

Analysis of STFBC-OFDM for BWA in SUI channel

IEEE 802.16 Presentation Submission Template (Rev. 8.21)

Document Number: IEEE C802.16aP-01/18

[The appropriate coordinator, normally the Task Group Chair, will fill in this number after obtaining it from the 802.16 Chair. The document number will match that of the base contribution, with “p” replacing “c”. For example: IEEE 802.16.Xp-01/NN].

Date Submitted: 2002-01-22

[The date the document is contributed, in the format 2002-01-22.]

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Venue: 802.16a meeting, Jan 21-25, 2002, Levi, Finland

Base Document: IEEE C802.16a-01/18

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

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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 E_b/N_0 enhancement)

STBC: space time block code

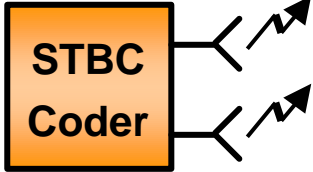
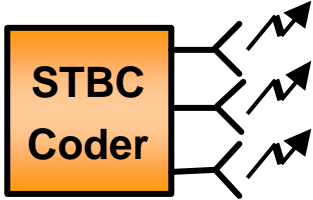
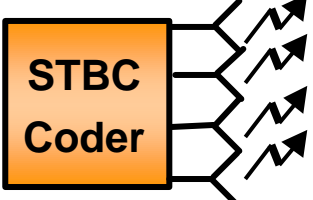
STFBC: space time frequency block code

History of MIMO techniques

- Space-Time Trellis Code (STTC)
 - Guey *et al.* (1996) and Tarokh *et al.* (1998) independently derived design criteria for STTC
- Alamouti 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 Alamouti 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 exist (**Proved by V. Tarokh**)

Num. of Tx. Ant.	Space-Time Block Code	BW
2	 <ul style="list-style-type: none"> • (2×2) Matrix : 2 symbol transmission in $2T_s$ (Proposed by Alamouti) 	1
3	 <ul style="list-style-type: none"> • (8×3) Matrix : 4 symbol transmission in $8T_s$ (Proposed by Tarokh) 	1/2
4	 <ul style="list-style-type: none"> • (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 \times # of rx antenna \times 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**

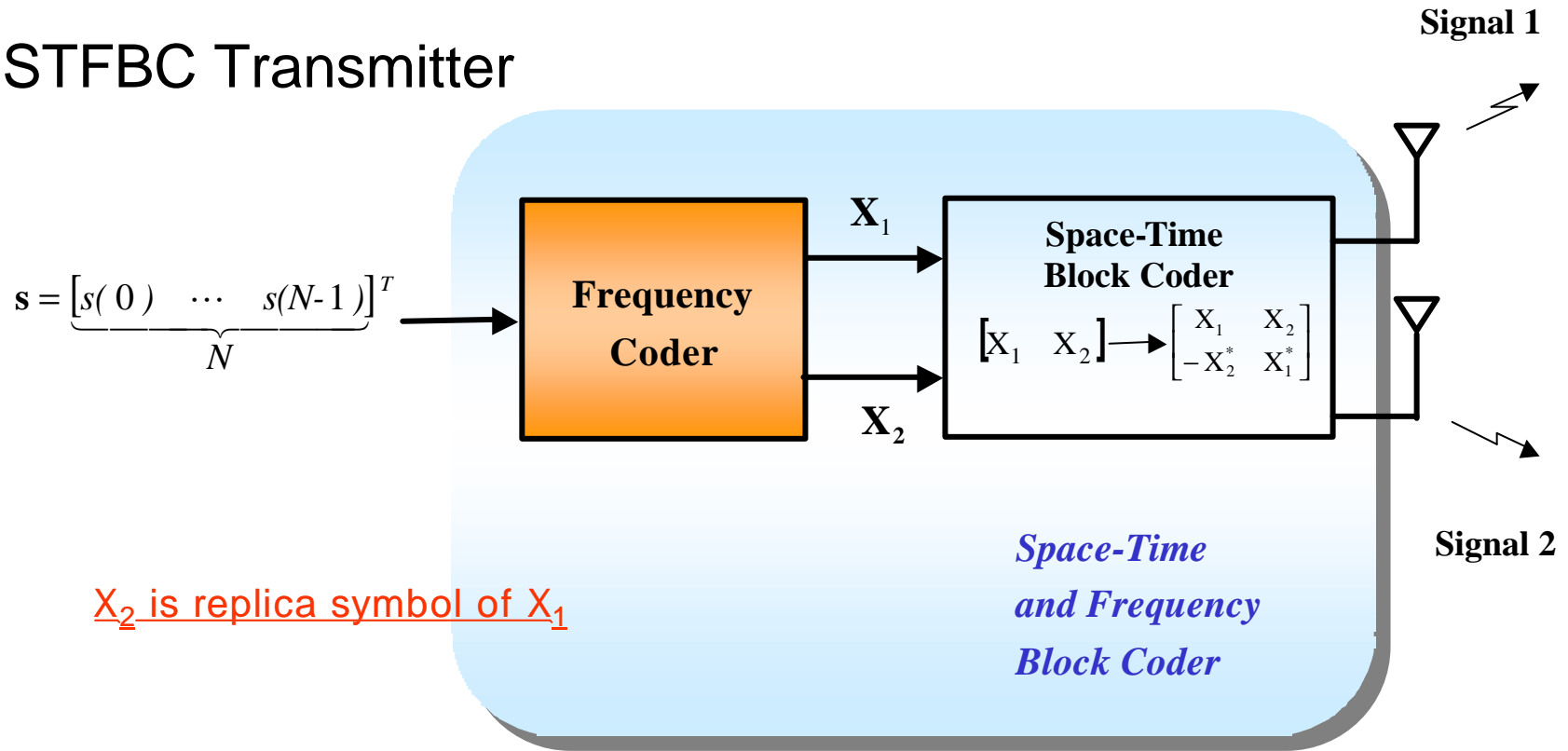
• Minimize complexity increase

• Maximize Diversity Gain

→ Space-Time and Frequency Block Coding Technique

Space-Time and Frequency Block Coding Wideband OFDM - III

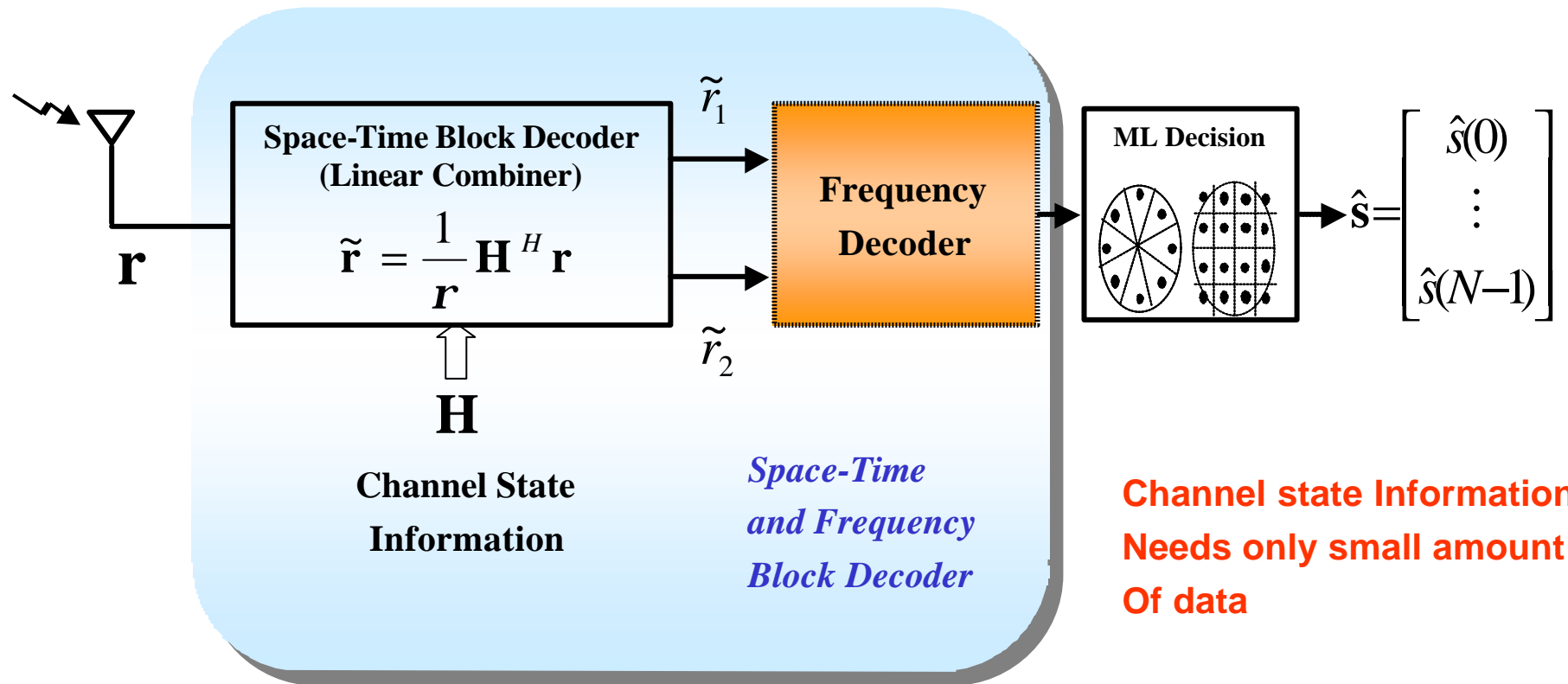
- STFBC Transmitter



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

Space-Time and Frequency Block Coding Wideband OFDM - IV

- STFBC Receiver



Channel Covariance Matrix(CCM)

•Channel impulse response of L multi-path frequency selective fading can be modeled as L-Tap FIR filter as,

$$g(t) = \sum_{i=0}^{L-1} h(i)d(t - t_i)$$

Then $H(k) = \sum_{i=0}^{L-1} h(i)e^{-j2\pi ki/N}, 0 \leq k \leq N-1$

$$\begin{aligned} \mathbf{r}_{\Delta k} &= E[H(k)H^*(k + \Delta k)] = \sum_{i=0}^{L-1} s_i^2 e^{j2\pi \Delta ki/N} \\ \mathbf{r}_{\Delta k} &= \frac{1}{L} \sum_{i=0}^{L-1} e^{j2\pi \Delta ki/N} = \frac{1}{L} \frac{\sin\left(\frac{p\Delta kL}{N}\right)}{\sin\left(\frac{p\Delta k}{N}\right)} e^{j\pi \Delta k(L-1)/N} \end{aligned} \quad (1)$$

Channel covariance matrix is ..

$$C_H = E[H H^H] = \begin{bmatrix} \mathbf{r}_0 & \mathbf{r}_1 & \cdots & \mathbf{r}_{N-1} \\ \mathbf{r}_{-1} & \mathbf{r}_0 & \cdots & \mathbf{r}_{N-2} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{r}_{-N+1} & \mathbf{r}_{-N+2} & \cdots & \mathbf{r}_0 \end{bmatrix}$$

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

- 1 $\mathbf{r}_{-\Delta k} = \mathbf{r}_{\Delta k}^*$
- 2 $|\mathbf{r}_{-\Delta k}| = |\mathbf{r}_{\Delta k}|$
- 3 $\mathbf{r}_{-\Delta k} = \mathbf{r}_{N-\Delta k}$

CCM has Cyclic Shift property

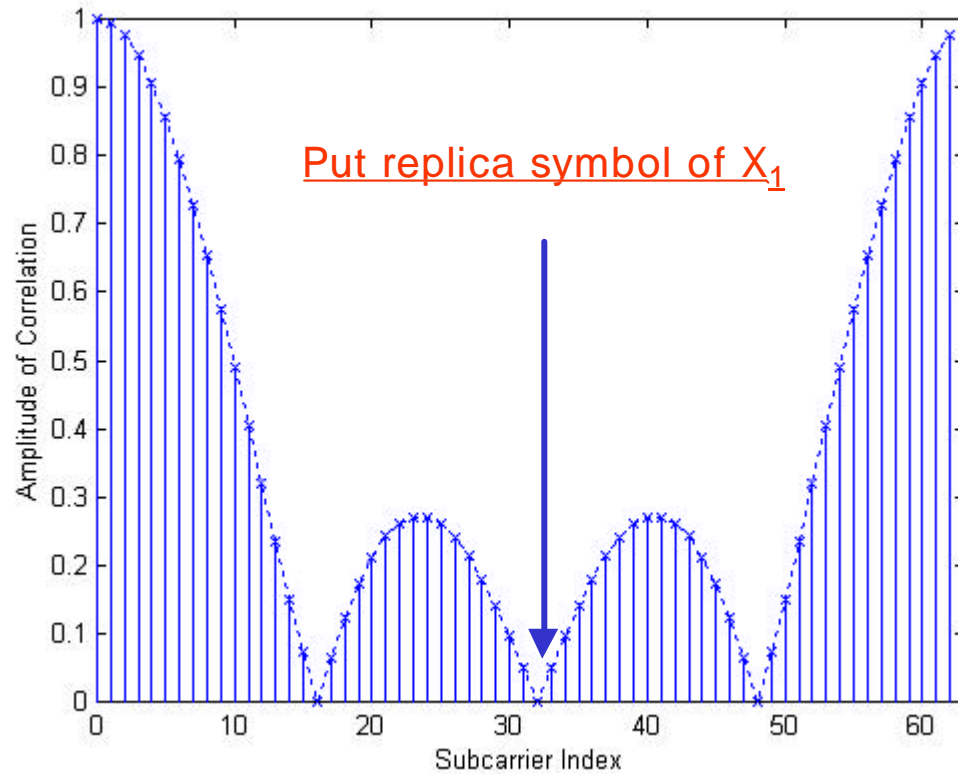
To maximize the frequency diversity select optimum sub-carrier position

- Let $r_{\kappa_1\kappa_2}=0$, in Eq. (1), then
- $$\sin\left(\frac{p\Delta k_{12}L}{N}\right)=0 \quad (2)$$
- Δk_{12} is function of the distance of 2 sub-carriers.
- $\Delta k_{12} = \frac{mN}{L}$ is general solution.
- $\frac{L}{N} \leq m \leq L - \frac{L}{N}$, m , N & L all positive integer
- $1 \leq m \leq L - 1 \quad (3)$
- 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 $\Delta k = d = \left\lfloor \frac{N}{L} \right\rfloor \cdot \left\lfloor \frac{L}{2} \right\rfloor$ $\mathbf{r}_{-\Delta k} = \mathbf{r}_{N-\Delta k}$
- 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
- $k' = (k+d) \bmod N$

Optimum Position of Sub-carrier of Symbol X_1

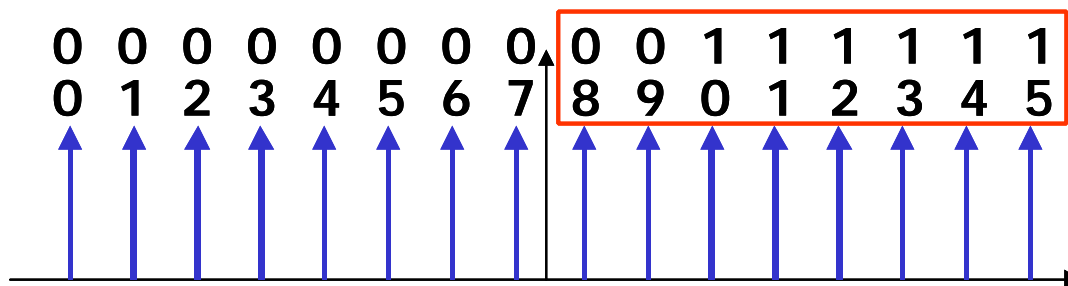


- Put the 0th sub-carrier of the replica symbol here!!
- Frequency Diversity Maximized

What is Replica Symbol?

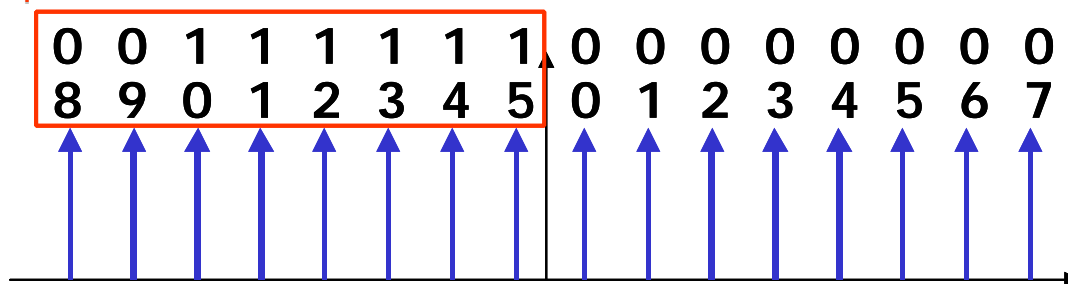
EX) If $d=8$ in 16 FFT, then . . .

X_1



X_1 = Tx symbol
 X_2 = replica symbol
 \sim means cyclic shift in frequency domain

$X_2 = \tilde{X}_1$



MIMO system performance

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

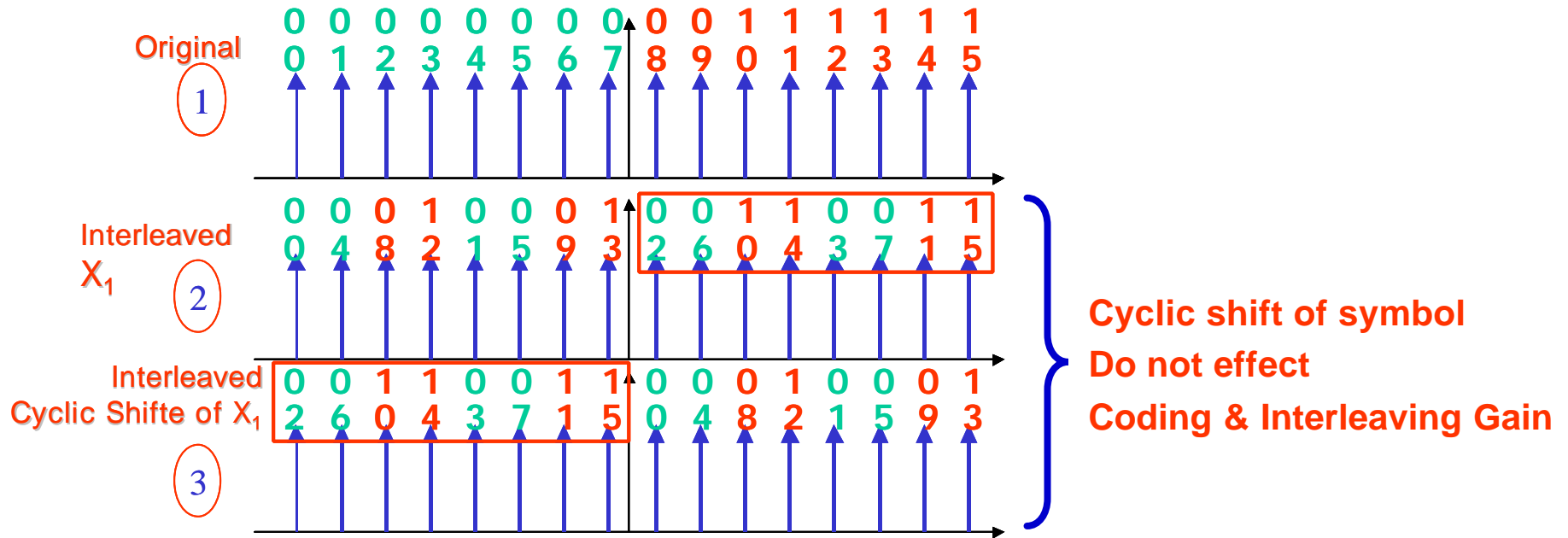
$$P(c \rightarrow e) \leq \left(\frac{E_s}{4N_0}\right)^{-LN_r} \left(\prod_{t=1}^L d_H^t(c, e)\right)^{-N_r}$$

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

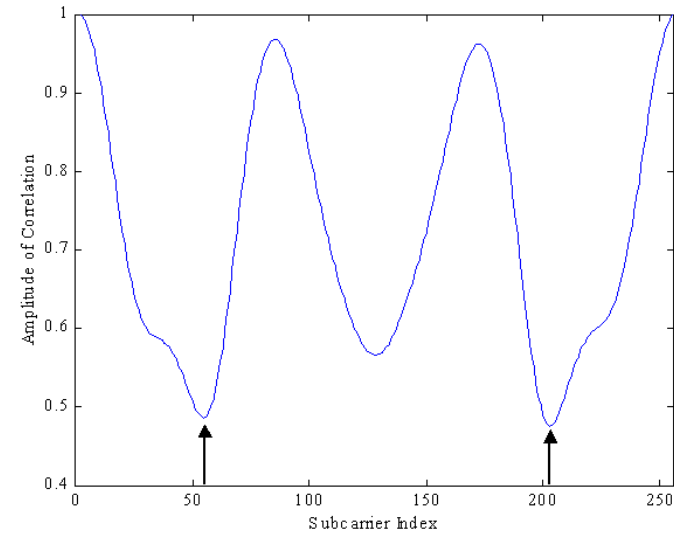
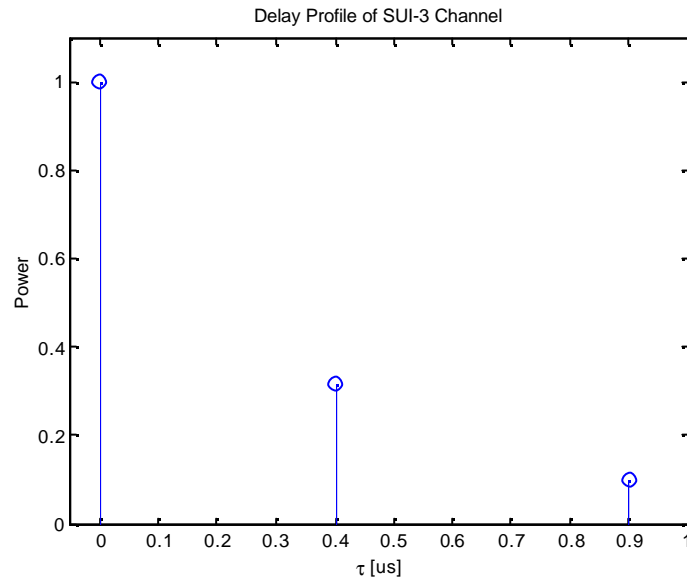
Symbol (frequency) Interleaving



Analysis in SUI channel model

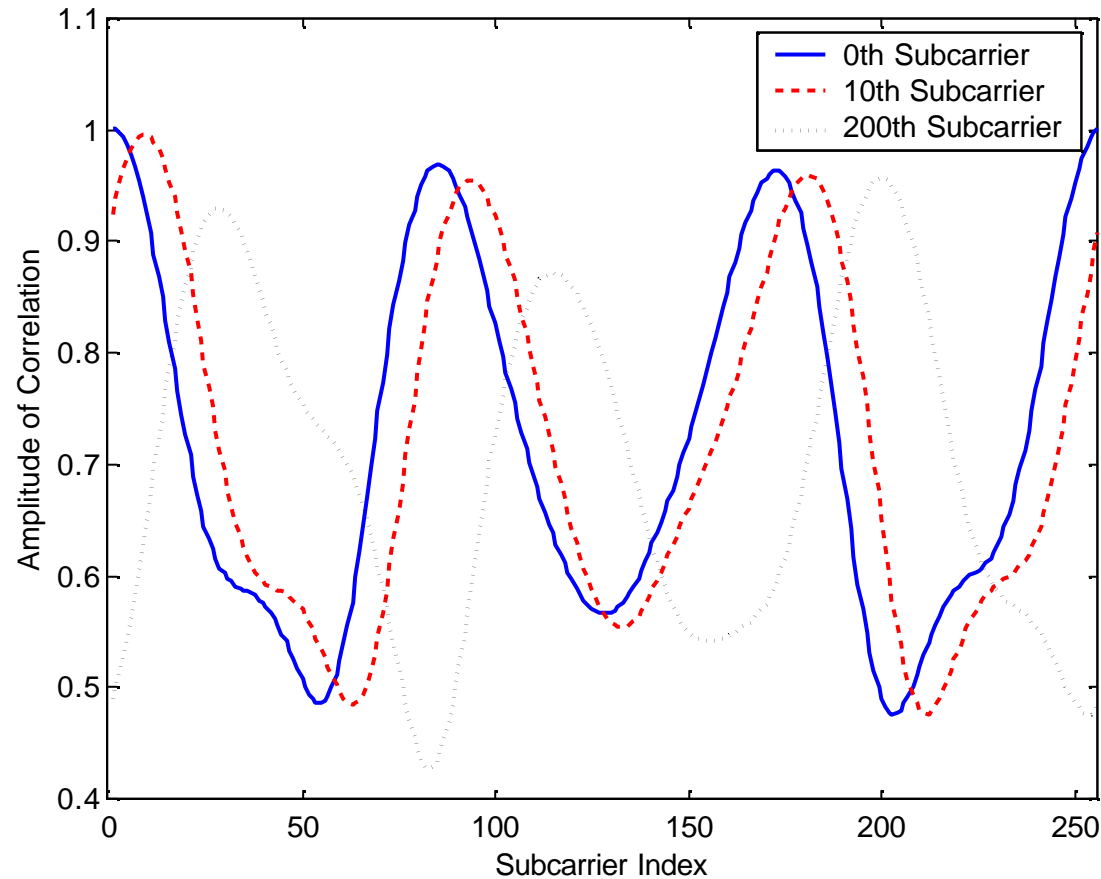
- In L path frequency selective fading,
 - Assumed Uniform delay spread
- But, It is different in SUI model
 - Ricean
 - Delay spread is **Not** uniform
- Two model is analysed
 - SUI 1 terrain Type C
 - SUI 3 terrain Type B

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	0	-15	-20	DB	Power	0	-5	-10	DB
(omni ant.) Doppler	0.4	0.3	0.5	Hz	(omni ant.) 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



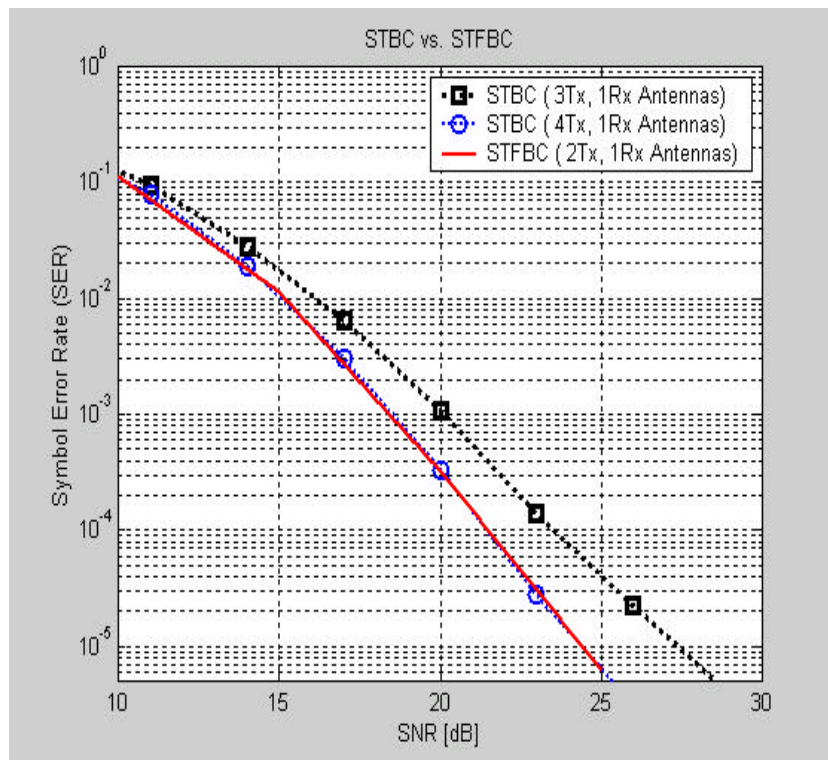
**Channel Covariance Matrix
Still Cyclic Shifting
Not in amplitude
But also in Delay.**

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

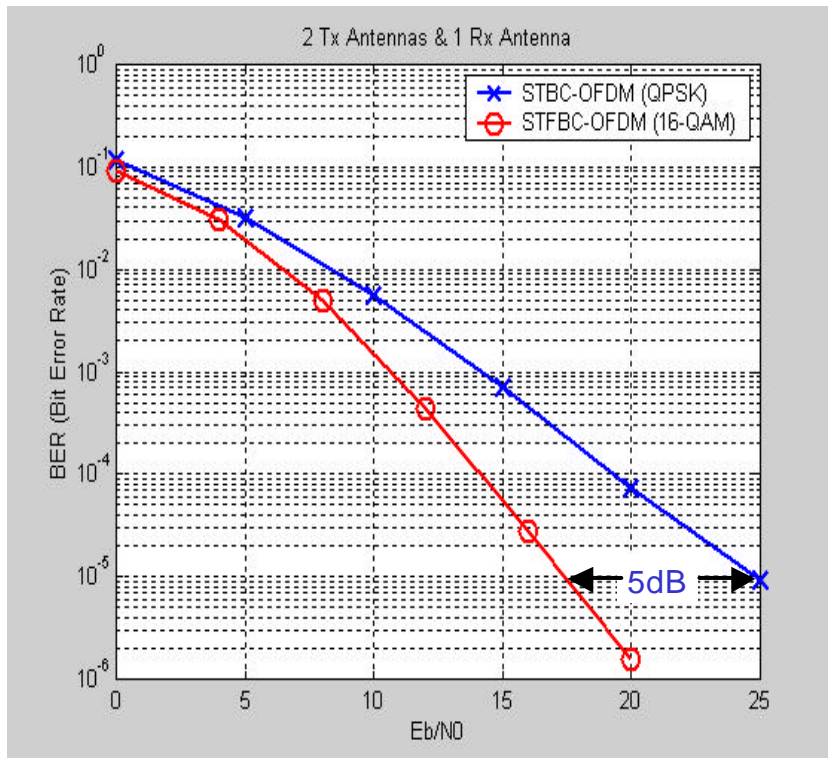
- Channel Order : 10
- Independent Rayleigh Fading Channel
- Perfect Channel & Order Information
- To match the Spectrum Efficiency
- Compares, 2bits/sub-carrier
 - QPSK (STBC) : 2 tx antennas & 1 rx antenna
 - 16QAM (STFBC) : 2 tx antennas & 1 rx antenna

Performance Result II

- In uniform delay spread Rayleigh Fading

- Simulation environments

– In 10^{-5} BER more than 5dB performance improvements.

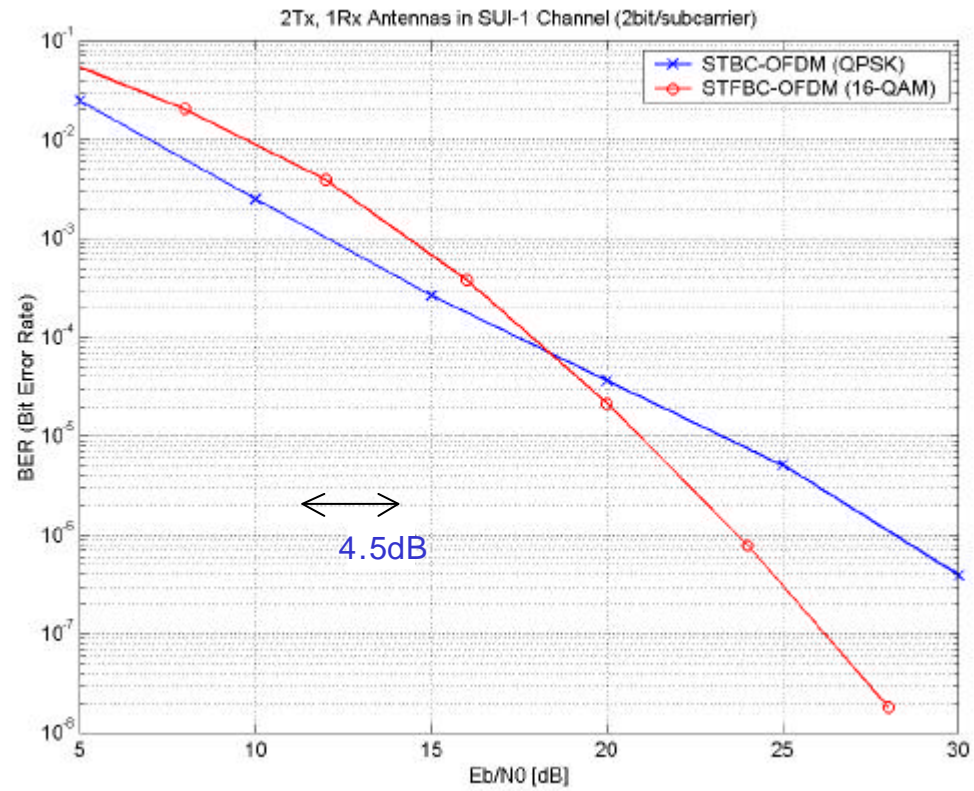


Performance Evaluation III

- 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 E_b/N_0 gain

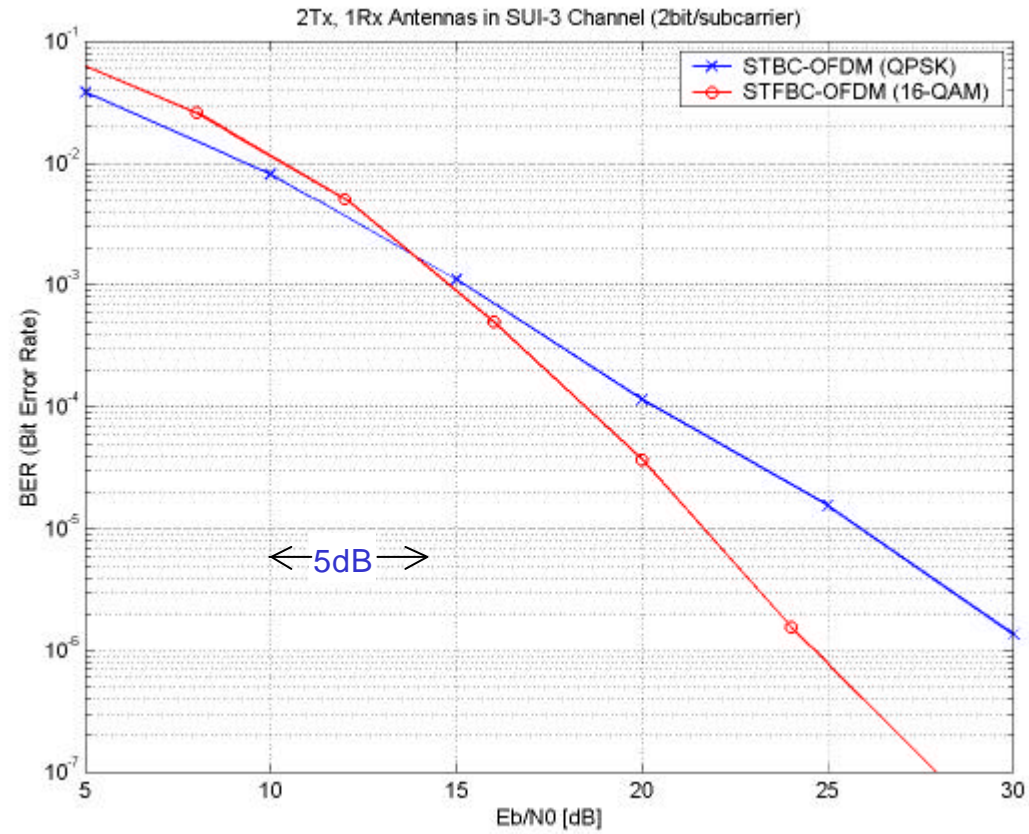


Performance Evaluation IV

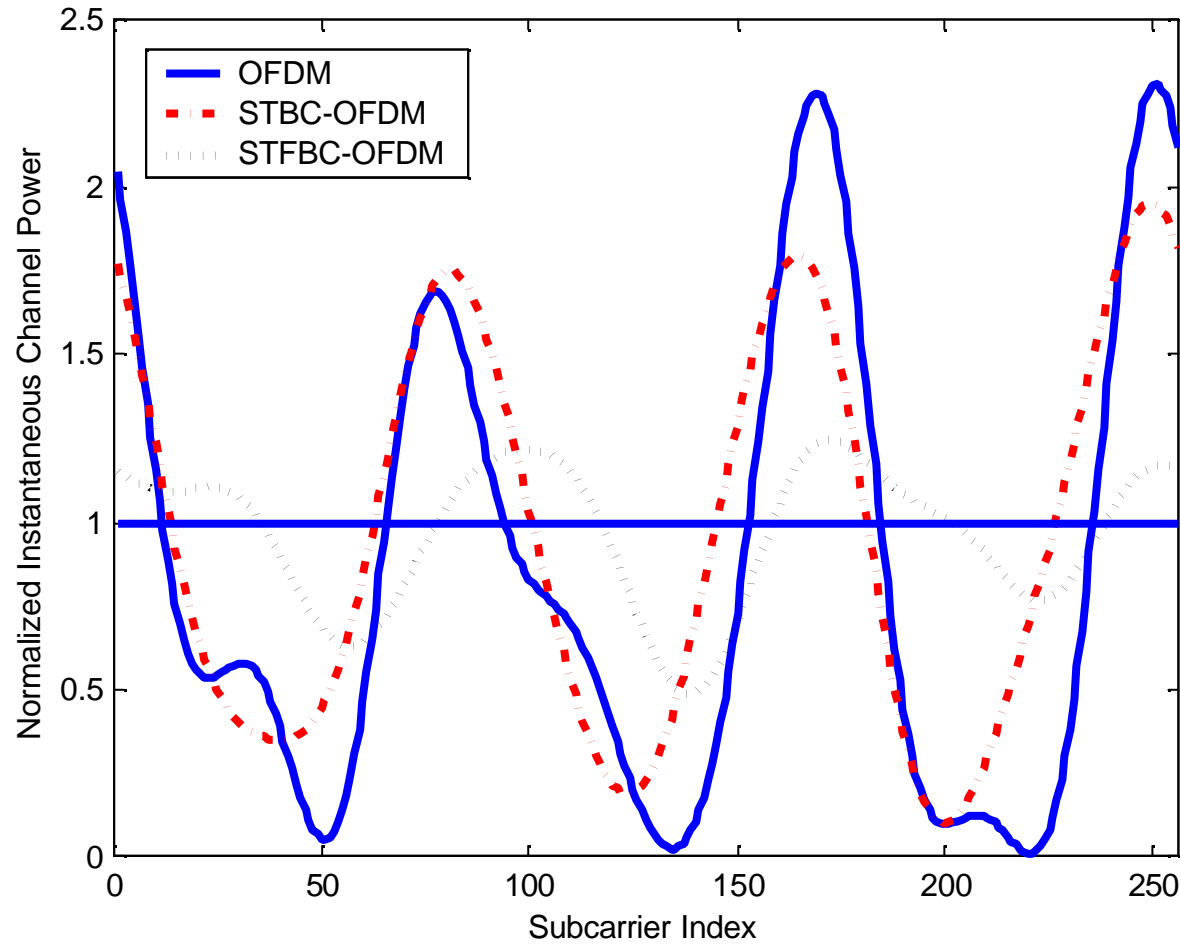
- SUI 3
 - 2bits/sub-carrier
 - QPSK (STBC) with 2 antenna
 - 16QAM (STFBC) with 2 antenna
 - Ricean Fading Channel
- Perfect Channel & Order Information

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.
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