The Error Performance and Fairness of CUWB Correlated Channels

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Abstract

The symbol period becomes smaller compared to the channel delay in multiband orthogonal frequency division multiplexing (MB-OFDM) cognitive ultra wideband (CUWB) wireless communications, the transmitted signals experiences frequency-selective fading and leads to performance degradation. In this paper, a new design method for space-time trellis codes in MB-OFDM systems with correlated Rayleigh fading channels is introduced. This method converts the single output code symbol into several STTC code symbols, which are to be transmitted simultaneously from multiple transmitter-antennas. By using Viterbi optimal soft decision decoding algorithm, we investigate both quasi-static and interleaved channels and demonstrate how the spatial fading correlation affects the performance of space–time codes over these two different MB-OFDM wireless channel models. Simulation results show that the performance of space–time code is to be robust to spatial correlation. When the system bandwidth increases, the long term fairness quality will gradually become better and finally converges to 1.

Keywords: Cognitive ultra wideband (CUWB), Multiband orthogonal frequency division multiplexing (MB-OFDM), Space-time trellis codes (STTC), Long term fairness

1. Introduction

Ultra wideband (UWB) technology is ideal for high rate short-range wireless communications. With a -10 dB instantaneous bandwidth that is larger than 500 MHz or 20\% of the fractional bandwidth, UWB signals can be generated by using a short pulse without a carrier or by using multiband orthogonal frequency division multiplexing (MB-OFDM). In a pulse-based UWB, bandpass pulses of extremely short duration, which are typically in the range of a fraction of a nanosecond to a few nanoseconds, are used for information transmission, whereas in MB-OFDM, hybrid frequency hopping and OFDM are used\cite{1}-\cite{3}. Cognitive radio can sense the environment, and has the ability to reconfigure itself by learning and adapting to the communication surroundings, and radio spectrum can be efficiently used for
secondary users to access a spectrum hole. It can combine with UWB signal, where UWB nodes can be regarded as secondary users.

With the rapid development of wireless services, spectrum resource is becoming in shortage. Cognitive ultra wideband (CUWB) technique provides a new way to solve the problem of increasing demand of wireless communication and limited wireless spectrum resource. The foundation of cognitive UWB is that the secondary users can access the authorized spectrum in an opportunistic way by sensing spectrum holes and thus greatly improve the spectrum efficiency.

Space-time coding (STC) is a coding technique designed for high data rate transmission over fading channels to achieve significant gains over communication systems. There are various coding techniques, including space-time block codes (STBC), space-time trellis codes (STTC), space-time turbo trellis codes and layered space-time codes (LST). Space-time trellis codes, first introduced by Tarokh et.al., is widely discussed in slow fading quasi-static channels, where the path gains are assumed constant in a frame. It’s also proposed in fast fading interleaved channels, where the path gains are assumed constant in a symbol interval [4]-[7]. These codes were developed originally for frequency-flat channels. While in MB-OFDM wireless communications, the symbol period becomes smaller compared to the channel delay, the transmitted signals experiences frequency-selective fading and leads to performance degradation. Applying space-time codes over frequency-selective channels becomes a challenging problem. Various techniques, such as spatial diversity and the frequency-selective fading diversity, have been applied to space-time coding in MB-OFDM to achieve higher path gains.

2. System Models

The proposed MB-OFDM CUWB systems, including the transmitter, the frequency selective fading channels and the receiver, can be illustrated in Figure 1. Since MB-OFDM signals are transmitted and received by using IFFT/FFT, the interleavers do not introduce any additional processing delay. From the receiver’s viewpoint, by using the same interleavers for different transmitter antennas, only a single deinterleaver is needed at the receiver and the Viterbi soft decision algorithm can be applied for STC decoding.

At the MB-OFDM receiver side,

$$r_l^n = \sqrt{\frac{E}{M}} \sum_{m=1}^{M} h_{m,l}^n x_{m,l} + z_l^n$$  \hspace{1cm} (1)

Where $M$ is the number of transmit antennas, $N$ is the number of receive antennas, $L$ is frame length. $m = 1, 2, ..., M$, $n = 1, 2, ..., N$, $l = 1, 2, ..., L$. $x_{m,l}^n$ is complex valued modulation symbol transmitted from $m$ transmit antenna at time slot $l$, $h_{m,l}^n$ is modeled as frequency-selective fading channel response, the fading is assumed to be constant over time slot $l$ and to vary from one time slot to another. $z_l^n$ is additive noise with zero mean and $N_0/2$ variance per dimension [7]-[10].
At the receiver side, we use soft decision Viterbi decoding algorithm to receive the original raw bits. The Viterbi algorithm calculates the ML of a path being corrected by its hamming distance from the real transmit message. It can be realized as the following steps: a) Select the state having the smallest accumulated error metric and save the number of that state; b) Iteratively perform the following step until the beginning of the trellis is reached: Working backward through the state history table, for the selected state, select a new state which is listed in the state history table as being the predecessor to that state. Save the state number of each selected state; c) Work forward through the list of selected state saved in the previous steps. Look up what input bit corresponds to a transition from each predecessor state to its successor state. That is the bit that has been encoded by the convolutional encoder.

We consider 4-state QPSK space-time trellis codes for 2 transmit antennas. For input bits $b_i$, $a_i$, $b_{i-1}$, $a_{i-1}$:

$$\begin{align*}
(x_{i,j} & \quad x_{2j}) = b_{i-1}(2,0) + a_{i-1}(1,0) + b_i(0,2) + a_i(0,1) \\
\end{align*}$$

(2)

We can get:

$$\begin{align*}
\begin{cases}
  x_{1,j} = 2b_{i-1} + a_{i-1} \\
  x_{2,j} = 2b_i + a_i
\end{cases}
\end{align*}$$

(3)

Rearranging, we obtain generator matrix representation:

$$\begin{align*}
\begin{bmatrix}
  x_{1,j} \\
  x_{2,j}
\end{bmatrix} = \begin{bmatrix} b_i & a_i & b_{i-1} & a_{i-1} \end{bmatrix} \begin{bmatrix} 0 & 2 \\
  0 & 1 \\
  2 & 0 \\
\end{bmatrix} \begin{bmatrix} x_1 \\
  x_2
\end{bmatrix}
\end{align*}$$

(4)

Correlated transmitting signals are defined as:

$$\begin{align*}
\begin{bmatrix}
  y_1 \\
  y_2
\end{bmatrix} = \frac{\beta}{\sqrt{1 + \beta^2}} \begin{bmatrix} \sqrt{1 + \beta^2} & \sqrt{1 + \beta^2} \\
  \sqrt{1 + \beta^2} & 1 \\
\end{bmatrix} \begin{bmatrix} x_1 \\
  x_2
\end{bmatrix}
\end{align*}$$

(5)

Where $\beta$ is the desired accuracy interval, and $P(1 - \beta)$ is the residue probability of PEP. If $\text{cov}(x_1, x_2) = \text{identity}$, then

$$\text{cov}(y_1, y_2) = \begin{bmatrix} 1 & 2\beta \\
  2\beta & \sqrt{1 + \beta^2} \\
\end{bmatrix}$$

(6)

As for the long term fairness quality, we define

$$F(L) = \frac{\left(\sum_{i=1}^{M} K_i(L)\right)^2}{M\left(\sum_{i=1}^{M} K_i^2(L)\right)}$$

(7)

Where $K_i(L)^{\text{th}}$ stands for the admitted possibility in $L$ frame length.

3. Simulation and Results Analysis

In simulations, the available bandwidth is 1 MHz and 256 sub-carriers are used for MB-OFDM modulation. We propose the interleaved channels which assume the fading coefficients are constant over one symbol interval and change from one symbol to another independently. Such an assumption can be
justified by the use of perfect interleaving. We also discuss quasi-static channels which assume that the channel fading coefficients remain constant over one frame and change from one frame to another independently. Each frame consists of 150 symbols. $M = 2$ transmit antennas and $N = 1$ receive antenna are used in the MB-OFDM systems. With the perfect CSI at the receiver, the optimal Viterbi soft decision algorithm is used to decode the STTC’s.

In our 4-state QPSK STTC MB-OFDM system, when we take channel correlation into consideration, actually when correlation coefficient $\rho$ approaches to 1, the channel acts as one channel in essence, and our Viterbi soft decision algorithms can handle this situation and the performance curves taking form as diversity order of 1. In both quasi-static and interleaved cases, the diversity order, and therefore the slope of the curve, is preserved. When $\rho$ increases to 1, diversity order is reduced to 1, as it can be observed from the slope of the curve.

Choose the time slots varies from 1 to 100. We get the result as follows.
Fig. 4 is derived when the system bandwidth $B = 6500$. We see that when $L$ becomes large, $F_2(L)$ becomes stationary and converge a value near 0.9.

![Fig. 4 Long term fairness with $B = 10000$.](image)

Fig. 5 describes the relationship derived when $B = 10000$. We see that when $L$ becomes large, $F_2(L)$ becomes stationary and converge a value near 0.96.

4. Conclusions

We provide analytical tools for the evaluation of space–time trellis codes operating over CUWB frequency-selective fading channels. PEP is derived for space–time codes which are limited to symbol-by-symbol interleaved channels where the path gains are assumed constant over one symbol interval and quasi-static channels where the path gains are assumed constant over one frame. Based on the PEP, our results show that the spatial channel correlation over the interleaved channel only results in a change in coding gain and does not affect the diversity order. For a large range of correlation values, the performance of space–time code is observed to be robust to spatial correlation. When the system bandwidth increases, the long term fairness quality will gradually become better and finally converges to 1.

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