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Re:	
Abstract	This document contains analysis and proposal for the OFDM STBC design for the 802.16ab system.
Purpose	This proposal should be used for the STBC-OFDM design
Notice	
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Patent Policy and Procedures	

Novel Design of STBC for OFDM/OFDMA using Frequency Diversity

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References

[1] IEEE 802.16ab-01/01r2. IEEE 802.16ab merged document. 2001-09-28

Introduction

In this contribution, a novel design method using frequency diversity for STBC in OFDM/OFDMA is proposed

Background

In this contribution we propose space-time frequency block coded OFDM using two transmission antennas. This space-time frequency block code can simultaneously obtain space & frequency diversity gain, so that the performance of using two transmission antennas are almost equivalent to use 4 transmission antennas. ST-frequency code is composed of 2 parts: One for replica generator, which reproduces OFDM symbol to make frequency diversity. Another symbol is cyclically shift data in sub-carrier basis. The amount of cyclic shift is based on the stochastic properties of the channel environments. And then, to obtain space diversity two symbols made of replica generator are mapped into space-time block code. At the receiver the transmission signal is decoded with respect to reverse process. The decoder of Space-Time frequency block code is composed of 2 parts. The first decoding pass is done by enable the received signal to the space-time block encoder. Through the first pass the signal split into two symbols. Then cyclically "re-shift" the signal to replace the replica symbol. The decoding process is completed after the combination of such two symbols and decides to the nearest signal point using channel state information. After above procedure space-time frequency block code obtains order-2 space diversity and order-2 frequency diversity gain. After all, the encoding and decoding process of the STFBC is made of linear function and requires simple operation.

Covariance matrix of OFDM system

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

$$g(t) = \sum_{i=0}^{L-1} h(i)\delta(t-\tau_i) \tag{1}$$

where h(i) is attenuation factor of channel impulse response of i-th path τ_i is time delay of i-th path. In multiple transmission antenna system each channel coefficient is zero-mean independent gaussian random variable. And also assume power delay profile of channel is uniformly distributed.

Then, of the properties of OFDM system give the frequency response of the channel of the kth sub-carrier of the received OFDM signal after FFT at receiver as,

$$H(k)=\sum_{i=0}^{L-1} h(i) e^{-j2\pi ki/N}, 0 \le k \le N-1 \qquad (2)$$

N is the total sub-carrier number of OFDM symbol. The channel correlation of the CIR of k-th and (k+Δk) -th sub-carrier for calculate the channel covariance matrix is as following,

$$\rho_{\Delta k} = E\left[H(k)H^{*}(k+\Delta k)\right]=\sum_{i=0}^{L-1}\sigma_i^2 e^{j2\pi\Delta ki/N} \qquad (3)$$

Because, each channel tap coefficients are uncorrelated to each other. σ^2 is variance of the i-th channel tap coefficients, and equivalent to power of i-th path. If all the channel power delay profiles are uniformly distributed, σ^2=1/L

$$\rho_{\Delta k} = \frac{1}{L}\sum_{i=0}^{L-1} e^{j2\pi\Delta ki/N} = \frac{1}{L}\frac{\sin\left(\frac{\pi\Delta kL}{N}\right)}{\sin\left(\frac{\pi\Delta k}{N}\right)} e^{j\pi\Lambda k(L-1)/N} \qquad (4)$$

The channel vector is defined as,

$$H = \left[H(0)H(1)\cdots H(N-1)\right]^T$$

Then Covariance matrix is as following

$$C_H = E\left[H\ H^H\right]=\begin{bmatrix} \rho_0 & \rho_1 & \cdots & \rho_{N-1} \\ \rho_{-1} & \rho_0 & \cdots & \rho_{N-2} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{-N+1} & \rho_{-N+2} & \cdots & \rho_0 \end{bmatrix} \qquad (5)$$

of the equation (4) $\rho_{\Delta k}$ have following properties

1. $\rho_{-\Delta k} = \rho_{\Delta k}^{*}$
2. $|\rho_{-\Delta k}| = |\rho_{\Delta k}|$
3. $\rho_{-\Delta k} = \rho_{N-\Delta k}$

from the property (1) and (3) the covariance matrix is expressed by cyclic hermite matrix.

To maximize the frequency diversity select optimum sub-carrier position

The basic concept of diversity is receive transmitted signal contain same symbol but independent fading channel. So realize diversity concept in OFDM system transmit two symbols, and each symbol have to allocate in different sub-carrier. But, to maximize the diversity gain each replica symbol should experience independent fading channel. Since, the sub-carriers of replica symbol is transmitted through uncorrelated sub-carriers.

Such uncorrelated sub-carrier can be found through the condition $\rho_{\kappa 1 \kappa 2}$=0 in equation 4, and then the following equation should be satisfied.

$$\sin\left(\frac{\pi \Delta k_{12} L}{N}\right) = 0 \qquad (7)$$

where $\Delta k_{12} \neq 0$. Finally Δk_{12} is the function of the distance of two sub-carriers. Then general solution of equation 7 is

$$\Delta k_{12} = \frac{mN}{L} \qquad (8)$$

where m is none-zero integer. If let $\mathrm{k}_1 = 0$ then $1 \leq \Delta k_{12} \leq N-1$, so

$$\frac{L}{N}\pi \leq \frac{\pi \Delta k_{12} L}{N} \leq L\pi - \frac{L}{N}\pi \qquad (9)$$

and

$$\frac{L}{N} \leq m \leq L - \frac{L}{N} \qquad (10)$$

where m, L and N is positive integer, so,

$$1 \leq m \leq L-1 \qquad (11)$$

From equation 11 the number of sub-carrier uncorrelated to 0th sub-carrier is L-1. Include 0th carrier the number is L. According to the property 3 of the channel covariance matrix, the number of sub-carrier uncorrelated to arbitrary k-th sub-carrier is L in L-path fading channel environments.

Maximum frequency diversity achievable OFDM system structure

Three things have to be considered in the frequency diversity system.

1. Maximize diversity gain
2. Distance between all sub-carrier shall be maintained.
3. Robust property of channel correlation between sub-carrier.

When L=4 and N=64 the following figure is the magnitude of the correlation of sub-carriers respective to 0th sub-carrier.

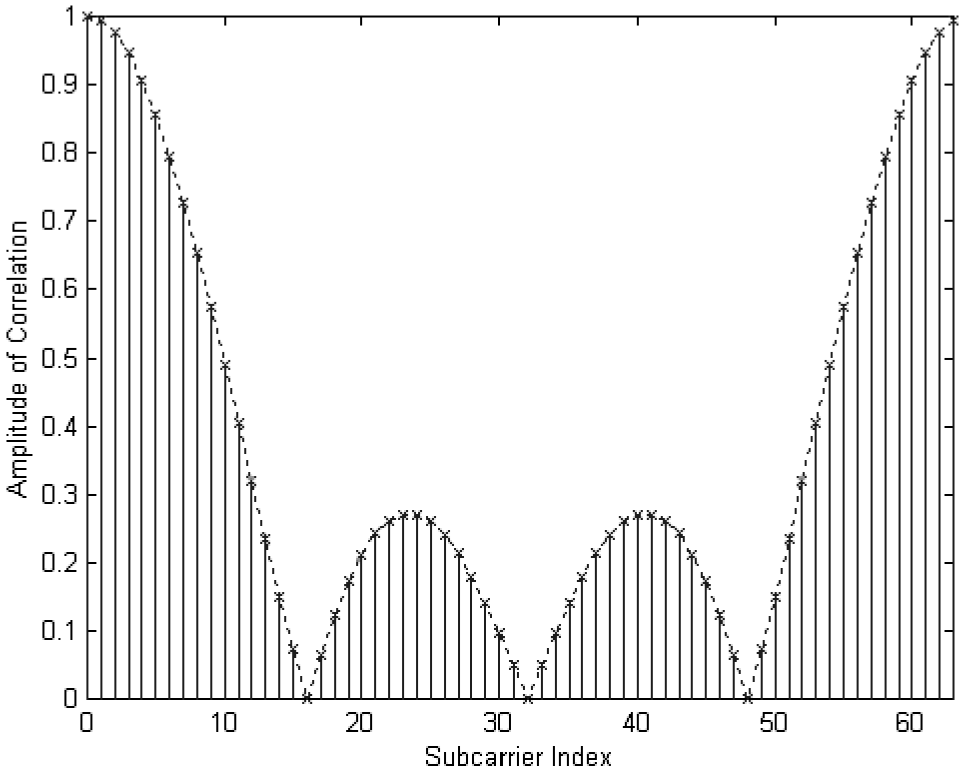

Figure 1

As the figure indicate the maximum separation of sub-carrier is N/2. And in general, the optimum

$$\Delta k = d = \left\lfloor \frac{N}{L} \right\rfloor \cdot \left\lfloor \frac{L}{2} \right\rfloor \qquad (12)$$

Where, $\lfloor x \rfloor$ is maximum integer not exceed x. 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

$$k' = (k+d) \bmod N \qquad (13)$$

where, mod is modulo operator.

Cyclic sub-carrier shift frequency diversity

An OFDM symbol s is composed of N modulation symbols

$$S=[s(0) \ \ldots \ s(N-1)]^T$$

Before the symbol transmission, we can generate another symbol using cyclic shift device. The amount of sub-carrier shift *d* is defined by equation (12). Then

$$X_1=s=[s(0), \ldots s(N-1)]^T$$

$X_2 = [s(N\text{-}d), \ldots s(N\text{-}1), s(0), \ldots s(N\text{-}d\text{-}1)]^T$

Two symbols sequentially transmitted through STBC structure. Figure 3 is STFBC transmission block diagram and figure 4 is receiver block diagram.

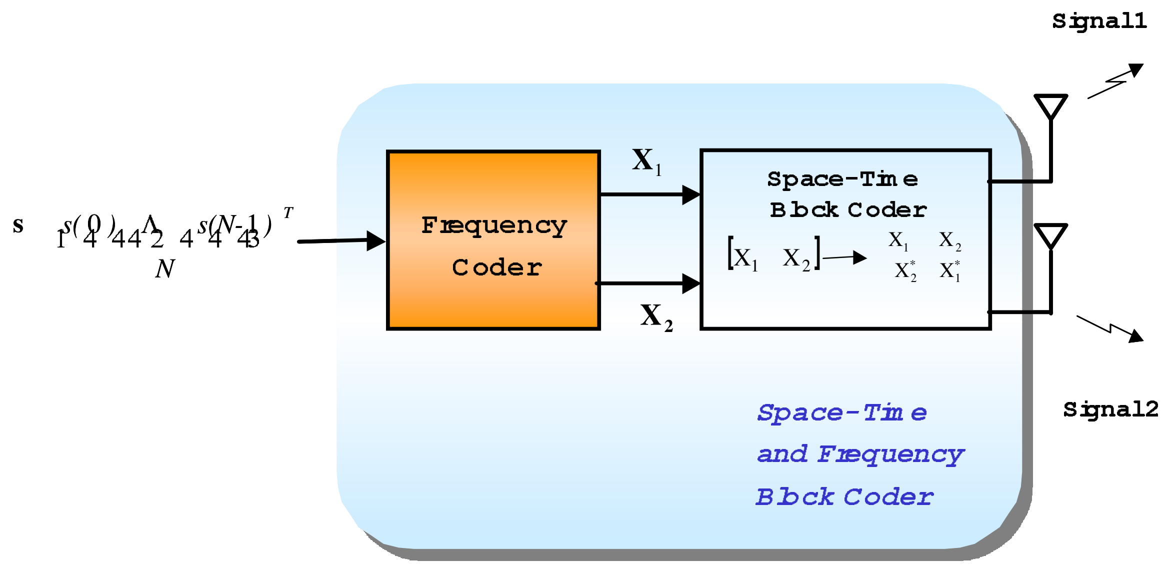

Figure 2 Transmission scheme of ST-frequency Block code

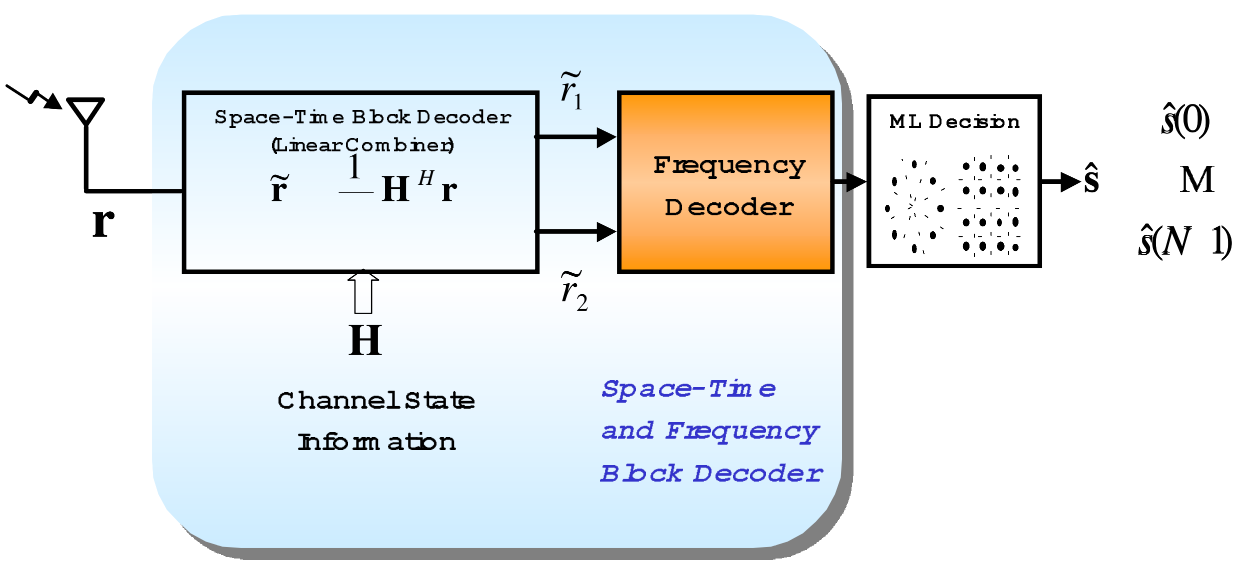

Figure 3 Rx scheme of ST-frequency Block code

Simulation environments and results

In this section we shall consider the case of simulation of STFBC(space-time frequency block code) under independent Rayleigh fading channels environments. The channel order is set to 10 and the modulation uses 16 QAM. It assumes the channel state & order information is given. In the case of simulation of STBC 4 tx antenna is compared to 2 tx antenna STFBC, same performance is shown in figure 4. Compare to 3 tx antenna using STBC in 10^{-4} SER(symbol error rate) it shows approx. 2.5dB SNR gain.

When we set the transmission rate constraints under same condition the STFBC shows further improvements. AS shown in figure 5 the STBC parameter is set to 2 tx antennas and 1 rx antenna, and the channel & order information is assumed perfectly estimated. Then using 16QAM in STFBC and QPSK in STBC results same transmission rate of 2bits/sub-carrier. In 10-5 BER, the performance improvements shown in figure 5 are approximately more than 5dB gain in EbN0. If correlation between transmission antennas increases, the performance also improves impressively

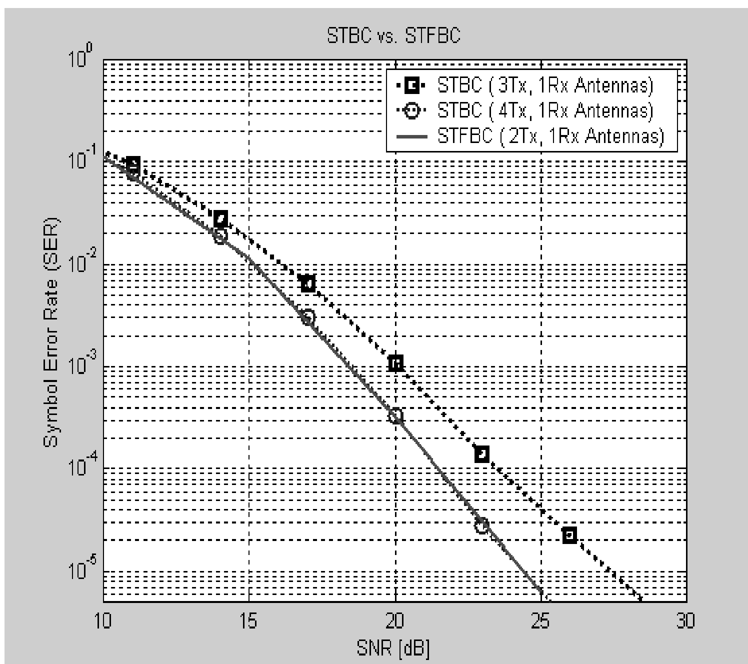

Figure 4 comparisons of performance of STBC and STFBC

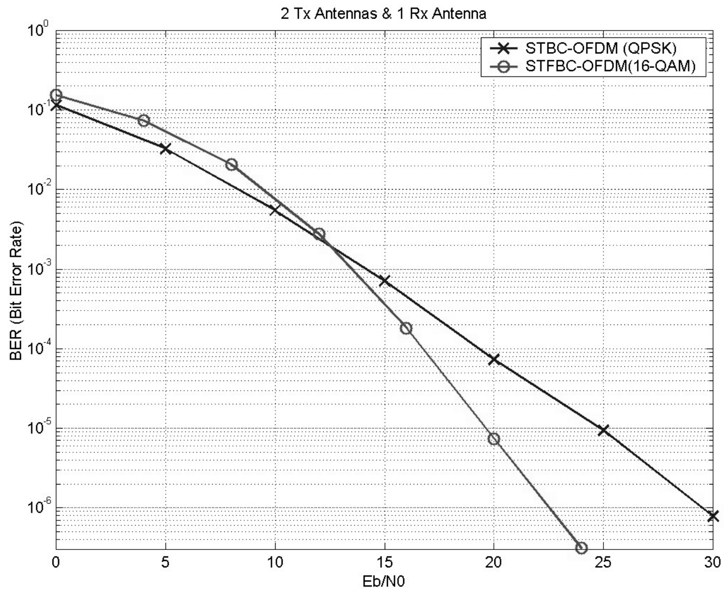

Figure 5 comparisons of STBC and STFBC in same transmission rate constraints

Conclusion

• Characteristics of Space-Time Block Coding (STBC)

It has simple structure and full space diversity gain. But there are many problem when using more than 3 antennas in OFDM system. The hardware and operational complexity is increase, and transmission rate decrease)

• Advantage of Space-Time and Frequency Block Coding (STFBC)

Novel structure of STBC using OFDM can overcome the problem of STBC-OFDM. This scheme not only maximizes Space Diversity but also frequency Diversity gain. And it is also because of using frequency diversity so that the number of tx antenna is not required to be increased.

• Compatible to existing STBC-OFDM

Proposed scheme also minimizes change of existing structure. The only added process is the cyclic shift of sub-carrier as replication of original symbols. And the length the channel impulse response L can be easily obtained from channel estimation process of the receiver end. A small amount of channel estimation error is not affect whole performance much. Finally, the frequency diversity process is a simple linear function, so further performance gain can be obtained from code combining and ARQ schemes.

• Tx diversity scheme for OFDM/OFDMA system is desirable to use the STFBC is strongly requested.