbols,

$$s_i = x_i e^{j\theta}, i = 1,..,4$$

$$= s_{iI} + js_{iQ}$$

$$\theta = \tan^{-1}\frac{1}{3}$$

Current STC Matrix for 3Tx Rate 2

Subcarrier

$$\overbrace{\qquad\qquad}^{f_1}\ \overbrace{\qquad\qquad}^{f_2}$$

$$B = \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & \tilde{s}_5 & -\tilde{s}_6^* \\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_6 & \tilde{s}_5^* \\ \tilde{s}_7 & \tilde{s}_8 & \tilde{s}_3 & \tilde{s}_4 \end{bmatrix}$$

1 2 1 2

OFDM symbol

$$\tilde{s}_1 = s_{1I} + js_{3Q}, \quad \tilde{s}_2 = s_{2I} + js_{4Q}$$

$$\tilde{s}_3 = s_{3I} + js_{1Q}, \quad \tilde{s}_4 = s_{4I} + js_{2Q}$$

$$\tilde{s}_5 = s_{5I} + js_{7Q}, \quad \tilde{s}_6 = s_{6I} + js_{8Q}$$

$$\tilde{s}_7 = s_{7I} + js_{5Q}, \quad \tilde{s}_8 = s_{8I} + js_{6Q}$$

Here x_i are the QAM symbols,

$$s_i = x_i e^{j\theta}, i = 1,..,8$$

$$= s_{iI} + js_{iQ}$$

$$\theta = \tan^{-1}\frac{1}{3}$$

Antenna Circulation for 3 Tx

- Rate 1: diversity order 3

$$A_1 = \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & 0 & 0 \\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_3 & -\tilde{s}_4^* \\ 0 & 0 & \tilde{s}_4 & \tilde{s}_s^* \end{bmatrix} \qquad A_2 = \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & \tilde{s}_3 & -\tilde{s}_4^* \\ \tilde{s}_2 & \tilde{s}_1^* & 0 & 0 \\ 0 & 0 & \tilde{s}_4 & \tilde{s}_s^* \end{bmatrix} \qquad A_3 = \begin{bmatrix} \tilde{s}_1 & -\tilde{s}_2^* & 0 & 0 \\ 0 & 0 & \tilde{s}_3 & -\tilde{s}_4^* \\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_4 & \tilde{s}_s^* \end{bmatrix}$$

- Rate 2: 3 permuted matrices

$$B_1 = \begin{bmatrix} \sqrt{\frac{3}{4}} & 0 & 0 \\ 0 & \sqrt{\frac{3}{4}} & 0 \\ 0 & 0 & \sqrt{\frac{3}{2}} \end{bmatrix} \begin{bmatrix} \tilde{S}_1 & -\tilde{S}_2^* & \tilde{S}_5 & -\tilde{S}_6^* \\ \tilde{S}_2 & \tilde{S}_1^* & \tilde{S}_6 & \tilde{S}_5^* \\ \tilde{S}_7 & \tilde{S}_8^* & \tilde{S}_3 & -\tilde{S}_4^* \end{bmatrix} \quad B_2 = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix} B_1 \quad B_3 = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} B_1$$

Current STC Matrix for 4Tx

- Transmission format A uses Matrix A (rate = 1)

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

- Transmission format B uses Matrix B (rate = 2)

$$B = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_2 & s_1^* & s_6 & -s_8^* \\ s_3 & -s_4^* & s_7 & s_5^* \\ s_4 & s_3^* & s_8 & s_6^* \end{bmatrix}$$

- Transmission format C uses Matrix C (rate = 4)

$$C = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix}$$

Antenna Circulation for 4Tx

- Rate 1: 3 permuted matrices

$$A_1 = \begin{bmatrix} S_1 & -S^*_2 & 0 & 0 \\ S_2 & S^*_1 & 0 & 0 \\ 0 & 0 & S_3 & -S^*_4 \\ 0 & 0 & S_4 & S^*_3 \end{bmatrix} A_2 = \begin{bmatrix} S_1 & -S_2 & 0 & 0 \\ 0 & 0 & S_3 & -S^*_4 \\ S_2 & S^*_1 & 0 & 0 \\ 0 & 0 & S_4 & S^*_3 \end{bmatrix} A_3 = \begin{bmatrix} S_1 & -S^*_2 & 0 & 0 \\ 0 & 0 & S_3 & -S^*_4 \\ 0 & 0 & S_4 & S^*_3 \\ S_2 & S^*_1 & 0 & 0 \end{bmatrix}.$$

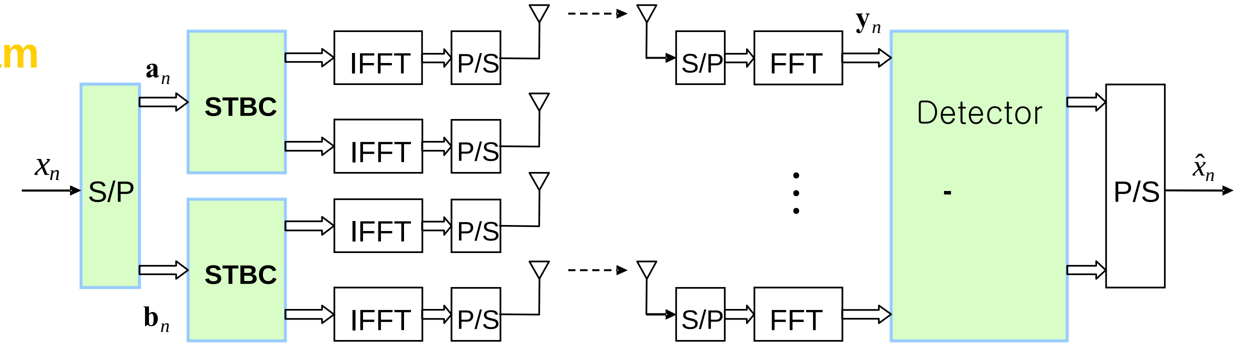
- Rate 2: 6 permuted matrices

$$B_1 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_2 & s_1^* & s_6 & -s_8^* \\ s_3 & -s_4^* & s_7 & s_5^* \\ s_4 & s_3^* & s_8 & s_6^* \end{bmatrix} B_2 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_2 & s_1^* & s_6 & -s_8^* \\ s_4 & s_3^* & s_8 & s_6^* \\ s_3 & -s_4^* & s_7 & s_5^* \end{bmatrix} B_3 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_3 & -s_4^* & s_7 & s_5^* \\ s_2 & s_1^* & s_6 & -s_8^* \\ s_4 & s_3^* & s_8 & s_6^* \end{bmatrix}$$

$$B_4 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_4 & s_3^* & s_8 & s_6^* \\ s_2 & s_1^* & s_6 & -s_8^* \\ s_3 & -s_4^* & s_7 & s_5^* \end{bmatrix} B_5 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_3 & -s_4^* & s_7 & s_5^* \\ s_4 & s_3^* & s_8 & s_6^* \\ s_2 & s_1^* & s_6 & -s_8^* \end{bmatrix} B_6 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_4 & s_3^* & s_8 & s_6^* \\ s_3 & -s_4^* & s_7 & s_5^* \\ s_2 & s_1^* & s_6 & -s_8^* \end{bmatrix}$$

Antenna Circulation (Rate 2)

Block Diagram

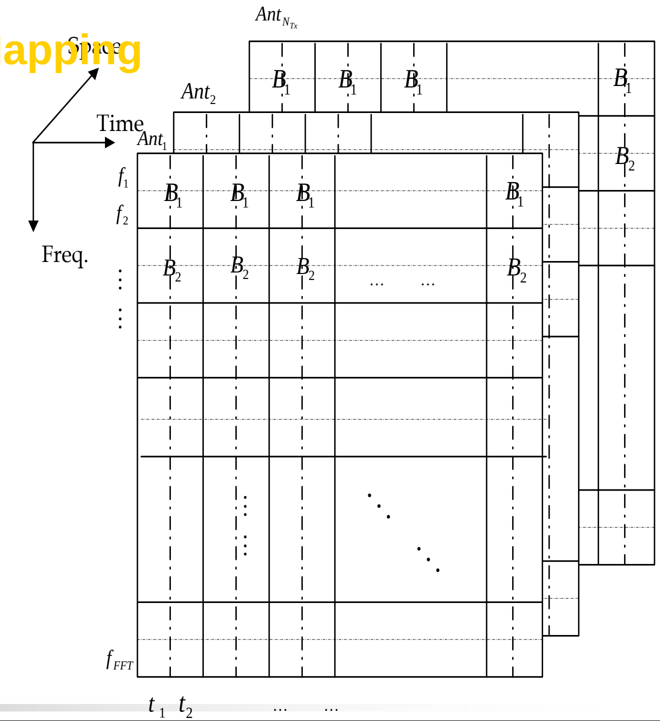


4Tx

$$B_1 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_2 & s_1^* & s_6 & -s_8^* \\ s_3 & -s_4^* & s_7 & s_5^* \\ s_4 & s_3^* & s_8 & s_6^* \end{bmatrix} \quad B_2 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_2 & s_1^* & s_6 & -s_8^* \\ s_4 & s_3^* & s_8 & s_6^* \\ s_3 & -s_4^* & s_7 & s_5^* \end{bmatrix} \quad B_3 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_3 & -s_4^* & s_7 & s_5^* \\ s_2 & s_1^* & s_6 & -s_8^* \\ s_4 & s_3^* & s_8 & s_6^* \end{bmatrix}$$

$$B_4 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_4 & s_3^* & s_8 & s_6^* \\ s_2 & s_1^* & s_6 & -s_8^* \\ s_3 & -s_4^* & s_7 & s_5^* \end{bmatrix} \quad B_5 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_3 & -s_4^* & s_7 & s_5^* \\ s_4 & s_3^* & s_8 & s_6^* \\ s_2 & s_1^* & s_6 & -s_8^* \end{bmatrix} \quad B_6 = \begin{bmatrix} s_1 & -s_2^* & s_5 & -s_7^* \\ s_4 & s_3^* & s_8 & s_6^* \\ s_3 & -s_4^* & s_7 & s_5^* \\ s_2 & s_1^* & s_6 & -s_8^* \end{bmatrix}$$

Mapping



Ant. Circulation (Rate 2)

subcarrier →
time ↓

	B1	B2	B3	B4	B5	B6
Ant.4	S_4 S_8 S_3^* S_6^*	S_3 S_7 $-S_4^*$ S_5^*	S_4 S_8 S_3^* S_6^*	S_3 S_7 $-S_4^*$ S_5^*	S_2 S_6 S_1^* $-S_8^*$	S_2 S_6 S_1^* $-S_8^*$
Ant.3	S_3 S_7 $-S_4^*$ S_5^*	S_4 S_8 S_3^* S_6^*	S_2 S_6 S_1^* $-S_8^*$	S_2 S_6 S_1^* $-S_8^*$	S_4 S_8 S_3^* S_6^*	S_3 S_7 $-S_4^*$ S_5^*
Ant.2	S_2 S_6 S_1^* $-S_8^*$	S_2 S_6 S_1^* $-S_8^*$	S_3 S_7 $-S_4^*$ S_5^*	S_4 S_8 S_3^* S_6^*	S_3 S_7 $-S_4^*$ S_5^*	S_4 S_8 S_3^* S_6^*
Ant.1	S_1 S_5 $-S_2^*$ $-S_7^*$	S_1 S_5 $-S_2^*$ $-S_7^*$	S_1 S_5 $-S_2^*$ $-S_7^*$	S_1 S_5 $-S_2^*$ $-S_7^*$	S_1 S_5 $-S_2^*$ $-S_7^*$	S_1 S_5 $-S_2^*$ $-S_7^*$

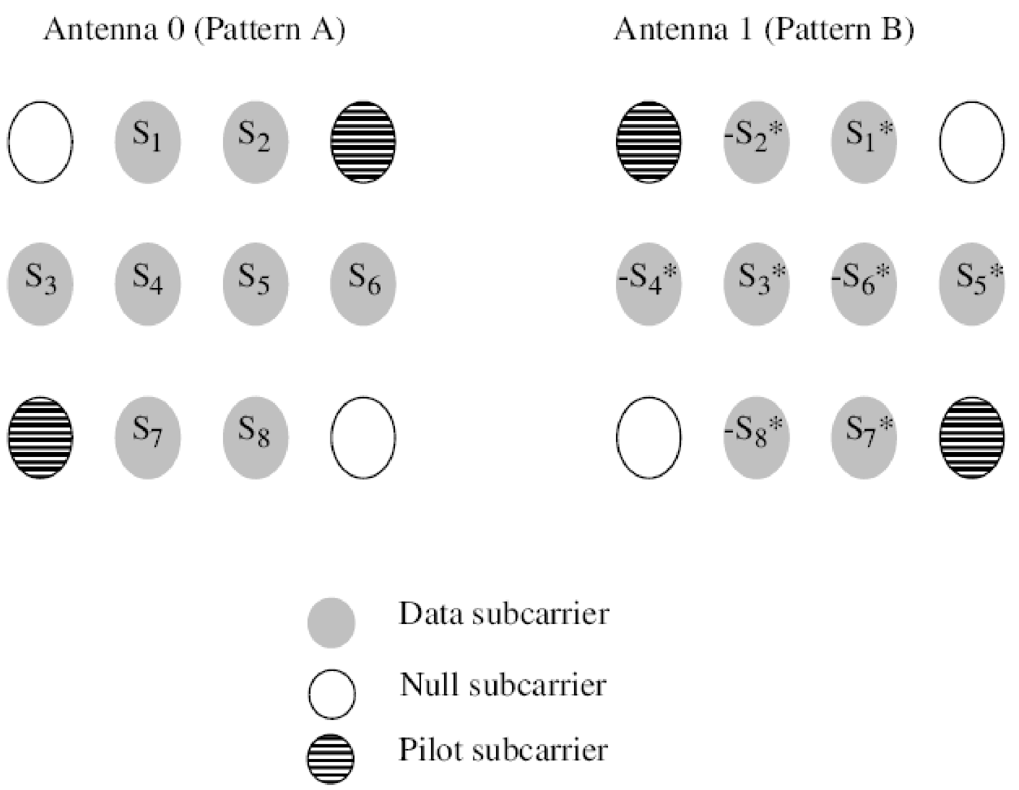
{S1, S2}	Ant.1, ant.2	Ant.1, ant.2	Ant.1, ant.3	Ant.1, ant.3	Ant.1, ant.4	Ant.1, ant.4
{S3, S4}	Ant.3, ant.4	Ant.3, ant.4	Ant.2, ant.4	Ant.2, ant.4	Ant.2, ant.3	Ant.2, ant.3
{S5, S7}	Ant.1, ant.3	Ant.1, ant.4	Ant.1, ant.2	Ant.1, ant.4	Ant.1, ant.2	Ant.1, ant.3
{S6, S8}	Ant.2, ant.4	Ant.2, ant.3	Ant.3, ant.4	Ant.2, ant.3	Ant.3, ant.4	Ant.2, ant.4

UL MIMO Transmissions

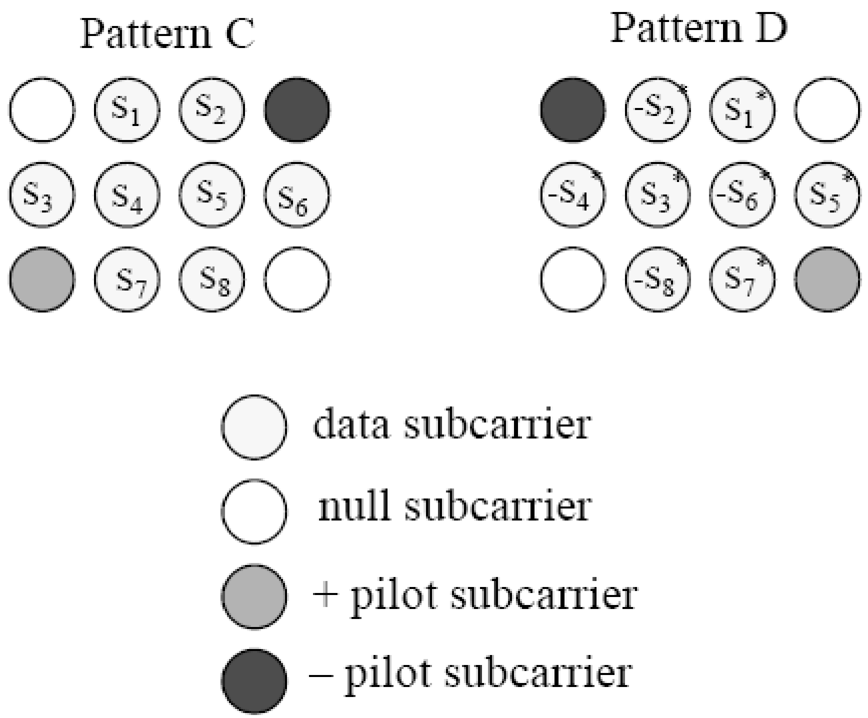
	Matrix A	**Matrix B**
2 Tx	$A = \begin{bmatrix} S_i & -S^*_{i+1} \\ S_{i+1} & S^*_i \end{bmatrix}$	$B = \begin{bmatrix} S_i \\ S_{i+1} \end{bmatrix}$

UL (No. SS Antennas)				**2 Tx**	**1 Tx**	**Comments**
Open-loop	TD			Matrix A	**N/A**	Ns= 1
	SM	VE		Matrix B	**N/A**	Single user : Ns = 2, Num_layer =1
		HE	SU	Matrix B	**N/A**	
			MU	**two MSs of rate 2 each**	**two MSs of rate 1 each**	Collaborative MIMO

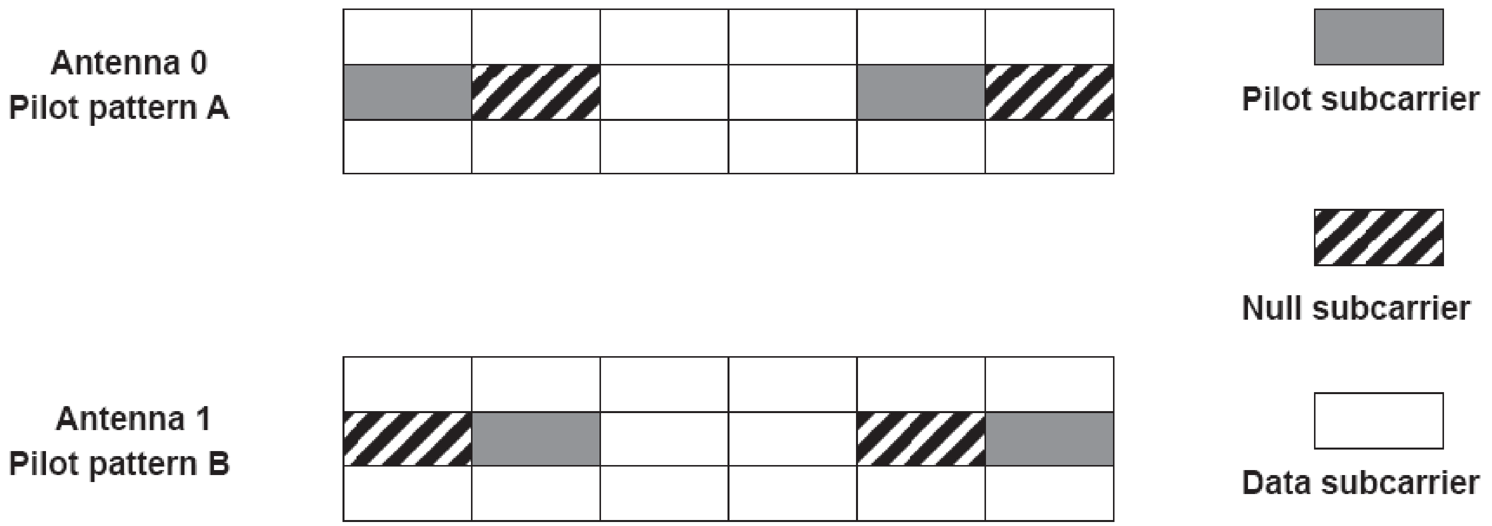
Pilot Pattern in UL PUSC (1)



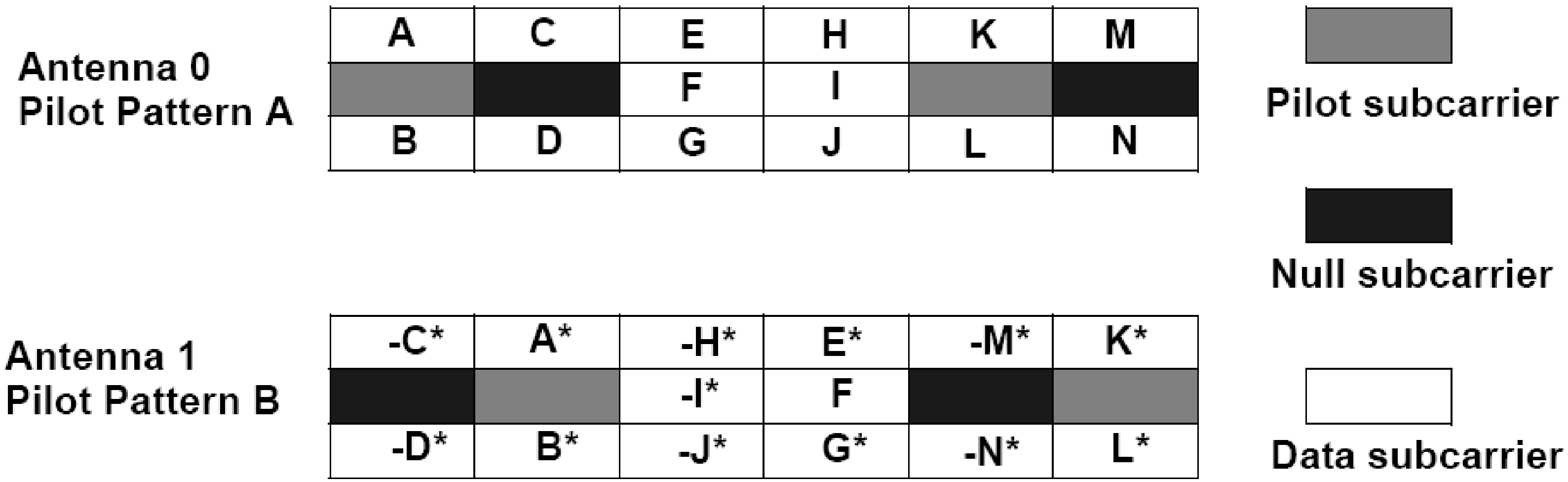
Pilot Pattern in UL PUSC (2)



Pilot Pattern in UL OPUSC



Data mapping in UL OPUSC

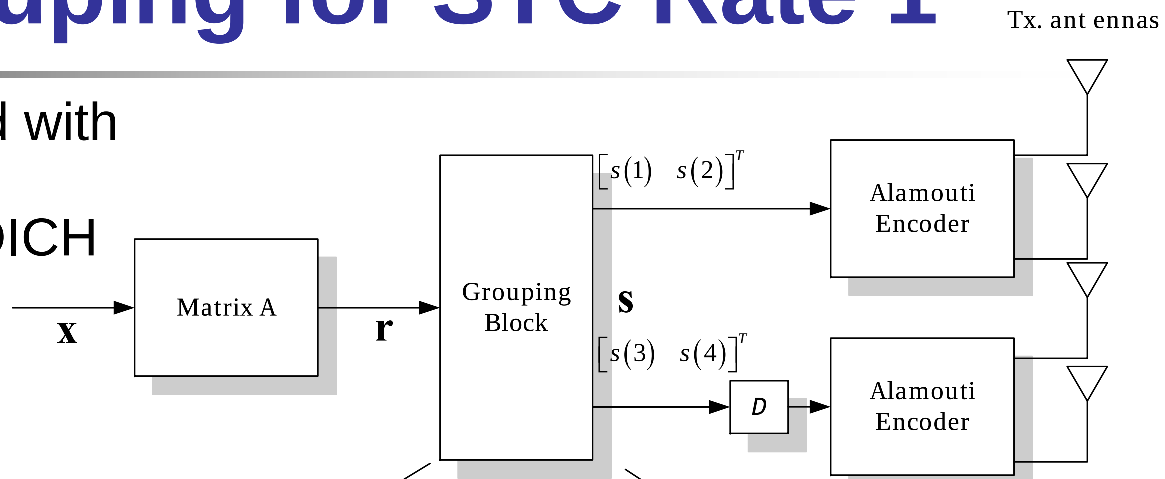


Enhancement of STC (Closed Loop MIMO)

- **Antenna Grouping for STC Rate 1**
- **Antenna Grouping for STC Rate 2**
- **Codebook based CL MIMO**

Antenna Grouping for STC Rate 1

- Matrices may be employed with adaptive antenna grouping which is feedback on a CQICH from MSS



$$A=\begin{bmatrix}\tilde{s}_1 & -\tilde{s}_2^* & 0 & 0\\ \tilde{s}_2 & \tilde{s}_1^* & \tilde{s}_3 & -\tilde{s}_4^*\\ 0 & 0 & \tilde{s}_4 & \tilde{s}_s^*\end{bmatrix}$$

$$A: \begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix}\quad B: \begin{bmatrix}1&0&0&0\\0&0&1&0\\0&1&0&0\\0&0&0&1\end{bmatrix}\quad C: \begin{bmatrix}1&0&0&0\\0&0&0&1\\0&1&0&0\\0&0&1&0\end{bmatrix}$$

Decision Rule

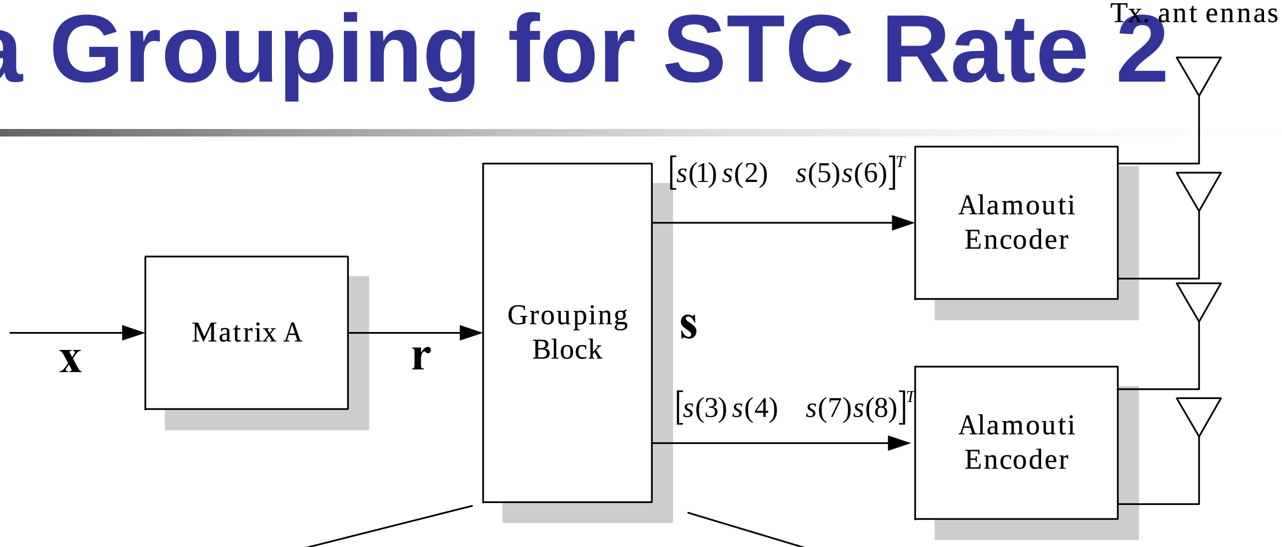
$$\arg \min_{antenna\_pair} |\rho_1-\rho_2|$$

$$A^H A=\begin{bmatrix}\rho_1 & 0 & 0 & 0\\ 0 & \rho_1 & 0 & 0\\ 0 & 0 & \rho_2 & 0\\ 0 & 0 & 0 & \rho_2\end{bmatrix}$$

$$P_e \le N_e Q\left(\sqrt{\frac{E_s}{N_0} d_{MIN}^2}\right)$$

$$d_{MIN}^2(\mathbf{H}) \le \frac{\min\left(\|\mathbf{H}\|_F^2(a,b), \|\mathbf{H}\|_F^2(c,d)\right)}{N_T} d_{\min}^2$$

Antenna Grouping for STC Rate 2



$$\mathbf{W}_1 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad \mathbf{W}_2 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix} \quad \mathbf{W}_3 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\mathbf{W}_4 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \end{bmatrix} \quad \mathbf{W}_5 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \quad \mathbf{W}_6 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

Decision Rule

$$q = \arg \min_{l=1,\cdots,6} \left[abs\left(\det(\mathbf{H}_{l,1}) + \det(\mathbf{H}_{l,2}) \right) \right]$$

$$q = \arg \min_{l=1,\cdots,6} \left[trace\left(\left[(\mathbf{X}(\mathbf{HW}_l))^H \mathbf{X}(\mathbf{HW}_l) \right]^{-1} \right) \right]$$

MIMO Precoding (1/2)

- Space time coding output can be weighted by a matrix mapping onto transmit antennas
  - 4 actual antennas and 2 space-time coding output streams

$$z = Wx$$

$$W = \begin{bmatrix} W_{11} & W_{12} \\ W_{21} & W_{22} \\ W_{31} & W_{32} \\ W_{41} & W_{42} \end{bmatrix}$$

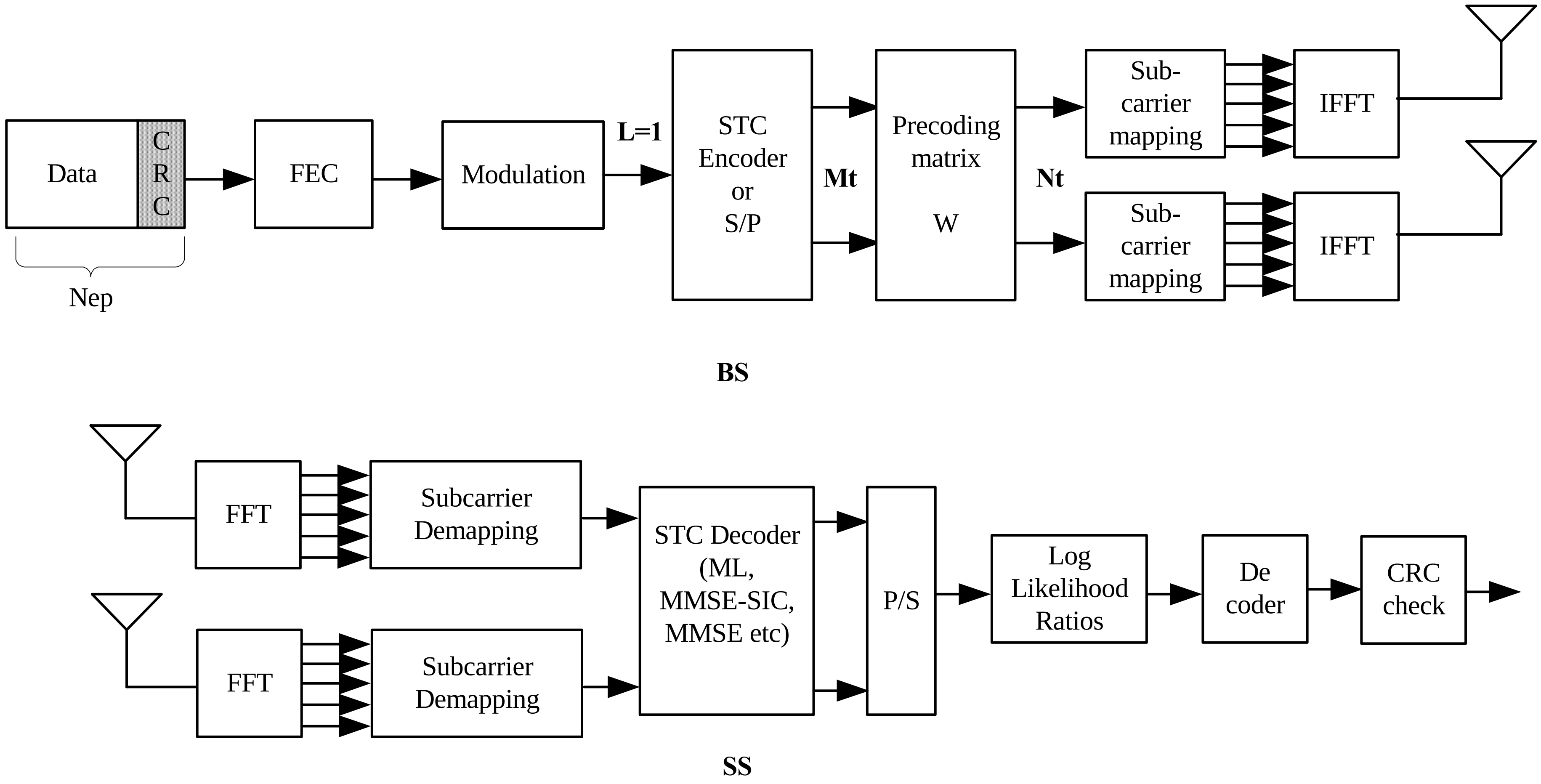
- Closed-loop
  - Channel quality indications feedback from the SS

MIMO Precoding (2/2)

- Short-term Closed-loop Precoding
  - Frequency selective approach
  - Band AMC
  - Eigen beamforming
- Long-term Closed-loop Precoding
  - Frequency independent approach
  - E.g, channel covariance and/or channel mean
- Grassmanian Manifolds
  - A precoder only contains information about that the subspace we would like to transmit energy
- Multiple precoder for band AMC Operation
  - N best bands selected

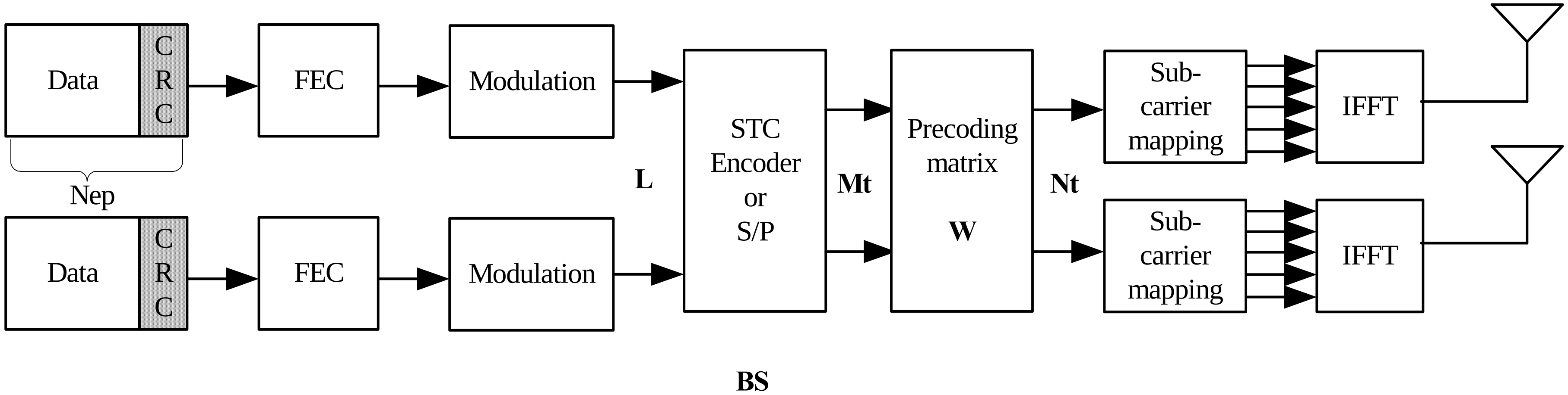
MIMO Precoding Operation (1/3)

- Vertical Encoded 2x2 MIMO System



MIMO Precoding Operation (2/3)

- Horizontal Encoded 2x2 MIMO System (Tx shown only)



MIMO System Operation (3/3)

MIMO System Operation

- **Step 1. Capability Selection**
  - Transmission Matrix: A,B,C for 2 ~ 4 Tx.
  - Feedback Capability: Precoding index, AG/AS, Channel Sounding
- **Step 2. Operation Mode Selection**
  - Operation Mode Selection within Capability
  - Decision Factor: User Geometry (SNR), Antenna Correlation, Mobility
- **Step 3. Packet Scheduling**
  - Maximize Multi-user Diversity
  - Monitor RF Condition & Decide BW Allocation Instants
  - Required Feedback Signals: CQI, AG/AS Index, Precoding Index, Channel Sounding

Implementation Issues

Mode Selection

- Open loop vs. Closed loop : Mobility
- STC vs. Multiplexing: User Geometry, Antenna Correlation
- Vertical vs. Horizontal Encoding: Decoding Capability, Feedback Info.

Terminal Complexity

- Multiple RF Path Design
- ST Decoder: MMSE, MMSE-SIC, ML Decoding
- CTC Codec: Peak Data Rate with Spatial Multiplexing

AAS Technology

- AAS System Design
- AAS System Operation
- Air Interface Details

MIMO vs. AAS

Technology Comparison

Category	AAS	MIMO
Pilot Preamble	Per Beam	Per Antenna/Per Beam
Channel State Information	Necessary (Closed-Loop)	Necessary or Not (Closed or Open Loop)
Favorable Conditions	Near LOS Macro-Cell	Rich-Scattering Pico-Cell/Indoor
General Design Approach	Coverage Enhance BS Throughput	Link Reliability (TD) SS Data Rate (SM)

AAS System Design

Design Requirement

- **Data Channel Coverage Extension**
  - Beam-formed Transmission of Data & Pilot Signals
  - Dedicated Pilot Processing
- **Control Coverage Extension**
  - Beam-formed Access & BW Allocation Channel
- **SDMA Scheduling**
  - Periodic Channel Sounding Signals
- **Wide-band TDD OFDMA System**
  - Band-narrow Orthogonal Signal Design in Freq. Domain

AAS System Design

Air Interface Specification

- **Downlink Design**
  - MAP Coverage Extension
    - AAS DLFP: Diversity Beam Scan of System & Access Information
    - AAS Private MAP: Beam-formed MAP Transmission
  - SDMA Allocation: AAS SDMA DL IE
  - Dedicated Pilot: AAS Preamble, Per-Beam Pilot
- **Uplink Design**
  - Access Channel Coverage Extension
    - AAS Ranging Channel Pointed by AAS DLFP
  - SDMA Allocation: AAS SDMA UL IE
  - Dedicated Pilot: AAS Preamble, Per-Beam Pilot
  - Signature Estimation: Sounding Symbol

AAS System Design

부채널 구조 및 특징

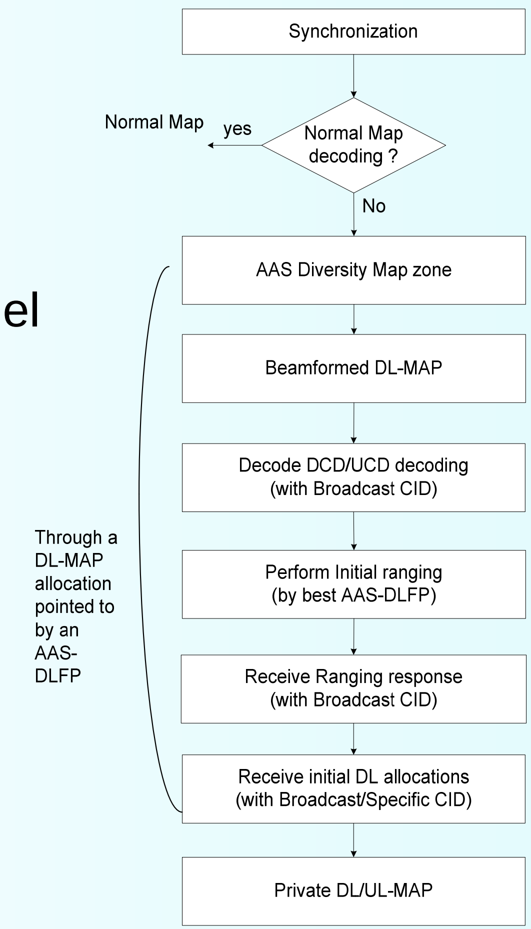
	Pilot overhead	AAS 적용 용이성 (DL/UL Symmetry)
DL PUSC	1/8	No symmetry
DL FUSC	~1/11	No symmetry
DL OFUSC	~1/9	No symmetry
UL PUSC	1/4	Symmetry with TUSC
UL OPUSC	1/9	Symmetry with TUSC
DL/UL Band AMC	1/9	Symmetry & Better for beamforming

AAS System Operation

AAS Operation

- AAS Diversity-MAP Scan
  - Diversity-Map Zone
    - AMC - first/last subchannel
    - Diversity - two highest subchannel
  - AAS-DLFP
    - AAS beam index
    - Preamble configuration & type
    - UL initial ranging allocation
    - AAS_DL_COMP_DL_IE()
  - Coverage Extension

< AAS Network Entry Procedure >



AAS System Operation

AAS System Operation

- Basic AAS
  - AAS_DL_IE or AAS_UL_IE()
  - Adaptive Beamformed data transmission
    - AMC 2x3
    - DL TUSC1/TUSC2 ←→ UL PUSC/OPUSC
    - UL AAS preamble, Channel sounding
  - SDMA (Spatial Division Multiple Access)
    - Spatial signature - UL AAS preamble, Channel sounding
    - AMC, TUSC1/TUSC2
      - Dedicated pilots: pattern #A~#D

AAS System Operation

AAS System Operation

- **Signature Estimation**
  - TDD Channel Reciprocity
  - Band-narrow Estimation (Bin/Tile)
- **Paired Operation**
  - Symmetric DL/UL BW Allocation
  - Signature Estimation from UL Allocation
  - DL Beam-forming based on Estimated Signature
- **Scheduling Operation**
  - Maximize Multi-user Diversity
  - Monitor RF Condition & Decide BW Allocation Instants
  - Required Feedback Signals: Sounding Symbol, CQI Information

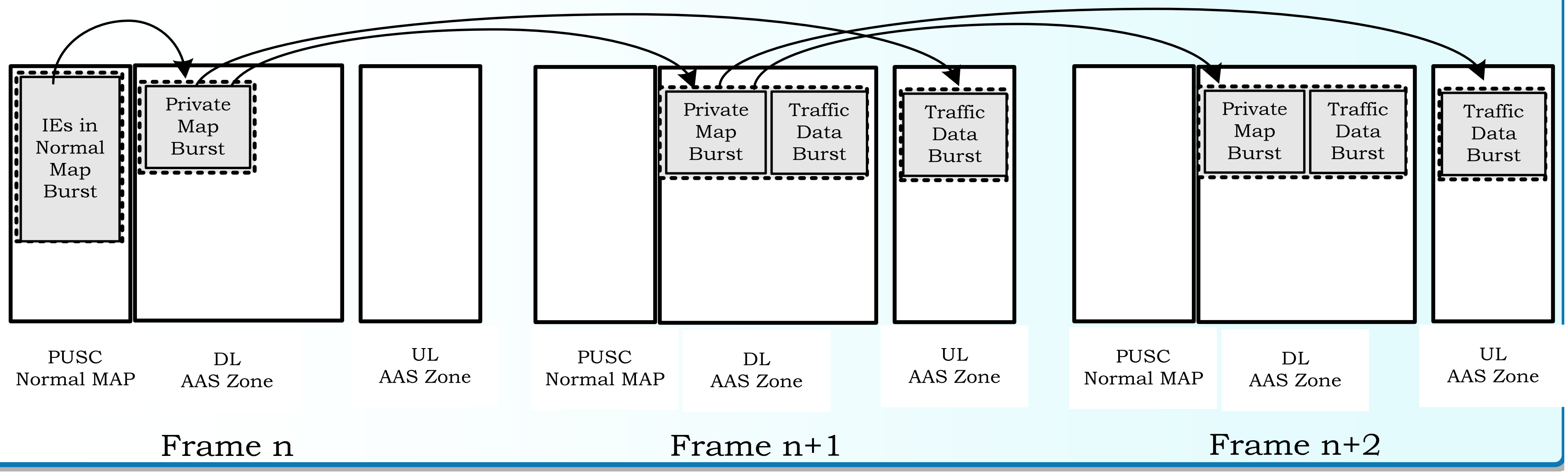
Air Interface Details

MAP Signaling for AAS Mode

MAP	Pointed by	Code Rate	비 고
Normal Map	FCH	QPSK 1/2 ~1/12 (Fixed)	H-ARQ Support
Sub-Map	Sub-Map Pointer IE in DL Map	DIUC & Repetition (Variable)	H-ARQ Support
Private Map	DL IE in DL Map DL Comp IE in AAS DLFP Private Map (Chain)	DIUC & Repetition (Variable)	H-ARQ Support MAP SDMA

Air Interface Details

Private Map Chain



- Initiated from Normal Map, AAS-DLFP
- Specify DL/UL BW Allocation for Next Frame
- Concatenation of MAP and DL Data Burst
- Beam-formed/SDMA Transmission in AAS Zone

Air Interface Details

Signal Design for AAS Mode

Category	Specifications	비 고
AAS Preamble	■ Combination of DL Preamble Sequence ■ Random Freq. Shift / Orthogonal Cyclic Shift	
Per-Beam Pilot	■ Orthogonal per-Beam Pilot for Tracking	PHY_MOD_DL_IE()
Sounding Symbol	■ Allocation Unit: 2 bins(1 band), Band Bit Map(4 bands), DL sub-channel ■ Orthogonality: Cyclic Shift vs. Freq. Decimation ■ Golay Seq. for Low PAPR (5.1 ~ 6.3 dB) ■ Originally Proposed for MIMO Operation	Type A/B

Air Interface Details

AAS Preamble

- AAS Preamble
  - Configuration & type are specified in AAS DL/UL IE() or AAS-DLFP
  - Using DL frame preamble sequences
  - Structure (in PHY_MOD_DL_IE() or AAS-DLFP)
    - Cyclically shifted in time
    - Shifted in frequency
  - DL AAS Preamble
    - Estimates the channel response
  - UL AAS Preamble
    - Estimates the spatial signature

Air Interface Details

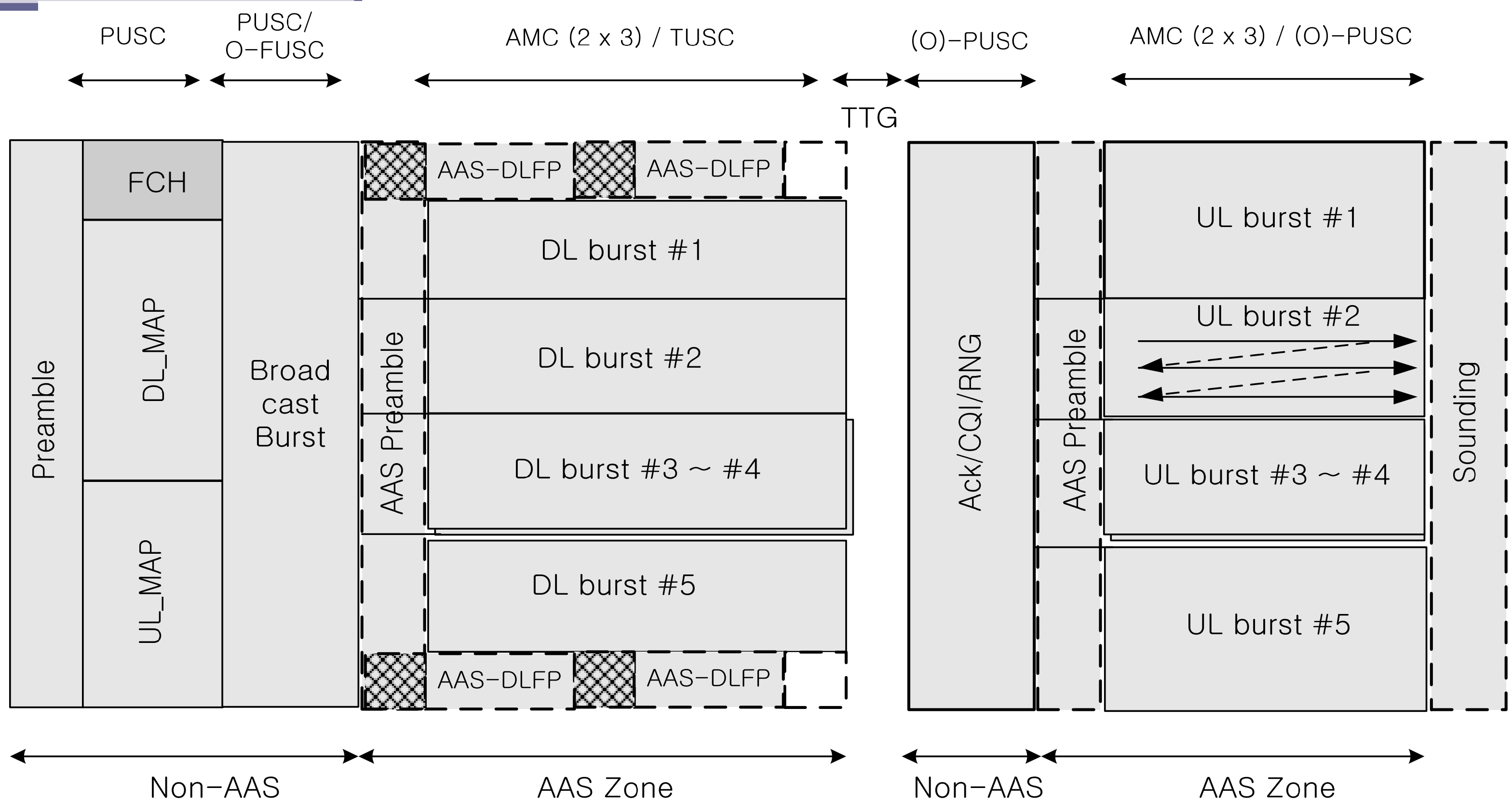
Channel Sounding

- Channel Sounding in TDD system
  - BS measures the UL channel response and use it for estimation of DL channel response (closed-loop transmission)
  - Type A
    - Non-distributed
    - 1band(2 bins) or Band Bit Map(4 bands)
    - Multiple multiplexed MS
      - Cyclic-shift separability or Frequency decimation separability
  - Type B
    - Distributed
    - The frequency bands are allocated according to a specified DL subcarrier permutation
    - No multiple multiplexed MS

Possible Frame Configuration

Acronyms

Tile **U**sage of **S**ub-**C**hannel
: DL TUSC1 ↔ UL PUSC
DL TUSC2 ↔ UL O-PUSC



MIMO Support

- STC
  - Reduce fade margin by spatial diversity
  - Peak rate limit
- SM
  - Improve capacity
  - Requires good SINR and low spatial correlation
- AAS(beamforming)
  - Improve link budget
  - Reduce interference
  - Minor change to MS
  - #Antennas $\geq$ 4 for good beamforming effect
  - Requires CSI feedback (e.g. sounding), good for slow varying channel
  - Only extends range for unicast transmission
- Adaptive MIMO switch(AMS)
  - Optimally select STC or SM to adapt to channel condition
  - Reduced feedback
  - Explore spatial diversity with 2x2 antenna configuration

MIMO Profile in WiMAX wave 2

<table>
<tr><td rowspan="4">DL 2 Tx</td><td colspan="8">Open-loop</td><td colspan="5">Closed-loop</td></tr>
<tr><td>TD</td><td colspan="2">HD</td><td colspan="3">SM (matrix C)</td><td colspan="2">Beamforming</td><td>TD/HD</td><td colspan="2">SM</td><td colspan="2" rowspan="2">Codebook</td></tr>
<tr><td rowspan="2">matrix A</td><td colspan="2">matrix B</td><td colspan="2">SU</td><td rowspan="2">MU</td><td>SDM</td><td>SDMA</td><td rowspan="2">AG</td><td colspan="2">AS</td></tr>
<tr><td>VE</td><td>HE</td><td>VE</td><td>HE</td><td>SU</td><td>MU</td><td>SU</td><td>MU</td><td>SU</td><td>MU</td></tr>
<tr><td>WiMAX</td><td>O</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td>O</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>Subchannel</td><td>PUSC</td><td>PUSC</td><td>-</td><td>-</td><td>-</td><td>-</td><td>PUSC,
AMC 2x3</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td colspan="14">Note) O: support, X: not support, OL-Beamforming based on UL sounding</td></tr>
</table>

<table>
<tr><td rowspan="4">UL 1 Tx</td><td colspan="6">Open-loop</td></tr>
<tr><td colspan="3">Collaborative SM (UL SDMA)</td><td rowspan="3">TD</td><td colspan="2">SM</td></tr>
<tr><td colspan="2">1 Tx</td><td rowspan="2">2 Tx</td><td rowspan="2">VE</td><td rowspan="2">HE</td></tr>
<tr><td>Beamformi
ng</td><td>MIMO</td></tr>
<tr><td>WiMAX</td><td>O (receive)</td><td>O</td><td>X</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>Subchannel</td><td colspan="6">PUSC w/o subchannel rotation</td></tr>
<tr><td colspan="7">Note) O: support, X: not support</td></tr>
</table>

References

1. Space-Time Processing for 3.5G Networks : Part I, II, Wonil Roh, 2004
2. Capacity of Multi-antenna Gaussian Channels, I.E. Telatar, 1999
3. Capacity Limits of MIMO Channels, A. Goldsmith et al, JSAC June 2003
4. A. J. Paulraj, D. A. Gore, R. U. Nabar, and H. Bolcskei, “An Overview of MIMO Communications – A Key to Gigabit Wireless”, Proc. Of the IEEE, vol. 92, no. 2, Feb. 2oo4
5. Gesbert et al, “From Theory to Practice: An Overview of MIMO Space-Time Coded Wireless Systems”, JSAC, Apr 2003
6. Lecture Slides of EE492m, A. Paulraj, Stanford University, 2003
7. Thesis by S. A. Jafar, Stanford University, Aug 2003
8. Guest Editorials: MIMO Systems and Applications: Part I & II, JSAC Apr. June, 2003
9. Zheng and Tse, “Diversity and Multiplexing: A fundamental tradeoff in multiple antenna channels”, Trans. IT, May 2003
10. Catreux et al, “Some Results and Insights on the Performance Gains of MIMO Systems”, JSAC, June 2003
11. Yu and Ottersten, “Models for MIMO propagation channels: a review”, WCMC 2002
12. Ariyavisitakul, “Turbo Space-Time Processing to Improve Wireless Channel Capacity”, Trans. Comm. Aug 2000
13. Foschini et al, “Analysis and Performance of Some Basic Space-Time Architectures”, JSAC Apr. 2003
14. Chizhik et al, “MIMO Measurements and Modeling in Manhattan”, JSAC Apr. 2003
15. Liang, “A High-Rate Orthogonal Space-Time Block Code”, Comm. Let., May 2003

References (Cont'd)

18. Liang, "Orthogonal Designs with Maximal Rates," Trans. IT, Oct., 2003
19. Yao, Thesis. MIT 2003
20. Molisch et al, "Space-time-frequency coding for MIMO-OFDM systems", IEEE Comm. Let. Sep., 2002
21. Bolcskei et al, "On the Capacity of OFDM-Based Spatial Multiplexing Systems", IEEE Tran. Comm.,
22. Van zelst et al, "Implementation of a MIMO OFDM based wireless LAN systems", IEEE Tran. SP, Feb, 2004
23. Sampath et al, "A fourth generation MIMO-OFDM broadband wireless system: design, performance and field trial results", IEEE Comm. Mag., Sep, 2002
24. Chae et al, "Adaptive spatial modulation for MIMO-OFDM", WCNC 2004
25. Bauch, "Space-time block codes versus space-frequency block codes", 2003
26. IEEE P802.16-REVd/D5-2004 and other contributions to 802.16d
27. IEEE P802.16-REVe/D11 and other contributions to 802.16e
28. Batariere et al, "Wideband MIMO mobile impulse response measurements at 3.7 GHz", VTC '02
29. Batariere et al, "An experimental OFDM system for broadband mobile communications", VTC '01
30. Su et al, "Obtaining full-diversity space-frequency codes from space-time codes via mapping", Trans. SP., Nov. 2003
31. Intarapanich et al, "Effect of tap gain correlation on capacity of OFDM MIMO systems", EL, Jan. 2004
32. H.J.Kim et al, "Precoding-based MIMO in IEEE802.16e"
33. Yong Soo Cho, "Multiple Antenna OFDM"

Thank you