Adaptive Transmission Techniques for Ubiquitous Personal Area Networks with Multiple Antennas

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Abstract

In the ubiquitous personal area network, huge amount of multimedia data and software components will be transmitted, and this huge data will require very high transmission capacity. Therefore, in this paper, various adaptive MIMO schemes are considered for ubiquitous personal area network based on MB-OFDM. For the adaptive transmission, the proposed technique includes STBC, BLAST, and combined STBC/BLAST in all. By properly selecting the MIMO scheme using adaptive transmission, the proposed technique has the advantage of each technique, e.g. diversity gain or high transmission rate. And also, we investigate some adaptive techniques for ubiquitous personal area network using the BLAST. The first investigated technique is adaptive antenna selection which selects the properly 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.

Keywords: uPAN, MB-OFDM, STBC, BLAST, combined STBC/BLAST, SNR estimation, adaptive transmission.

1. INTRODUCTION

A primary goal of ubiquitous personal area network (uPAN) is to allow users to perform various communication anywhere [2]. The uPAN provides a feasible solution of the seamless operation among home or business devices and systems. In the uPAN, remote access and data communication is generally achieved by ad-hoc network or wireless PAN (WPAN). The uPAN offers the flexibility to relocate people and equipment or to reconfigure and add more nodes to the network. This flexibility is achieved without much planning effort and cost of re-cabling, thereby making future upgrades inexpensive and easy. In the uPAN, huge amount of multimedia data including e.g. streaming multimedia content and full motion video, and software components will be transmitted. Therefore, the uPAN system requires high-rate transmission.

As a core technique for realizing high speed data transmission, multiple input multiple output (MIMO) structures popularized as space time coding (STC) [4] and space division multiplexing (SDM) [5], have received considerable attention recently. STC system increases the error performance of the communication systems and obtains the space-time diversity gain by coding over the different transmitting antennas, while SDM system provides very high data-rate communication over wireless channels without increasing the total transmitting power and bandwidth. And the combined STC/SDM technique [6] can achieve the high-speed and reliable communication. The combined STC/SDM obtains the advantages of both STC and SDM. Therefore, in this paper the uPAN system based on MB-OFDM which is the proposal of IEEE802.15.3a [3] employing various MIMO schemes is considered for high-speed and reliable communication. The space-time block coding (STBC) for STC, the Bell Labs layered space time (BLAST) for SDM and combined STBC/BLAST for combined STC/SDM techniques are used for MIMO structures.

In the uPAN environment, user will utilize various communications through functional objects anytime and anywhere at the various channel condition such as indoor, outdoor, high mobile speed and low mobile speed. Therefore, the uPAN system should change their system reliability and data rate depending on dynamically changing user's demand and channel condition [1].

In this paper, we propose the adaptive MIMO transmission scheme using various MIMO techniques in uPAN system. By properly selecting the MIMO technique, the proposed scheme brings both the diversity gain and the improvement of transmission rate. And also, some adaptive schemes are investigated for uPAN system using BLAST. The first investigated scheme is adaptive antenna selection which selects the properly 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.

The outline of the paper is as follows. Section II describes the system modeling. The basic theory of adaptive transmission is addressed in section III. In section IV and V, the adaptive MIMO scheme and the adaptive BLAST schemes

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This research is supported by the Ubiquitous Autonomic Computing and Network Project, the Ministry of Information and Communication (MIC) 21st Century Frontier R&D Program in Korea

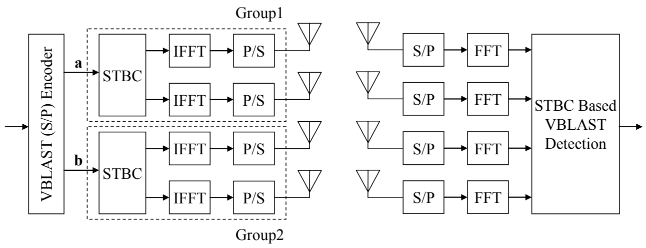

Fig. 1. A Combined STBC/BLAST for *M* = 4 and *N* = 4

$$\mathbf{X}_{ST}=\begin{bmatrix} \mathbf{X}_1 & -\mathbf{X}_2^* & \mathbf{X}_3 & -\mathbf{X}_4^* \\ \mathbf{X}_2 & \mathbf{X}_1^* & \mathbf{X}_4 & \mathbf{X}_3^* \\ \mathbf{X}_3 & -\mathbf{X}_4^* & \mathbf{X}_1 & -\mathbf{X}_2^* \\ \mathbf{X}_4 & \mathbf{X}_3^* & \mathbf{X}_2 & \mathbf{X}_1^* \end{bmatrix} \quad \mathbf{X}_B=\begin{bmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \\ \mathbf{X}_3 \\ \mathbf{X}_4 \end{bmatrix} \quad \mathbf{X}_C=\begin{bmatrix} \mathbf{X}_1 & -\mathbf{X}_2^* \\ \mathbf{X}_2 & \mathbf{X}_1^* \\ \mathbf{X}_3 & -\mathbf{X}_4^* \\ \mathbf{X}_4 & \mathbf{X}_3^* \end{bmatrix}$$

Fig. 2. MIMO transmission matrix for M = 4 ($\mathbf{X}_{ST} = \text{STBC}$, $\mathbf{X}_B = \text{BLAST}$ and $\mathbf{X}_C = \text{combined STBC/BLAST}$ **)**

are presented. In section VI, simulation results and discussions are presented. Section VII concludes the paper.

2. SYSTEM MODEL

2.1 uPAN System based on MB-OFDM

In the uPAN system based on MB-OFDM, the whole available ultra wideband spectrum between 3.1-10.6GHz is divided into several sub-bands with smaller bandwidth, whose bandwidth is approximately 500MHz [3]. 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 [3]. Consider the uPAN 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 $\{X_i^S(k) \mid k = 0,\ldots,K-1\}$ 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

$$\mathbf{R}^s = \mathbf{H}^s\mathbf{X}^s + \mathbf{W}^s \qquad (1)$$

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).

2.2 MIMO techniques

MIMO antenna techniques could provide higher spectral efficiency and increase potentially the system capacity. Generally, MIMO systems are classified into two large groups. Firstly, MIMO diversity transmission technique exists. Particularly, STBC is a representative diversity transmission technique. The STBC obtains gain of transmitting diversity by transmitting the same data for multiple transmitting antennas. Therefore, STBC technique brings the improvement of error performance through the diversity gain. However, MIMO diversity technique has a waste of bits per subcarrier (BPS) performance in a high SNR environment by giving up the transmission of data despite of link capability. On the other side, MIMO multiplexing technique (known also as BLAST) transmitting the different data at multiple transmitting antennas supports the high speed transmission rate without increasing of system bandwidth. The BLAST can theoretically offer a nearly linear increase in capacity. The BLAST happens the loss of BER performance at a low SNR environment. The combined STBC/BLAST can achieve the high-speed and reliable communication. A schematic of this idea is depicted in Fig. 1. The combined STBC/BLAST obtains the advantages of both STBC and BLAST. However, the scheme has the disadvantage of both STBC and BLAST, too. And since the combined STBC/BLAST uses diversity technique, the transmission efficiency of combined STBC/BLAST is only one half of BLAST. Therefore, the combined STBC/BLAST is not an optimum solution of MIMO-uPAN system. Fig. 2 shows the MIMO transmission matrixes..

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

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

The overall SNR can be obtained by the following equation

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

and channel state information can be determined on the analogy of immediate SNR value. This channel information representing the transmission mode-switching levels is correctly transmitted through feedback channel.

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. 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 [8].

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

where γ and μ_l denote the channel quality value and the mode-switching level, respectively. Generally, the mode-switching level μ_l is determined such that the average BPS 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,

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

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

4. ADAPTIVE MIMO TRANSMISSION TECHNIQUE

In this section, the MIMO structures are considered for adaptive MIMO-uPAN system. In this technique, the transmission modes correspond to the STBC (transmission rate 1), BLAST (transmission rate 4), and combined STBC/BLAST (transmission rate 2). In the BLAST, the number of the receiving antennas is equal to or larger than that of the transmitting antennas. For this reason, the number of transmitting and receiving antennas is the same in the proposed adaptive transmission scheme. And basic mode selection probability $\Pr(T_l)$ is defined as the probability of selecting the *l*-th mode from the set of available MIMO transmission modes. In this section, the transmission mode T_l is defined by the following rules

$$T_l = \begin{cases} \text{STBC} & \text{if } \gamma < \mu_1 \\ \text{Combined} & \text{if } \mu_1 \le \gamma < \mu_2 \\ \text{STBC/BLAST} & \\ \text{BLAST} & \text{if } \gamma \ge \mu_2 \end{cases} \tag{6}$$

5. ADAPTIVE BLAST TECHNIQUES

5.1 Adaptive Antenna Selection

In the MIMO-uPAN system with the BLAST scheme, different signals are transmitted through the different antennas simultaneously. Therefore, in the case without error, the MIMO-uPAN system using 4 transmitting antennas has more 4 times transmission rate than that using 1 transmitting antenna. So, the transmission rate is increased efficiently by increasing the number of antennas. In this section, the number of transmitting antennas is selected by using eqn.(4). Since we consider that the maximum number of transmitting antennas is 4, the SNR of eqn.(3) has to be estimated for all transmitting antennas M = 4. The antenna selection probability $\Pr(A_l)$ is defined as the probability of selection of the *l* transmitting antennas. In this section, the number of transmitting antennas A_l is selected by the following rules

$$A_l = \begin{cases} M = 1 & \text{if } \gamma < \mu_1 \\ M = 2 & \text{if } \mu_1 \le \gamma < \mu_2 \\ M = 3 & \text{if } \mu_2 \le \gamma < \mu_3 \\ M = 4 & \text{if } \gamma \ge \mu_3 \end{cases} \tag{7}$$

5.2 Adaptive Modulation

In this section, we apply an adaptive modulation (AM) to the MIMO-uPAN system with the BLAST scheme. The goal of AM is to select an appropriate modulation mode for the subcarrier in order to provide high quality of transmission. This AM can be used after the adaptive antenna selection is executed. In eqn.(3), the SNR at *k*-th subcarrier and *i*-th transmitting antenna can be obtained by the following equation

$$SNR_i^k = \left(\frac{1}{N} \sum_{j=1}^{N} | H_{ji}(k) |^2 \bullet X_i(k)^2 \right) / \varepsilon^2 \tag{8}$$

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 is selected by the following rules

$$X_l = \begin{cases} \text{No Tx} & \text{if } \gamma < \mu_1 \\ \text{BPST} & \text{if } \mu_1 \le \gamma < \mu_2 \\ \text{QPSK} & \text{if } \mu_2 \le \gamma < \mu_3 \\ \text{16QAM} & \text{if } \mu_3 \le \gamma < \mu_4 \\ \text{64QAM} & \text{if } \gamma \ge \mu_4 \end{cases} \tag{9}$$

6. SIMULATION RESULTS AND DISSCUSIONS

In this section, we examine the performance of the MIMO-uPAN system applying the proposed adaptive transmission techniques. To evaluate the performance of the MIMO-uPAN system, the MB-OFDM system with FFT size of 128, zero padded prefix duration of 32, and guard interval (GI) of 5 is considered in a bandgroup 1 of CM2 UWB channel environment. The frequency and time spreading are not used.

In Fig. 3, we show the performance of uPAN system using a proposed adaptive MIMO transmission technique with QPSK and $M = N = 4$. The performance of STBC, Combined STBC/BLAST and BLAST are also shown in this figure to compare with that of the proposed transmission scheme. BPS to measure throughput performance is considered. Also, the values of SNR threshold used to switch the transmission mode are μ_1 = 10dB and μ_2 = 20dB. From this figure, we can see that the BPS performance of the proposed scheme locate between that of STBC and that of BLAST. At SNR > 20 dB, the proposed scheme attain to a throughput of 8 BPS like a throughput performance of BLAST, but at SNR < 10 dB, the throughput performance is still 2 BPS. At low SNR, the BER performance of proposed scheme is dramatically improved by using the STBC, compared to that of the BLAST. Therefore, this proposed scheme can satisfy the diversity gain and the high transmission rate.

Fig. 4 shows the selection probability of transmission mode according to the SNR threshold. In this figure, we can see that the system mode transmitting to STBC scheme changes into the transmission mode of combined STBC/BLAST scheme at the neighborhood of the switching SNR threshold with an almost 50 percent probability of mode selection. In case of a low SNR, the probability which selects the transmission mode of BLAST is low, but at high SNR, SNR>20, the probability of BLAST is high. Therefore, the higher data rate or higher reliability can be achieved by changing the SNR thresholds.

Fig. 5 provides the BER and throughput performance of uPAN system with adaptive antenna selection. The thresholds of μ_1 = 5dB, μ_2 = 15dB and μ_3 = 25dB are used for this scheme. The performance of BLAST-uPAN system with $M = N = 1$ and $M = N = 4$ is 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 BLAST-uPAN,

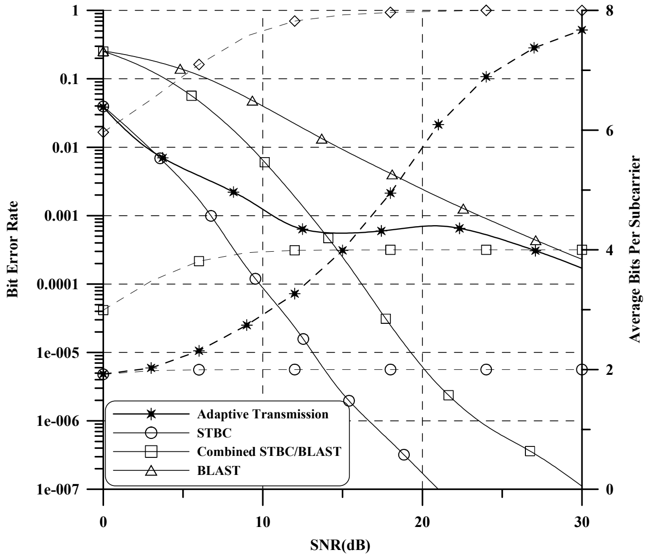

Fig. 3 BER and throughput performance of adaptive MIMO transmission scheme in uPAN system: (1) solid lines - BER and (2) dashed lines - BPS

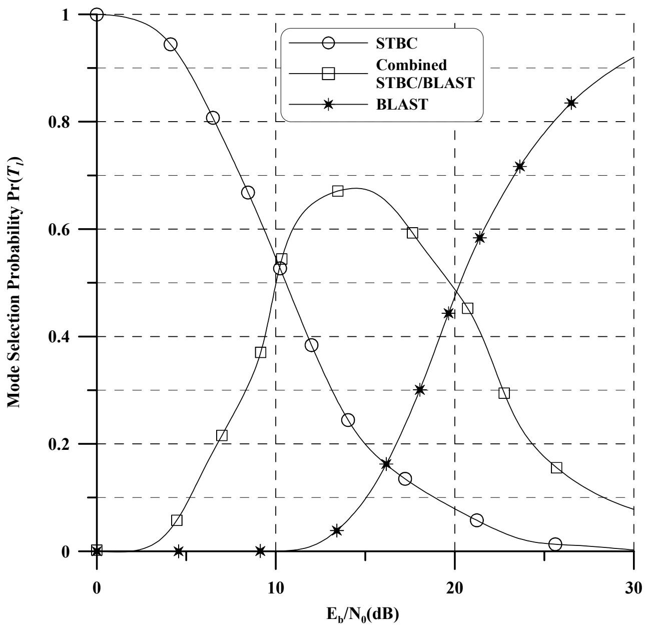

Fig. 4 Selection probability of MIMO transmission mode for MIMO-uPAN system with adaptive MIMO transmission scheme.

since the slope of BER performance is crossed at SNR = 15dB, the BER performance of BLAST-uPAN with $M = N = 4$ is better than that of BLAST-uPAN with $M = N = 1$ which is equal to single antenna uPAN at SNR > 15dB. Therefore, in the BLAST-uPAN with adaptive antenna selection, the BER performance is batter than that of uPAN with single antenna. This scheme can offer the higher reliability and throughput.

Fig. 6 provides the BER and throughput performance of uPAN system with both adaptive antenna selection and AM. In the adaptive antenna selection, the thresholds are μ_1 = 5dB, μ_2 = 15dB and μ_3 = 25dB. And the AM uses μ_1 = 0dB, μ_2 = 5dB, μ_3 = 15dB and μ_4 = 25dB. In this figure, performance of

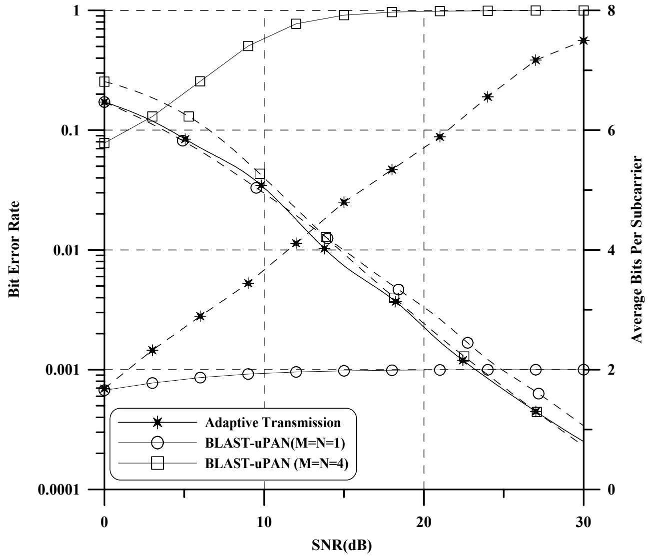

Fig. 4 BER and throughput performance of adaptive antenna selection scheme in BLAST-uPAN system: (1) solid lines - BER and (2) dashed lines - BPS

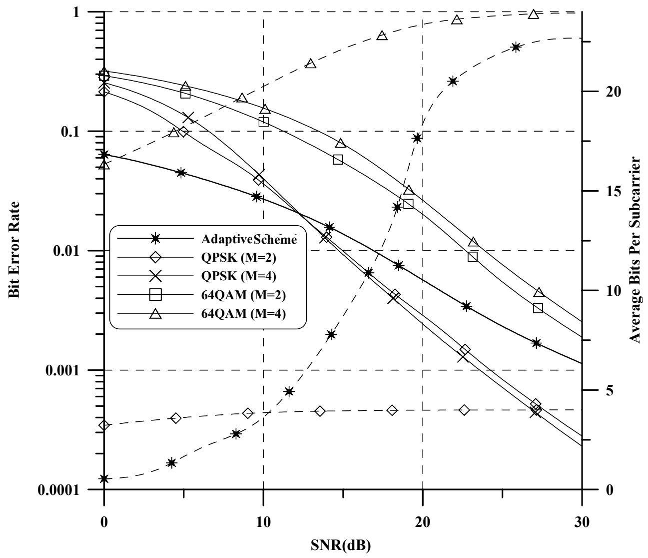

Fig. 4 BER and throughput performance of Adaptive MIMO transmission + AM scheme in uPAN system: (1) solid lines - BER and (2) dashed lines - BPS

fixed rate BLAST with QPSK and 64QAM is 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 BLAST. In this scheme, very various throughput and reliability can be achieved by changing the thresholds.

7. CONCLUTIONS

In the ubiquitous personal area networking environment, user will utilize various communications through functional objects anytime and anywhere at various channel condition. Therefore, the effective adaptive techniques are proposed for uPAN system with multiple antennas. Firstly, the adaptive MIMO scheme satisfying the diversity gain and the high transmission rate is derived. And, some adaptive techniques are proposed for MIMO-uPAN system with BLAST. The adaptive BLAST techniques select the properly number of transmitting antennas and modulation levels for very high and reliable transmission. In the adaptive BLAST techniques, compared with the fixed transmission using single antenna with QPSK modulation having a throughput of 2 BPS, the proposed transmission scheme brings the improvement in BPS performance, achieving a maximum throughput of 24 BPS. 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.

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