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PERFORMANCE EVALUATION OF ADAPTIVE UWB SYSTEM WITH MULTIPLE ANTENNAS

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Abstract—The speedy dissemination of digital consumer electronics devices within personal area causes increments of multimedia communication and advent of entertainment networking. This feature of communication requires high data-rate transmission. In order to meet the demand, in this paper, we apply multiple antenna schemes to MB-OFDM UWB system. And to use the UWB system with multiple antennas for various channel environment, some adaptive MIMO schemes are considered for multiple antenna MB-OFDM system. The first investigated technique is adaptive antenna selection which selects the proper number of transmitting antennas using estimated SNR. And the second technique is adaptive modulation which can be used after the adaptive antenna selection is executed. By using these adaptive techniques, the reliable and high data-rate communications which are well adapted to the various user's demands and channel conditions are achieved.

1. INTRODUCTION

The speedy dissemination of digital consumer electronics devices within home and personal area, such as digital video disk (DVD) players, MP3 audio players, camcoders, and digital audio and television, causes increments of multimedia communication. In order to meet consumer's demand for low cost and high performance wireless personal area network able to support streaming multimedia content and full motion video, ultra-wideband (UWB) technology is considered [2, 3]. The MB-OFDM UWB system achieves up to 480 Mbps [1]. However, recent multimedia communication requires higher data rate as gigabit rate.

Conventionally, more bandwidth is required for higher data-rate transmission. However, due to spectral limitations, it is often impractical or sometimes very expensive to increase bandwidth. In this case, the scheme using the multiple transmitting and receiving antennas for spectrally efficient transmission is alternative solution [4–12]. Therefore, we apply multiple input multiple output (MIMO) architectures using Bell laboratories layered space-time (BLAST) concepts, which provides significant capacity gain in wireless channels to MB-OFDM system.

Recently, in the UWB communication environment, user will utilize various communications at the various channel condition such as indoor, outdoor, high mobile speed and low mobile speed. Therefore, the UWB communication system should change their system reliability and data rate depending on dynamically changing user's demand and channel condition. Therefore, there are many researches of adaptive technique for user demand and channel condition [14–18].

In this paper, we design the MB-OFDM UWB system with multiple antennas for high rate transmission. And we propose the adaptive MIMO transmission scheme for MB-OFDM UWB system. The first investigated scheme is adaptive antenna selection which selects the proper number of transmitting antennas using estimated SNR. And the second scheme is adaptive modulation which can be used after the adaptive antenna selection is executed. By using these adaptive techniques, the reliable and high data-rate communications which are well adapted to the various user's demands and channel conditions are achieved.

2. SYSTEM MODEL

In the UWB system based on MB-OFDM, the whole available ultra wideband spectrum between 3.1–10.6 GHz is divided into several sub-bands with smaller bandwidth, whose bandwidth is approximately 500 MHz [1]. In each sub-band, a normal OFDM modulated signal with $K = 128$ subcarriers and QPSK is used. The main difference between the MB-OFDM system and other narrowband OFDM systems is in the way that different sub-bands are used in the system. The transmission is not done continually on all sub-bands. Different patterns of sub-band switching is chosen for different users (different piconets) such that the multiuser interference is minimized [1]. Consider the MB-OFDM system link comprising M transmitting antennas and N receiving antennas. The received signals are corrupted by additive noise that is statistically independent among the N receivers. Let $\{X_i^s(k)|k = 0, ..., K-1\}$ denote the K subcarrier symbols where k and i represent the corresponding subcarrier and transmitting antenna in s-th sub-band, respectively. At the receiver, the output in the frequency domain is

$$\mathbf{R}^s = \mathbf{H}^s\mathbf{X}^s + \mathbf{W}^s \tag{1}$$

where $\mathbf{H}^s$ is an $M \times N$ matrix of propagation coefficient which is statistically independent in s-th sub-band and $\mathbf{W}^s$ is an additive white Gaussian noise (AWGN).

3. BASIC THEORY OF ADAPTIVE TRANSMISSION

3.1. SNR Estimation

First, we assume that the channel transfer function is estimated perfectly and the suitable parameters are employed for the next transmission.

The noise power can be obtained by the following equation, from difference between corrupted signals and original signals

$$\varepsilon^2 = \frac{1}{NMK}\sum_{j=1}^{N}\left[\sum_{i=1}^{M}\left(\sum_{k=0}^{K-1}(R_j(k) - H_{ji}(k)X_i(k))^2\right)\right]. \tag{2}$$

The overall SNR can be obtained by the following equation

$$\mathrm{SNR} = \frac{\sum_{j=1}^{N}\left[\sum_{i=1}^{M}\left(\sum_{k=0}^{K-1}X_i(k)^2 \cdot |H_{ji}(k)|^2\right)\right]}{NMK \cdot \varepsilon^2}. \tag{3}$$

By using this instantaneous channel SNR, the proper transmission mode is selected and transmitted to the transmitter through feedback channel. The transmitter can transmit its data through the received transmission mode.

3.2. Estimated SNR-based Adaptive Transmission Theory

The information about the selection of transmission mode is delivered into the transmitter, using the system's control channel (feedback channel). This side-information is named mode-selecting feedback information. The different transmission modes are used according to the available mode-selecting feedback information. Specifically, a transmission mode is selected as shown in Eqn. (4), if the instantaneous channel SNR perceived by the receiver exceeds the corresponding switching levels [20].

$$S_l = \begin{cases} \text{Mode}_1 & \text{if } \gamma < \mu_1 \\ \text{Mode}_2 & \text{if } \mu_1 \leq \gamma < \mu_2 \\ & \vdots \\ \text{Mode}_L & \text{if } \gamma \geq \mu_{L-1} \end{cases} \tag{4}$$

where γ and μ_l denote the instantaneous channel SNR and the mode-switching level, respectively. The S_l of Eqn. (4) is the selected mode for transmission. This information is delivered into the transmitter, and then the transmitter transmits its data using this selected mode.

Generally, the mode-switching level μ_l is determined such that the average throughput is maximized, while satisfying the average target bit error ratio (BER) requirement.

And mode selection probability $Pr(X_l)$ is defined as the probability of selecting the l-th mode from the set of available transmission modes as

$$\begin{aligned} Pr(X_l) &= Pr[\mu_{l-1} \leq \gamma < \mu_l] \\ &= \int_{\mu_{l-1}}^{\mu_l} f(\gamma) d\gamma \end{aligned} \tag{5}$$

where $f(\gamma)$ represents the probability density function (PDF) of γ.

4. ADAPTIVE ANTENNA SELECTION

In the multiple antenna MB-OFDM system with the V-BLAST scheme, different signals are transmitted through the different antennas simultaneously. Therefore, in the case without error (ideal case), data rate of the MB-OFDM system with 4 transmitting antennas is 4 times as much as MB-OFDM system with single antenna. So, the transmission rate is increased efficiently by increasing the number of antennas. However, in inferior channel condition, when a lot of antennas are used, system performance can be reduced because of the interference among each antenna. Therefore, in this section, the number of transmitting antennas are selected by using Eqn. (4). The antenna selection probability Pr_{A_l} is defined as the probability of selecting the l transmitting antennas. In this section, the number of transmitting antennas A_l is selected by the following rules

$$A_l = \begin{cases} M = 1 & \text{if } \gamma < \mu_1 \\ M = 2 & \text{if } \mu_1 \leq \gamma < \mu_2 \\ M = 3 & \text{if } \mu_2 \leq \gamma < \mu_3 \\ M = 4 & \text{if } \gamma \geq \mu_3. \end{cases} \tag{6}$$

4.1. Adaptive Modulation

In this Section, we apply an adaptive modulation (AM) to the MB-OFDM system with the V-BLAST scheme. The goal of AM is to select an appropriate modulation mode for each subcarrier in order to provide high quality transmission. This AM can be used after the adaptive antenna selection is executed. By using Eqn. (3), the SNR at k-th subcarrier and i-th transmitting antenna can be obtained as

$$\mathrm{SNR}_i^k = \left(\frac{1}{N} \sum_{j=1}^{N} X_i(k)^2 \cdot |H_{ij}(k)|^2 \right) / \varepsilon^2. \tag{7}$$

The mode selection probability $Pr(S_l)$ is defined as the probability of selecting the l-th mode from the set of available modulation modes. The modulation mode S_l for each subcarrier is selected as

$$S_l = \begin{cases} \text{No TX} & \text{if } \gamma < \mu_1 \\ \text{BPSK} & \text{if } \mu_1 \leq \gamma < \mu_2 \\ \text{QPSK} & \text{if } \mu_2 \leq \gamma < \mu_3 \\ \text{16QAM} & \text{if } \mu_3 \leq \gamma < \mu_4 \\ \text{64QAM} & \text{if } \gamma \geq \mu_4. \end{cases} \tag{8}$$

Fig. 1 shows a block diagram of the proposed adaptive communication schemes. As Fig. 1, by using channel information adaptive antenna selection and AM are executed. Transmission mode selector selects the number of transmit antennas and modulation technique using the

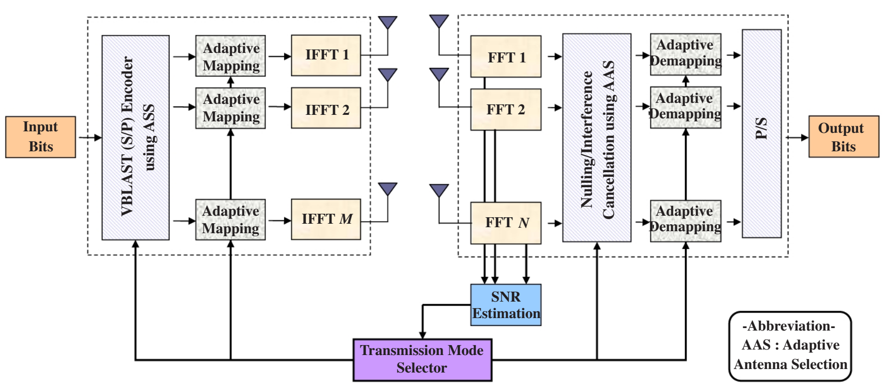

Figure 1. Proposed adaptive communication schemes (adaptive antenna selection + AM).

estimated SNR. And the information is transmitted to the transmitter. Transmitter transmits data according to the received information. The implementation of the proposed schemes is very simple since proposed scheme does not require large change except transmission mode selector.

5. PERFORMANCE EVALUATION AND DISCUSSION

In this section, we examine the performance of the MB-OFDM UWB system applying the proposed adaptive transmission techniques in a bandgroup 1 of CM2 UWB channel environment. To simulate the proposed schemes, 128 FFT size and 37 points zero-padded sux are considered. For the simulation, we consider the maximum number of transmit antennas as 8. In this simulation, we consider the maximum data rate 480 Mbps of MB-OFDM system. Therefore, the frequency and time spreading are not used.

5.1. Throughput of Multiple Antenna MB-OFDM System

To evaluate the throughput of multiple antenna MB-OFDM system, the MB-OFDM system using V-BLAST is simulated for rich scattering environment, and we assume that the MB-OFDM receiver employs a perfect channel estimation and is perfectly synchronized. When original MB-OFDM system using single antenna is used, the ideal throughput is 480 Mbps because the frequency and time spreading are not used.

Table 1. The required SNR when the throughput is about 90% of the ideal throughput rate.

Antennas	SNR	Throughput rate
1	4 dB	91%
2	6 dB	91%
4	7 dB	91%

Figure 2 show the throughput performance according to the number of antennas. Since the multiple antenna system with layered space-time architecture offers spatial multiplexing, different signals are transmitted through the different antennas simultaneously. So, the transmission rate is increased efficiently by increasing the number of antennas. In the case of $M = 1$, the throughputs at SNR $= 20$ dB and

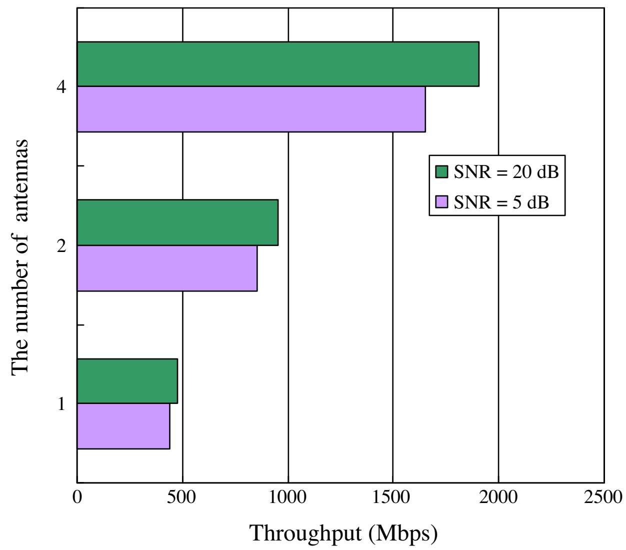

Figure 2. Throughput of multiple antenna MB-OFDM system according to the number of antennas.

5 dB are 478 Mbps and 440 Mbps, respectively. In the case of $M = 4$, the throughput is 1907 Mbps at SNR = 20 dB, but at SNR = 5 dB, the throughput is only 1650 Mbps. This performance degradation is caused by imperfect cancellation of interference among antennas. Therefore, the more transmitting antennas MB-OFDM system uses, the higher SNR the system requires to approach the ideal throughput. This phenomenon is also presented in Table 1. Table 1 shows the required SNR value when the throughput is about 90% of ideal throughput. As Table 1, the required SNR value is increased as increasing the number of antennas. However, the increased SNR value according to the increasing the number of antennas is not high and to achieve the 90% performance of ideal performance, required SNR value is lower than 10 dB. Therefore, to increase the data rate of MB-OFDM UWB system, the MIMO architecture can be efficiently used.

5.2. Adaptive Detection Technique of Multiple Antenna MB-OFDM System

In this subsection, we evaluate the performance of MB-OFDM system with proposed adaptive detection techniques. To evaluate the technique, BER and bits per subcarrier (BPS) performances are considered.

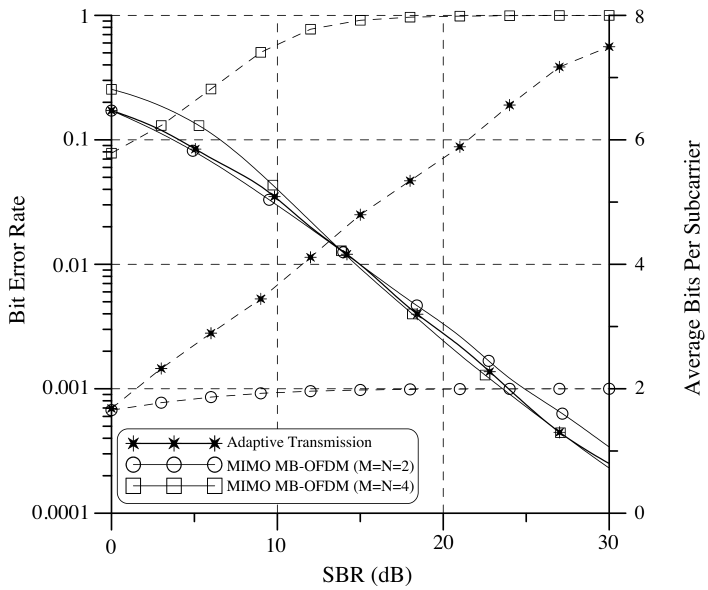

Figure 3. BER and throughput performance of adaptive antenna selection scheme in multiple antenna MB-OFDM system: (1) solid lines - BER and (2) dashed lines - BPS.

Figure 3 provides the BER and BPS performances of MB-OFDM system with adaptive antenna selection. The thresholds of $\mu_1 = 5\,\mathrm{dB}$, $\mu_2 = 15\,\mathrm{dB}$ and $\mu_3 = 25\,\mathrm{dB}$ are used for this scheme. Therefore, in this simulation, the number of transmit antennas is selected as

$$A_l = \begin{cases} M = 1 & \text{if } \ \gamma < 5\,\mathrm{dB} \\ M = 2 & \text{if } \ 5\,\mathrm{dB} \leq \gamma < 15\,\mathrm{dB} \\ M = 3 & \text{if } \ 15\,\mathrm{dB} \leq \gamma < 25\,\mathrm{dB} \\ M = 4 & \text{if } \ \gamma \geq 25\,\mathrm{dB}. \end{cases} \tag{9}$$

The performances of MB-OFDM systems with $M = N = 1$ and $M = N = 4$ are also shown. As mention in previous section, the throughput of BLAST is linearly increased by increasing the number of antennas. Therefore, the BPS throughput of the proposed scheme is linearly increased by increasing SNR. In the conventional MB-OFDM with multiple antennas, since the slope of BER performance is crossed at SNR $= 15\,\mathrm{dB}$, the BER performance of MB-OFDM with $M = N = 4$ is better than that of MB-OFDM with $M = N = 1$. Therefore, in the MB-OFDM with adaptive antenna selection, the BER performance is batter than that of MB-OFDM with single antenna. This scheme can

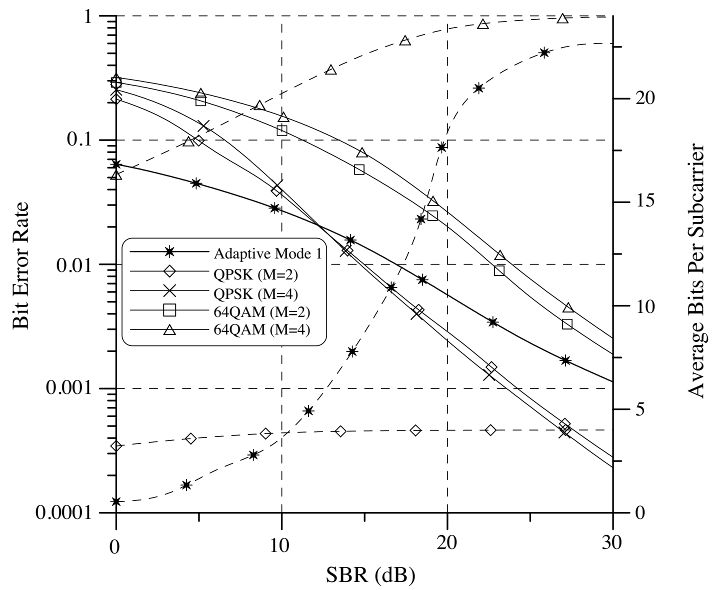

Figure 4. BER and throughput performance of adaptive antenna selection + AM scheme: (1) solid lines - BER and (2) dashed lines - BPS.

offer the higher reliability and throughput.

Figure 4 provides the BER and BPS performances of MB-OFDM system with both adaptive antenna selection and AM. In the adaptive antenna selection, the thresholds are $\mu_1 = 5\,\text{dB}$, $\mu_2 = 15$ and $\mu_3 = 25\,\text{dB}$. And the AM uses $\mu_1 = 0\,\text{dB}$, $\mu_2 = 5\,\text{dB}$, $\mu_3 = 15\,\text{dB}$ and $\mu_4 = 25\,\text{dB}$. Therefore, in this simulation, the QAM level is selected as

$$S_l = \begin{cases} \text{No TX} & \text{if } \gamma < 0 \\ \text{BPSK} & \text{if } 0 \leq \gamma < 5 \\ \text{QPSK} & \text{if } 5 \leq \gamma < 15 \\ \text{16QAM} & \text{if } 15 \leq \gamma < 25 \\ \text{64QAM} & \text{if } \gamma \geq 25. \end{cases} \quad (10)$$

In this figure, performances of fixed rate MB-OFDM system with QPSK and 64QAM are shown as reference. Since this scheme uses both the adaptive antenna selection and AM, the BPS of this scheme is very high at high SNR. The maximum ideal BPS throughput is 24, because maximum modulation level is 64QAM and the maximum number of transmission antennas is 4. At low SNR, the BER performance is improved due to the selection of low level modulation and a small number of transmitting antennas, compared to that of the fixed rate MB-OFDM system. In this scheme, very various throughput and reliability can be achieved by changing the thresholds.

6. CONCLUSIONS

Recent wireless communication of PAN environment requires very high data rate for transmitting large multimedia data. Therefore, in this paper, we consider MB-OFDM UWB system with multiple antennas. To increase data rate efficiently, V-BLAST architecture is used for MIMO scheme. And also, for communication in various channel environment, adaptive techniques are proposed for MB-OFDM system with MIMO scheme. The proposed adaptive techniques select the proper number of transmitting antennas and modulation levels for very high-speed and reliable transmission. By using MIMO scheme and these adaptive techniques, the reliable and high data-rate communications which are well adapted to the various user's demands and channel conditions are achieved.

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