Analysis of STFBC-OFDM for BWA in SUI channel

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Purpose: This presentation presents the concept & results for the proposed new diversity scheme feature.

Analysis of STFBC-OFDM for BWA in SUI Channel

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Objective

Idea

Efficient utilized methods of frequency diversity in OFDM system

Problem of STBC-OFDM

- **Limitation in Performance**
- **Complexity increase as Number of Antenna increase**
- **Transmission rate decrease as Number of Antenna increase**

Advantage of STFBC-OFDM

- **enhancement in BER (using Frequency Diversity)**
- **simple structure (do not increase number of antennas)**
- **Range enhancement (due to Eb/N0 enhancement)**

STBC: space time block code

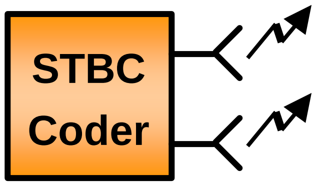
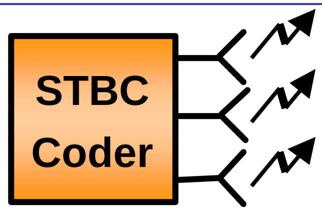
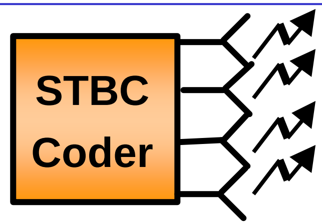
STFBC: space time frequency block code

History of MIMO techniques

- Space-Time Trellis Code (STTC)
  - Guey *et al.* (1996) and Tarokh *et al.* (1998) independently derived design criteria for STTC
- Alamouti뭘 scheme with 2 Tx and N_r Rx antennas
  - Alamouti (1998) proposed a novel scheme to orthogonalize the channel with a very simple decoder
- Space-Time Block Code (STBC)
  - Tarokh *et al.* (1999) generalized Alamouti뭘 scheme with an orthogonal block coding structure

Space-Time Block Coding

- Some STBC Examples for Multiple Transmit Antennas
  - **In the case of using more than three transmission antennas, simultaneously satisfy code orthogonality and transmission rate of STBC as 1, do not exists (Proved by V. Tarokh)**

Num. of Tx. Ant.	Space-Time Block Code	BW
2	 • (2×2) **Matrix** **: 2 symbol transmission in** $2T_s$ **(Proposed by Alamouti)**	1
3	 • (8×3) **Matrix** **: 4 symbol transmission in** $8T_s$ **(Proposed by Tarokh)**	1/2
4	 • (8×4) **Matrix** **: 4 symbol transmission in** $8T_s$ **(Proposed by Tarokh)**	1/2

Space-Time and Frequency Block Coding - OFDM - I

- Motivation
  - Request More reliable system in next generation comm. system
    - Request of higher Diversity Gain → should increase the number of antennas
  - Diversity Gain of STBC Depends on number of Tx antennas
    - To improve in performance **should increase number of tr antenna**
    - Of number of antenna increase **HW load** seriously increases.
    - Especially, In the case of STBC-OFDM compare to single carrier system, operational complexity increases depends on sub-carrier number. → **operational complexity greatly increases**

  ➡ In OFDM, an STBC-OFDM system that have more than 3 tx antennas is not easy in implementation.

  - The STBC using more than 3 tx antennas transmission rate decreases. OFDM can obtain **frequency diversity in simple method**.

Space-Time and Frequency Block Coding - OFDM - II

Design consideration

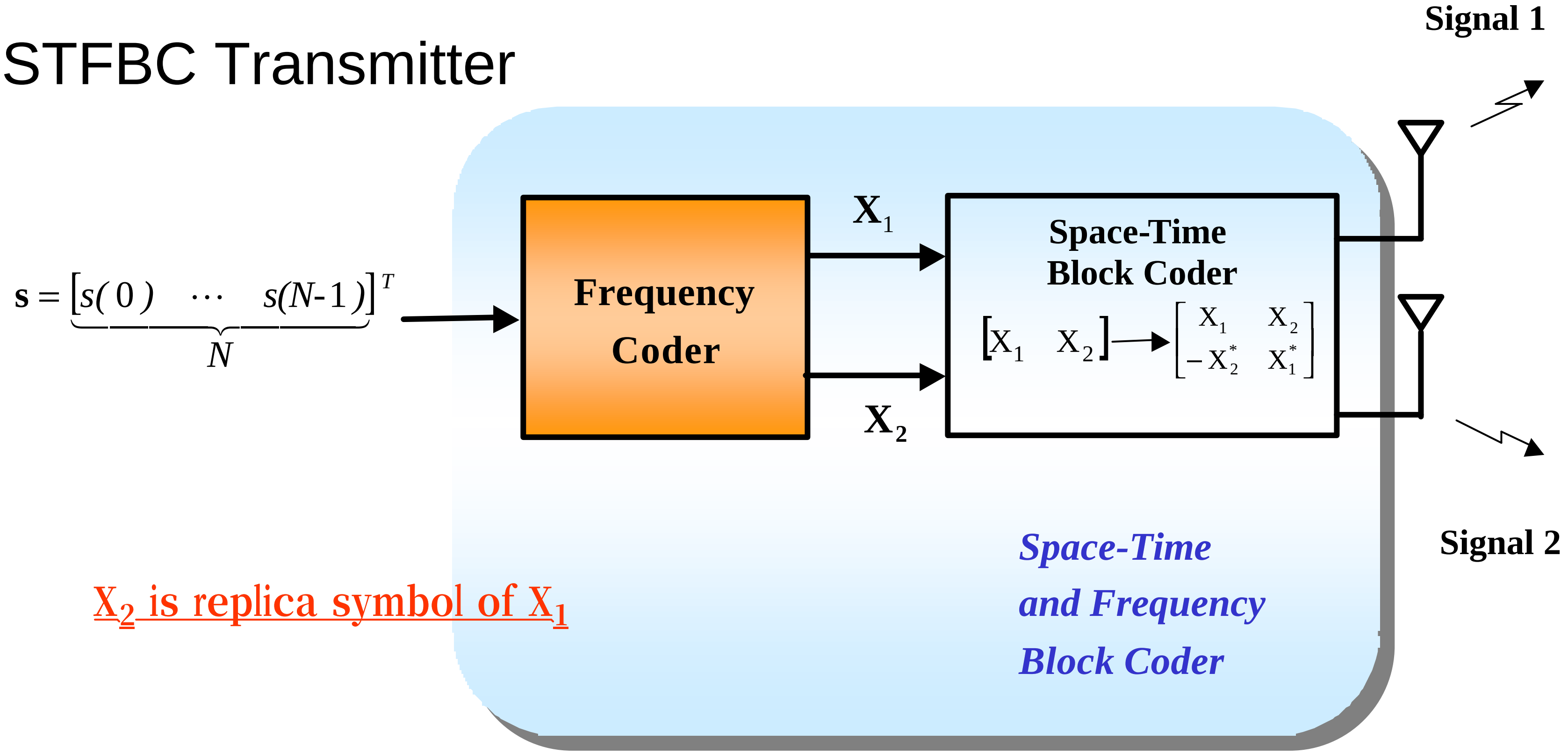
- **Maximum Frequency Diversity Gain**
  - # of Tx antenna × # of rx antenna × frequency gain
- **Simple Structure**
  - Should not increase number of transmission antenna.
  - To earn frequency Diversity Gain in Decoding process it should be incorporate with Linear Processing
- compatibility with **STBC-OFDM system**

- **Minimize complexity increase**
- **Maximize Diversity Gain**

→ **Space-Time and Frequency Block Coding Technique**

Space-Time and Frequency Block Coding Wideband OFDM - III

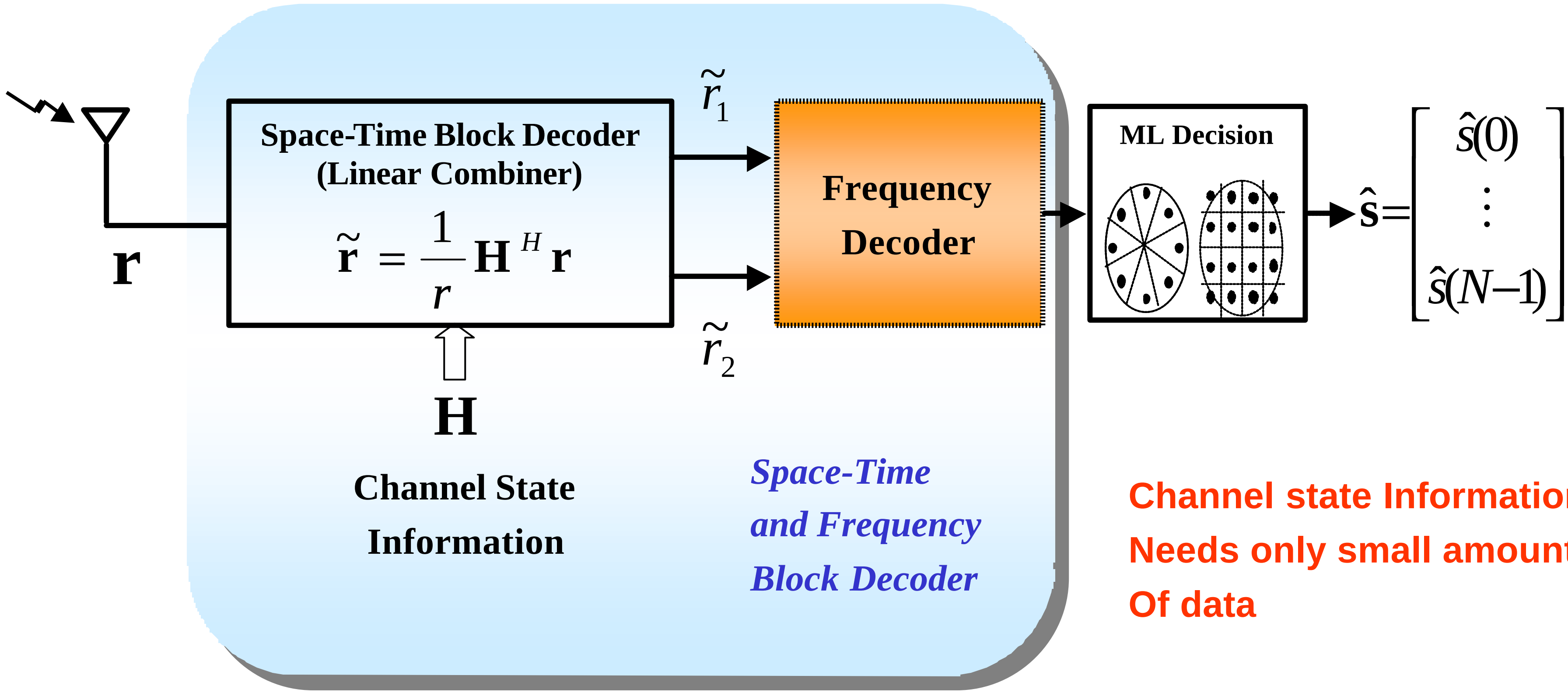
- STFBC Transmitter



Frequency Coder : Frequency diversity enabling part in STBC-OFDM system

Space-Time and Frequency Block Coding Wideband OFDM - IV

- STFBC Receiver



Channel state Information Needs only small amount Of data

Channel Covariance Matrix(CCM)

•Channel impulse response of L multi-path frequency selective fading can be modeled as L-Tap FIR filter as, $g(t)=\sum_{i=0}^{L-1}h(i)d(t-t_i)$

Than $H(k)=\sum_{i=0}^{L-1}h(i)e^{-j2pki/N},0\le k\le N-1$

$$r_{\Delta k}=E\left[H(k)H^*(k+\Delta k)\right]=\sum_{i=0}^{L-1}s_i^2 e^{j2p\Delta ki/N}$$

$$r_{\Delta k}=\frac{1}{L}\sum_{i=0}^{L-1}e^{j2p\Delta ki/N}=\frac{1}{L}\frac{\sin\left(\frac{p\Delta kL}{N}\right)}{\sin\left(\frac{p\Delta k}{N}\right)}e^{jp\Delta k(L-1)/N} \quad (1)$$

Channel covariance matrix is ..

$$C_H=E\left[H\,H^H\right]=\begin{bmatrix} r_0 & r_1 & \cdots & r_{N-1} \\ r_{-1} & r_0 & \cdots & r_{N-2} \\ \vdots & \vdots & \ddots & \vdots \\ r_{-N+1} & r_{-N+2} & \cdots & r_0 \end{bmatrix}$$

$H=[H(0)H(1)\cdots H(N-1)]^T$ Is defined

1 $r_{-\Delta k}=r^*_{\Delta k}$

2 $|r_{-\Delta k}|=|r_{\Delta k}|$

3 $\boxed{r_{-\Delta k}=r_{N-\Delta k}}$

CCM has Cyclic Shift property

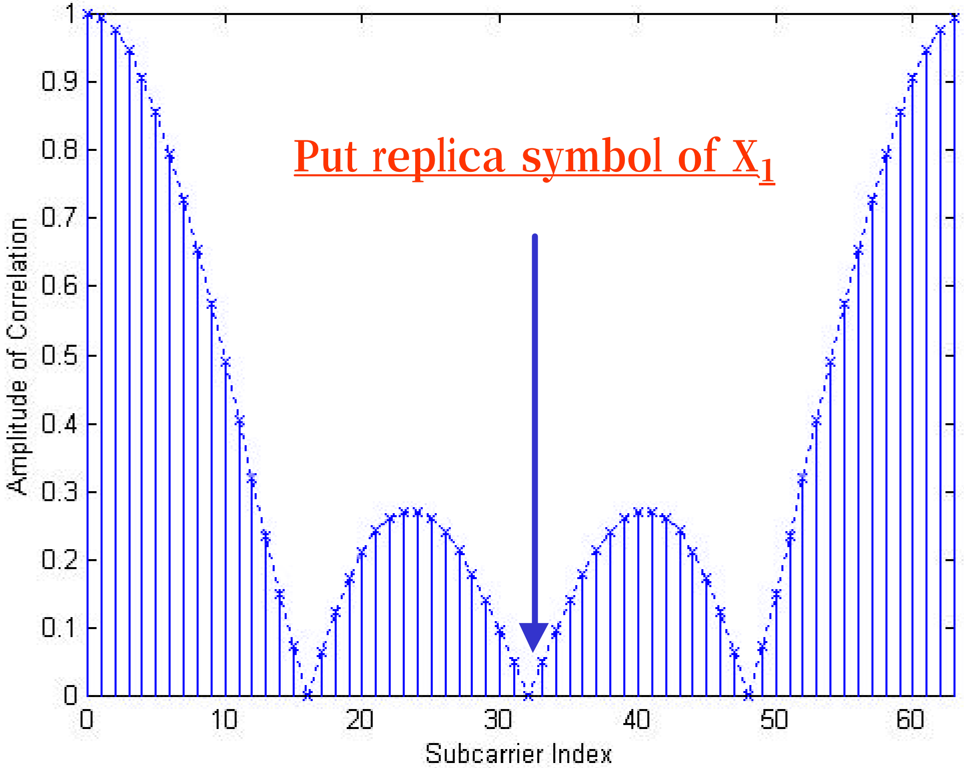
To maximize the frequency diversity select optimum sub-carrier position

- Let $r_{\kappa 1 \kappa 2}$=0,in Eq. (1), than
- $$\sin\left(\frac{p\Delta k_{12} L}{N}\right) = 0 \qquad (2)$$
- Δk_{12} is function of the distance of 2 sub-carriers.
- $\Delta k_{12} = \frac{mN}{L}$ is general solution.
- $\frac{L}{N} \le m \le L - \frac{L}{N}$, m, N & L all positive integer
- $1 \le m \le L - 1 \qquad (3)$
- The optimum sub-carrier position in one of m.
- Find minimum channel covariance in m sub-carrier

Maximum frequency diversity achievable OFDM system structure

- 3 things shall be considered in the FD system.
  - Maximize diversity gain
  - Distance between all sub-carrier shall be maintained.
  - Robust property of channel correlation between sub-carrier.
- The maximum separation of sub-carrier is N/2. And in general, the optimum $\Delta k = d = \left\lfloor \frac{N}{L} \right\rfloor \cdot \left\lfloor \frac{L}{2} \right\rfloor$ $r_{-\Delta k} = r_{N-\Delta k}$
- According to **channel covariance matrix** property 3 the correlation vector is cyclically rotate to each other. So the maximum separable sub-carrier spacing k' is
- k'=(k+d) mod N

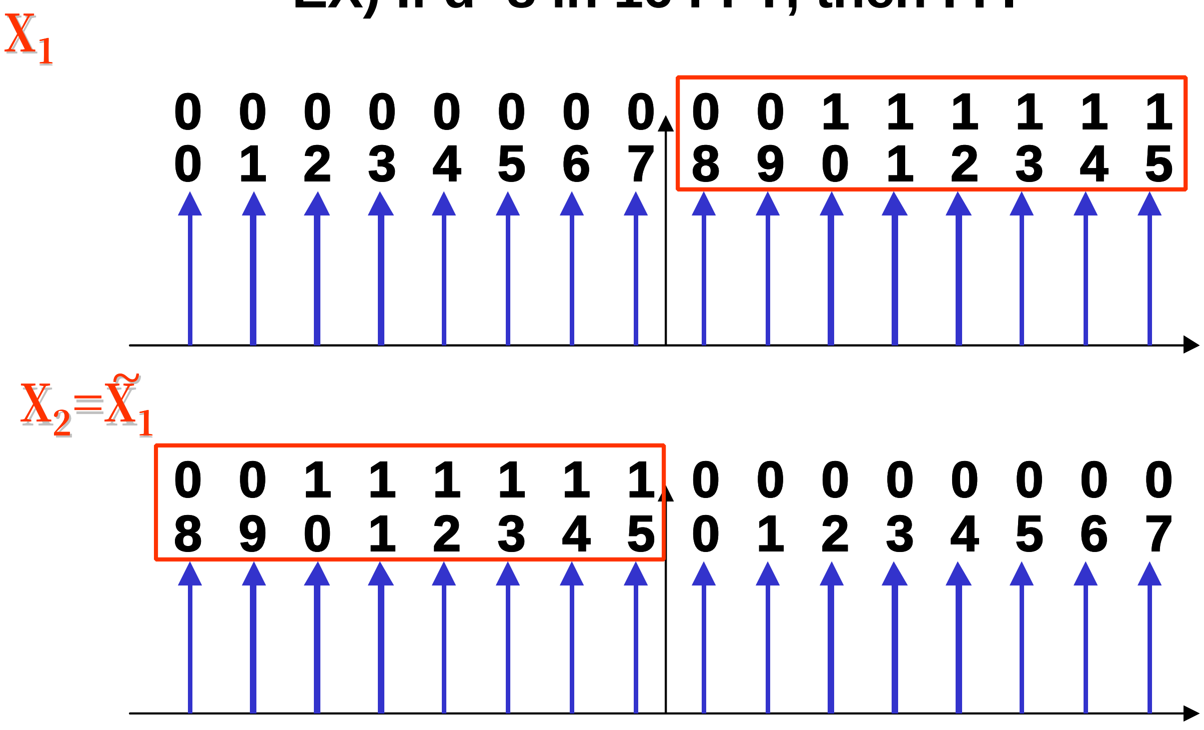
Optimum Position of Sub-carrier of Symbol X_1



- Put the 0th sub-carrier of the **replica symbol** here!!
- Frequency Diversity Maximized

What is Replica Symbol?

EX) If d=8 in 16 FFT, then . . .



X_1= Tx symbol

X_2= replica symbol

~ means cyclic shift in frequency domain

MIMO system performance

For the quasi-static flat fading channel with N_t transmit and N_r receive antennas, the pairwise error probability is

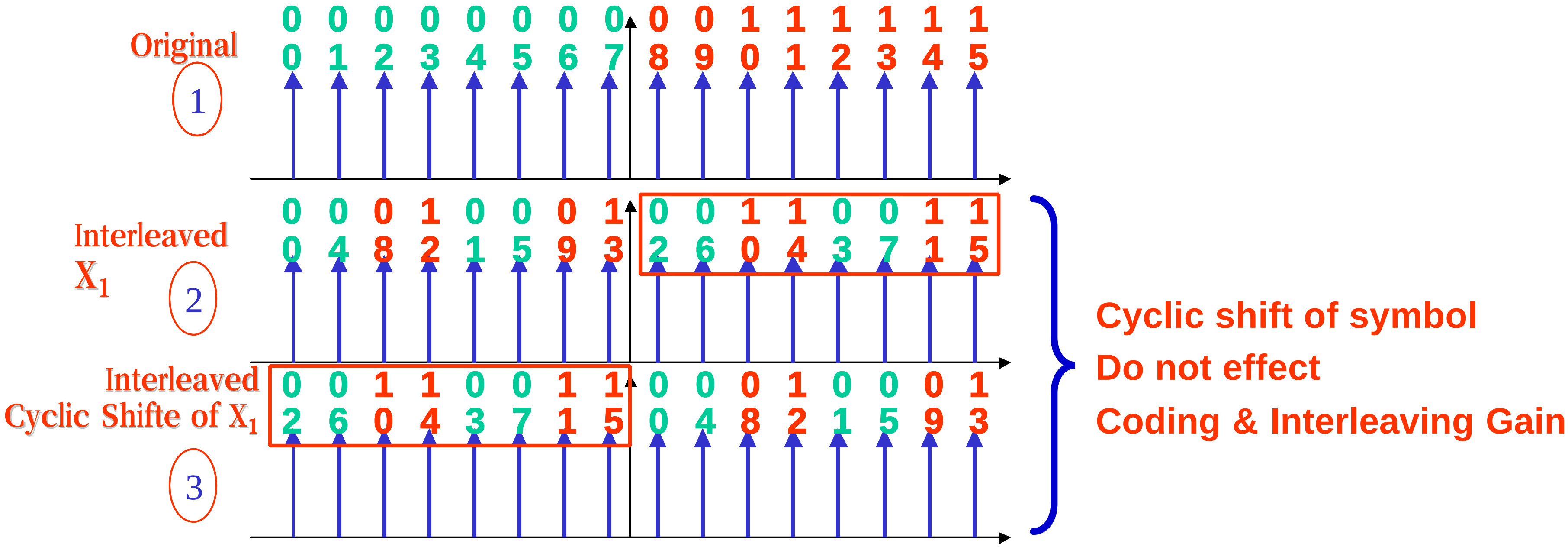
$$P(c \rightarrow e) \leq \left(\frac{E_S}{4N_0}\right)^{-LN_r} \left(\prod_{t=1}^{L} d_H^t(c,e)\right)^{-N_r}$$

where $L \leq N_t$ is the number of nonzero Hamming distances per branch $d_H^t(c,e)$

diversity gain: slope of BER curve

coding gain: horizontal shift of BER curve

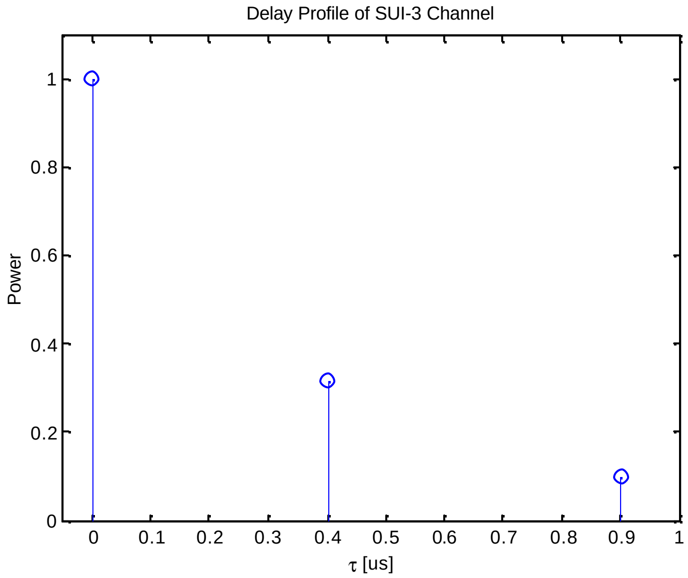
Symbol (frequency) Interleaving

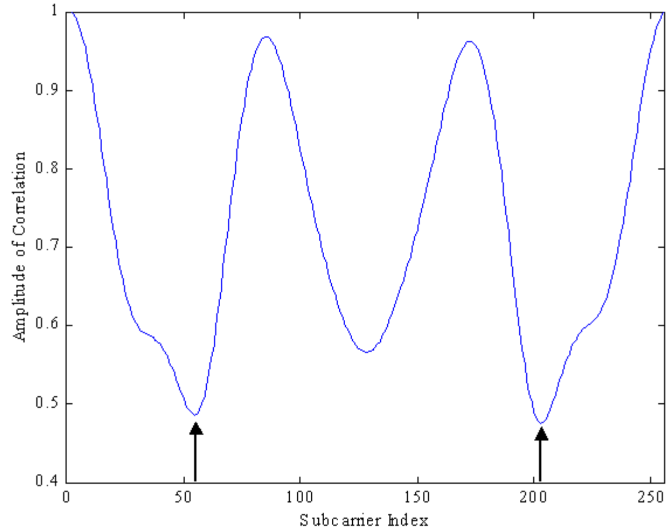


Analysis in SUI channel model

- In L path frequency selective fading,
  - –Assumed Uniform delay spread
- But, It is different in SUI model
  - –Ricean
  - –Delay spread is Not uniform
- Two model is analysed
  - –SUI 1 terrain Type C
  - –SUI 3 terrain Type B

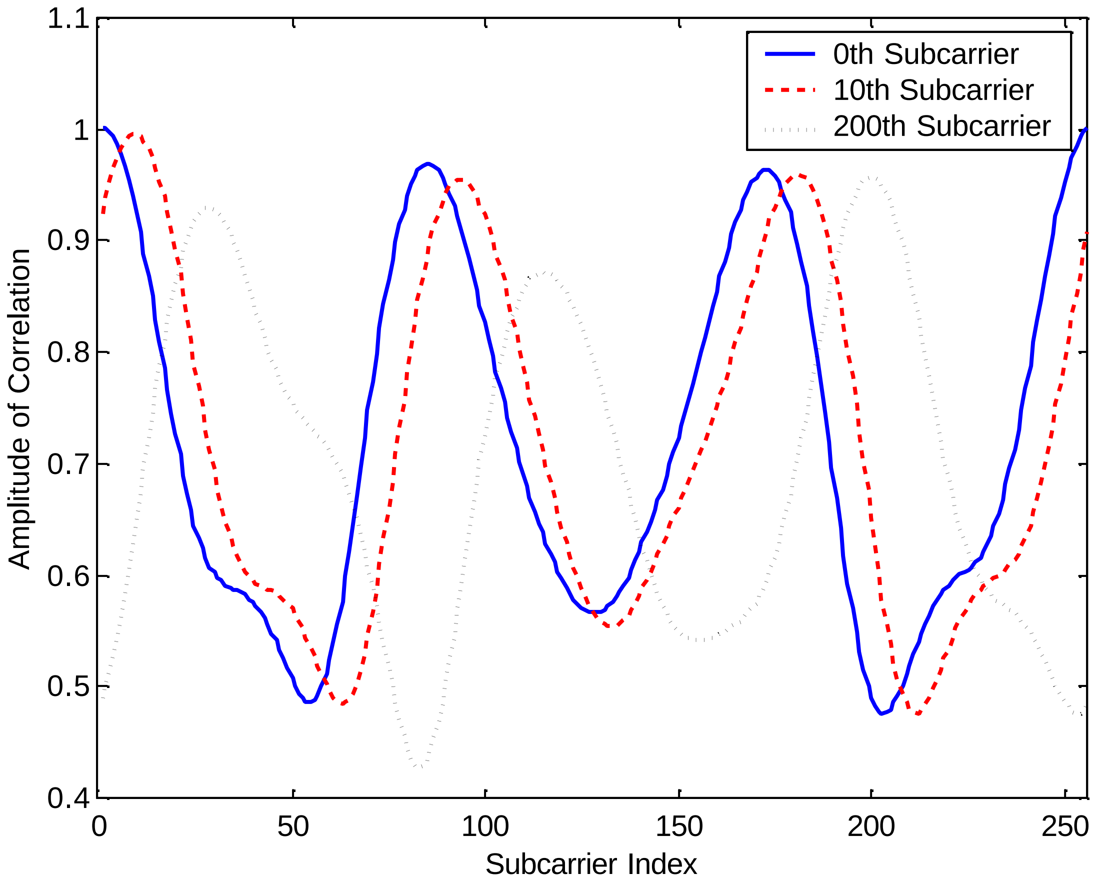
SUI channel model





SUI-1 Channel					SUI-3 Channel				
	Tap1	Tap2	Tap3	Units		Tap1	Tap2	Tap3	Units
Delay	0	0.4	0.9	*ms*	Delay	0	0.4	0.9	*ms*
Power (omni ant.)	0	-15	-20	DB	Power (omni ant.)	0	-5	-10	DB
Doppler	0.4	0.3	0.5	Hz	Doppler	0.4	0.3	0.5	Hz
Antenna Correlation	$r_{ENV} = 0.7$				Antenna Correlation	$r_{ENV}=0.4$			

CCM is Still Cyclic Shift in SUI model



Channel Covariance Matrix

Still Cyclic Shifting

Not in amplitude

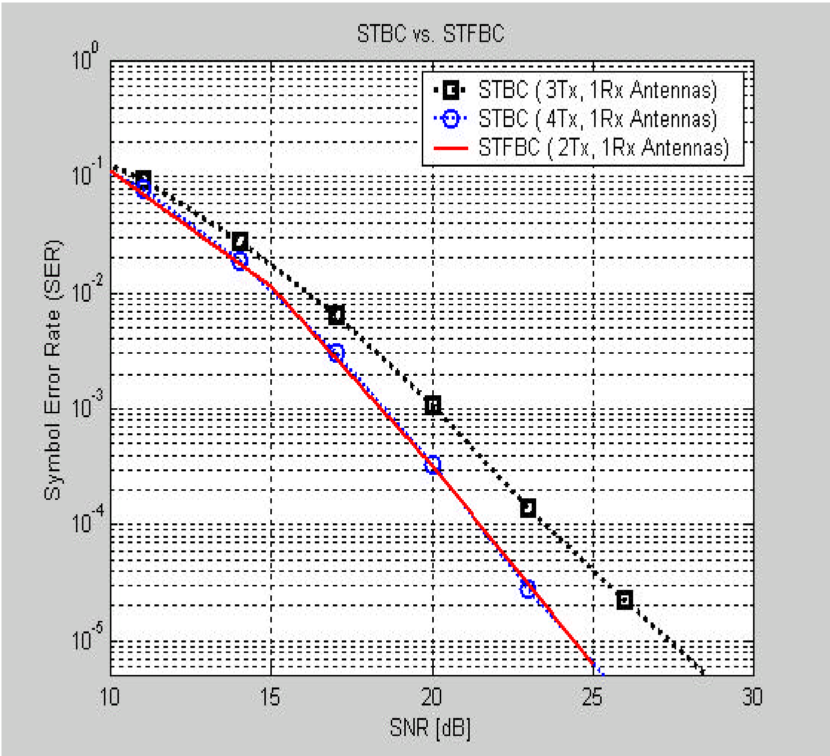
But also in Delay.

Performance Evaluation I

- Channel Order : 10
- Compares,
  - STBC 3x1,16QAM
  - STBC 4x1,16QAM
  - STFBC 2x1,16QAM
- Independent Rayleigh Fading Channel
- Perfect Channel & Order Information

Performance Result I

- In uniform delay spread Rayleigh Fading



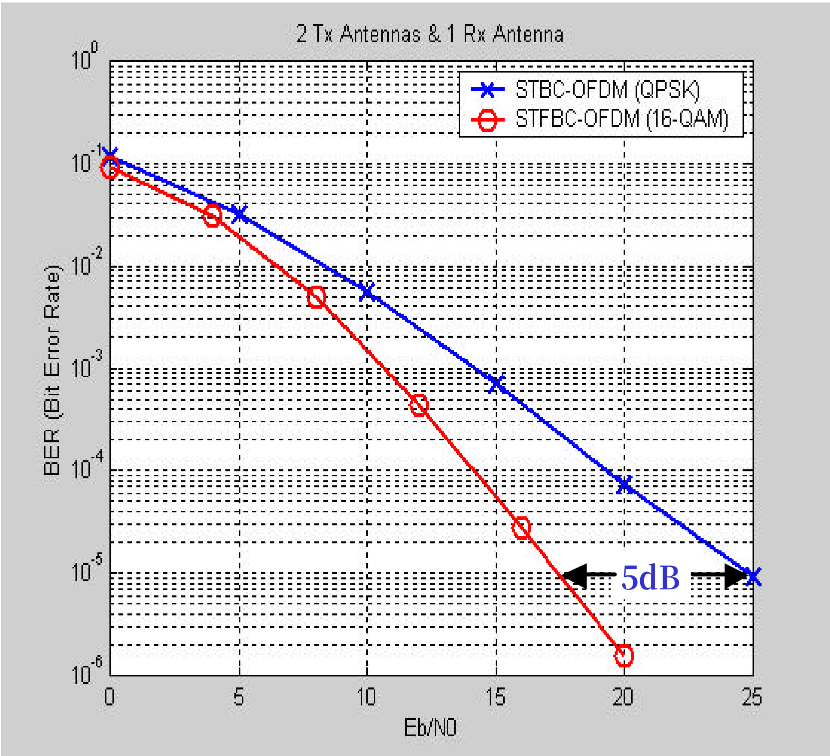
- **Simulation environments**
  - **4 tx antenna using STBC and 2 tx antenna using STFBC shows same performance**
  - Compare to 3 **tx antenna using STBC in** 10^{-4} SER shows **approx. 2.5dB** SNR gain

Performance Evaluation II

– Channel Order : 10
– Independent Rayleigh Fading Channel
– Pefect Channel & Order Information
– To match the Spectrum Efficiency
– Compares, 2bits/sub-carrier
  - QPSK (STBC) : 2 tx antennas & 1 rx antenna
  - 16QAM (STFBC) : 2 tx antennas & 1 rx antenna

Performance Result II

- In uniform delay spread Rayleign Fading



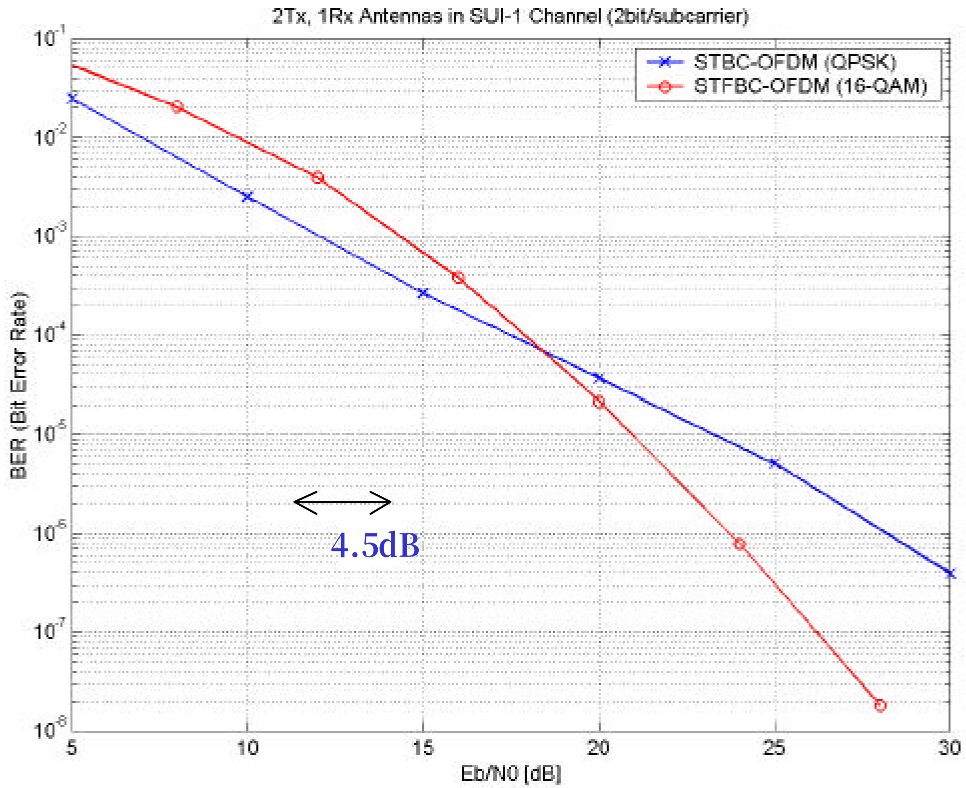
- **Simulation environments**
  - In 10^{-5} BER **more than 5dB** performance improvements.

Performance Evaluation III

- SUI 1
  - 2bits/sub-carrier
    - QPSK (STBC) with 2 antenna
    - 16QAM (STFBC) with 2 antenna
  - Ricean Fading Channel
- Perfect Channel & Order Information

Performance Result III

- **Simulation environments SUI 1**
  - **STFBC in** 10^{-5} BER shows **approx. 4.5dB** Eb/N0 gain

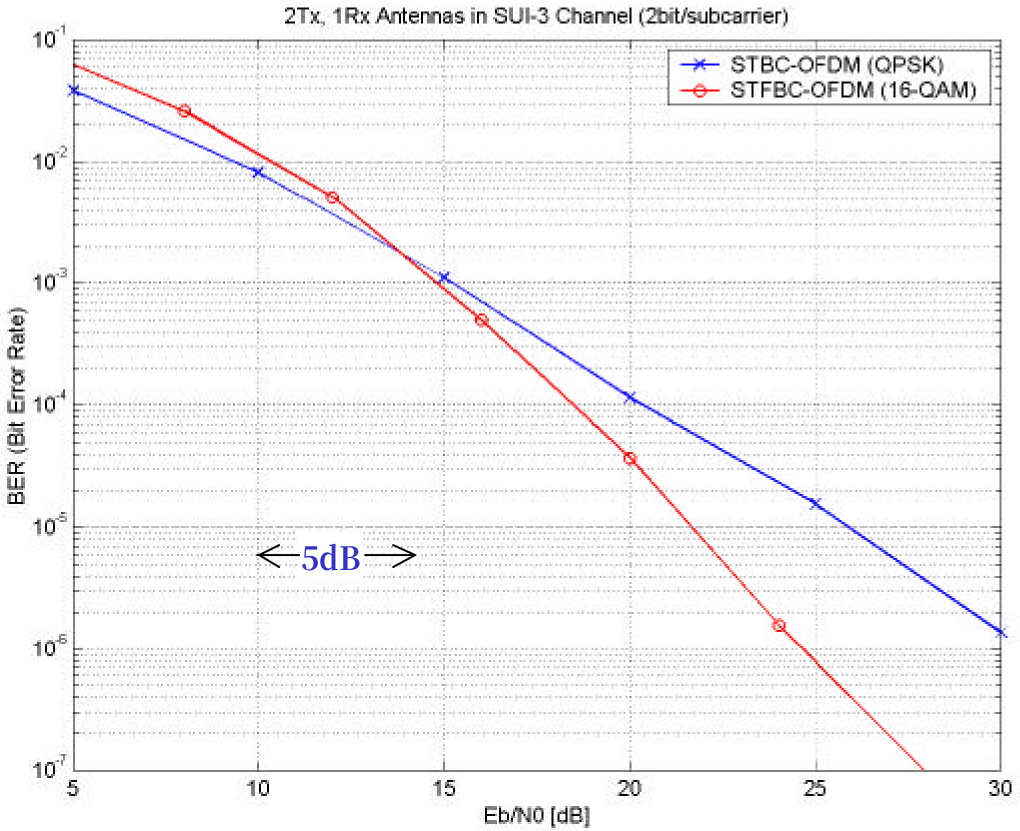


Performance Evaluation IV

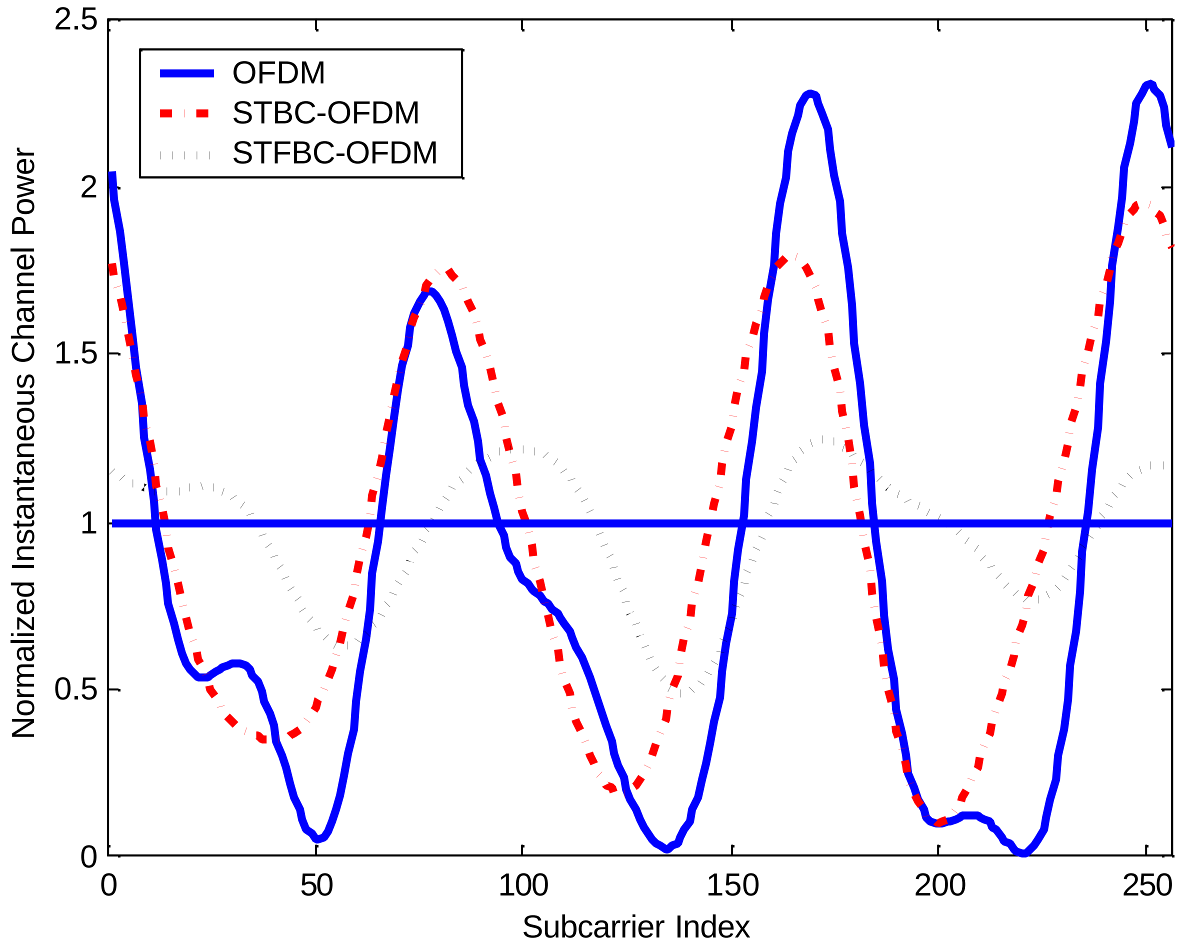
- SUI 3
  - 2bits/sub-carrier
    - QPSK (STBC) with 2 antenna
    - 16QAM (STFBC) with 2 antenna
  - Ricean Fading Channel
- Perfect Channel & Order Information

Performance Result IV

- **Simulation environments SUI 3**
  - **STFBC in** 10^{-5} BER shows **approx. 5dB** Eb/N0 gain



Comparison of diversity Gain



- •Blue : OFDM only
- •Red : STC-OFDM
- •Black : STFC-OFDM

Closing Comment

- **Space-Time Block Coding (STBC)**
  - Simple structure and Full space diversity gain
  - But there are many problem when using more than 3 antennas in OFDM system (HW and operational complexity, decrease in tx rate)
- **Space-Time and Frequency Block Coding (STFBC)**
  - Overcome the problem of STBC-OFDM
  - A scheme, Not only Maximize Space Diversity but also frequency Diversity gain
  - Using frequency diversity so that increasing the number of tx antenna is not required.
  - Compatible to existing STBC-OFDM
- **Tx diversity scheme for OFDM system is desirable to use the STFBC is strongly requested.**

References

- [1] V. Erceg, K.V.S. Hari, M.S. Smith, D.S. Baum et al, “Channel models for fixed wireless applications”, IEEE 802.16.3c-01/29r4, July, 2001.
- [2] IEEE 802.16 Working Group, “Unapproved Working Document: Standard air Interface for fixed broadband wireless access systems”, 802.16ab-01/01r2, Sep., 2001.
- [3] PanYuh Joo, JungJe Son, and DaeEop Kang, “ Novel Design of STBC for OFDM/OFDMA using Frequency Diversity”, IEEE 802.16abc-01/59, Nov., 2001.