Channel Estimation of High Rate WPAN System with Diversity Technique

Byung-Su Kang, Myung-Sun Baek, Dong-Jun Cho,
Young-Hwan You, and Hyoung-Kyu Song

uT Communication Research Institute
saturnus@sju.ac.kr, songhk@sejong.ac.kr

Abstract. A simple channel estimation technique for IEEE 802.15.3 HR WPAN system is proposed and assessed, which gives improved performance in multi-path channel. HR WPAN system can be designed for supporting multimedia traffic in the wireless home network. The demand for a high data rate and reliable technology will increase continuously. To satisfy the demand, we design a new architecture that applies the diversity technique to the HR WPAN system. The proposed scheme can estimate multi-path channel easily by simple operation using preamble, and also can be utilized in the situation of using one or two transmit antennas.

1 Introduction

There have been many communication systems for wireless home network. The development of Wireless Personal Area Network(WPAN) is prompted by the needs for wireless connectivity of high data rate, low cost, low complexity and low power consumption. IEEE 802.15.3 standard was designed particularly for the High Rate WPAN(HR WPAN) which can support short-range communications among portable consumer electronic devices at high data rate up to 55Mbps[1].

In the future more and more homes will have multiple PCs and multiple connections to outdoor public telecommunication and broadcasting networks. So, high data rate wireless communication becomes more concerned for support of multimedia services. To satisfy these demand, we introduce the multiple-input multiple-output(MIMO) systems promise improved performance compared to conventional systems in Rayleigh fading environment[2]. By using two transmit antennas, we can achieve higher data rate and more reliable communication than using single antenna. High data rate and reliability can be obtained by space time block code(STBC) algorithm.

One of the most important condition to use MIMO technique is that the accurate channel information is needed. In HR WPAN system, the channel estimation uses preamble called constant amplitude zero auto correlation(CAZAC). We propose an efficient method that estimates multi-path channel in MIMO environment by using CAZAC. The proposed channel estimation algorithm takes advantage of the orthogonal property of CAZAC. The BER performances of the proposed scheme have been shown through the simulation results.

The paper is organized as follows. The system model is described in Section 2. In Section 3, we explain the channel estimation algorithm and the proposed architecture. Section 4 shows the simulation results and discussions. Finally, our conclusions are presented in Section 5.

2 System Model

2.1 Space-Time Coded WPAN System

In HR WPAN system, a set of CAZAC sequences is sent in order to allow the receiver to estimate the channel. Before the data is transmitted, the data source is encoded by QPSK, 16/32/64-QAM with 8-state TCM scheme or DQPSK modulation. TCM offers bandwidth and power advantages over other modulations. The symbol rate of IEEE 802.15.3 is 11Msymbol/sec and raw physical layer data rates supported are 11, 22, 33, 44, 55Mbits/sec (QPSK-TCM, DQPSK, 16/32/64-QAM-TCM, respectively)[9].

A space-time block code is defined by a $p \times n$ transmission matrix [6]-[7]. The entries of the transmission matrix are linear combinations of the variables $x_1, x_2, \dots, x_k$ and their conjugates. The number of transmission antenna is n , and we usually use it to separate different codes from each other. Since p time slots are used to transmit k symbols, the rate R of the code is k/p . We consider only the transmission matrices for one and two transmit antennas, because the proposed channel estimation algorithm is suitable for two transmit antennas.

For one transmit antenna, the transmission matrix G_1 is simply $G_1 = [x_1]$, for which the code rate is one. For two transmit antennas, there exists a rate one STBC defined by the transmission matrix G_2 given by [4]

$$G_2 = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix}. \quad (1)$$

Suppose that there are 2^b signals in the constellation. At the first time slot, $2b$ bits arrive at the encoder and select two complex code symbol x_1 and x_2 . These code symbols are transmitted simultaneously from antennas one and two, respectively. At the second time slot, code symbols $-x_2^*$ and x_1^* are transmitted. Figure 1 represents the case of two-branch transmit diversity with one receive antenna[4].

2.2 WPAN Channel Model

A short range indoor propagation channel can be described by a Rayleigh fading model with exponentially decaying power profile [3]. The average root mean square(RMS) power of the taps can be obtained according to the RMS delay spread T_{RMS} . Then the coefficients $H(\tau)$ are selected according to

$$H(\tau) = G(0, \sigma_\tau^2/2) + jG(0, \sigma_\tau^2/2) \quad (2)$$

Fig. 1. Two-branch transmit diversity with one receiver

with

$$\sigma_\tau^2 = \sigma_0^2 \exp(-\tau T_s / T_{RMS}) \quad (3)$$

where T_s is the sampling rate, $G(0, \sigma_\tau^2/2)$ is a zero mean Gaussian random variable with variance $\sigma_\tau^2/2$ and $\sigma_0^2 = 1 - \exp(-T_s/T_{RMS})$ is chosen so that the unit energy constraint $\sum_{\tau=0}^L \sigma_\tau^2 = 1$ for $L = 10T_{RMS}/T_s$ is satisfied where L denotes the maximum number of paths. In practice, short range indoor channels usually induce a delay spread of 25-70ns at 2.4GHz.

3 The Proposed Channel Estimation Algorithm

According to the specification of the IEEE 802.15.3, the preamble contains 12 periods of a special sequence of $N = 16$ QPSK symbols called CAZAC sequence [9]. We apply two transmit antennas and m receive antennas to IEEE 802.15.3 high rate WPAN systems. The transmitted signals from each antenna undergo multi-path fading independently. The expression for the received signal at the j -th receive antenna is as follows

$$y(n) = \sum_{i=1}^2 \sum_{\tau=0}^{L-1} H_{ij}(\tau) P_{ij}(n - \tau) + w_j(n) \quad j = 1, 2 \quad (4)$$

where i is transmit antenna index, L is the number of paths, $H_{ij}(\tau)$ is the channel impulse response(CIR) for antenna i at j th receive antenna, $P_{ij}(n)$ is the detected CAZAC training sequence transmitted from antenna i at j th receive antenna, and

$w_j(n)$ is complex additive white Gaussian noise (AWGN). At the receiver, we assume perfect frequency and timing synchronization. To separate multi-channel coefficients, we multiply the received signal by the conjugate of the shifted CAZAC sequence. The expression for the estimated CIR values is denoted by

$$\begin{aligned}\hat{H}_{ij}(l) &= 1/N \left(\sum_{i=1}^2 \sum_{\tau=0}^{L-1} H_{ij}(\tau) P_{ij}(l - \tau) \right) \cdot P_i^*(l) \\ &\quad + \hat{w}_j(l) \\ &= H_{ij}(l) + \hat{w}_j(l) \quad \text{for } 0 < l \leq L\end{aligned}\quad (5)$$

where $(\cdot)^*$ denotes the complex conjugation and $\hat{w}_j(l)$ is the AWGN at the l th path. Also, $P_i^*(l)$ denotes l times shifted CAZAC sequence from antenna i and N is the CAZAC length. The first term in eq.(4) is always zero except that the transmitted CAZAC sequence exactly coincides with the conjugated version of transmitted CAZAC sequence at the receiver, which is called the orthogonality. When the two CAZACs from each transmit antenna do not guarantee the orthogonality, it is impossible to distinguish the two received signals because of breaking the autocorrelation property. So $P_2(n)$, which is K times cyclic shifted version of $P_1(n)$, is transmitted from second antenna. If we choose $K = N/2$ and assume $K \geq L$, two CAZACs do not overlap at the receiver, without corrupting autocorrelation property. Based on this assumption, eq.(5) is satisfied. The mean square error (MSE) of the proposed estimator is obtained by

$$MSE = E \left[\sum_{j=1}^m \sum_{i=1}^2 \sum_{l=0}^{L-1} \left(\hat{H}_{ij}(l) - H_{ij}(l) \right)^2 \right] = E [\hat{w}_j(l)^2]. \quad (6)$$

Because the channel estimation error, $\hat{H}_i(l) - H_i(l)$, equals to the AWGN, we can conclude the MSE is same to the noise variance from eq.(6). Now, we consider imperfect channel estimation. For a given number of cyclic shift $K = N/2$, if $L > K$, some multipath signals of CAZAC sequences are overlapped, which results in corrupting orthogonality. In this case, the estimated channel for i , $k = 1, 2$ and $k \neq i$ can be expressed as

$$\hat{H}_{ij} = \begin{cases} H_{ij}(l) + H_{kj}(l + N/2) + \hat{w}_j(l) & 0 < L - K \\ H_{ij}(l) + H_{kj}(l - N/2) + \hat{w}_j(l) & K < L \\ H_{ij}(l) + \hat{w}_j(l) & elsewhere \end{cases} \quad (7)$$

Eq.(7) shows that correct estimation is not possible because of the CIR estimates from the other antenna. Therefore, the additional channel estimation error, $H_{kj}(l + N/2)$ and $H_{kj}(l - N/2)$, is added to the noise variance. The equation for total MSE is as follows

$$\begin{aligned}MSE &= E \left[\sum_{k=1}^2 \sum_{j=1}^2 \sum_{l=0}^{L-K-1} (H_{kj}(l + N/2))^2 \right] \\ &\quad + E \left[\sum_{k=1}^2 \sum_{j=1}^2 \sum_{l=K}^{L-K-1} (H_{kj}(l - N/2))^2 \right] \\ &\quad + E [\hat{w}_j(l)^2]\end{aligned}\quad (8)$$

when $L > K$.

4 Simulation Results and Discussions

We illustrate the performance analysis of the proposed channel estimation algorithm in terms of MSE and BER.

Figure 2 shows the MSE performance in respect to RMS delay and E_b/N_0 . We simulated up to 100ns RMS delay, which means the number of paths is 10. When E_b/N_0 is increased by 10dB, the MSE is reduced by a factor of 0.1 where RMS delay increases up to 80ns. If the RMS delay is longer than 80ns, it can be known that the performance is degraded rapidly. This result is induced by exceeding the number of paths, $N/2$. Fortunately, since the RMS delay spread in an indoor wireless channel is less than 80ns[9], our scheme can be effectively applied to the IEEE 802.15.3 standard, without changing the training symbol.

Figure 3 displays the MSE of channel estimation versus E_b/N_0 . The MSE decreases linearly as E_b/N_0 increases up to RMS delay of 80ns. However, the MSE converges to 0.7 approximately with RMS delay of 90ns. It is also observed from two figures that the analytic error curves according to Eq.(8) match the simulated error curves.

To estimate channel, we require only one CAZAC. The computational complexity for each CIR estimate is 16 multiplications, 16 additions, and 1 division. Also it is possible to apply the proposed algorithm to single transmit antenna. The algorithm can be easily implemented because of low complexity.

The BER performance comparison between the conventional WPAN system and the space-time coded WPAN system with two transmit antennas is illustrated in Figure 4. As shown in this figure the BER performance of space-time coded WPAN system outperforms that of the conventional WPAN system. Also

Fig. 2. The MSE performance according to the RMS delay and E_b/N_0

Fig. 3. The MSE performance of the proposed scheme employing $M = 2$

Fig. 4. BER performance of both perfect channel and channel estimation with STBC and conventional WPAN system

the more receive antennas are used, the better BER performance is obtained. The performance difference between the WPAN system with channel estimation and WPAN system with perfect estimation becomes similar for high SNR. In low

SNR, on the other hand the performance degradation of the channel estimation is observed, which is due to the imperfect channel estimation.

5 Conclusions

In this paper, we apply multi-antenna scheme to HR WPAN system and investigate channel estimation problem. The proposed channel estimation algorithm can operate in single and multiple antenna system. To recover the transmitted data in multiple antenna system, we introduce the STBC algorithm. The proposed channel estimation algorithm can estimate the multi-channel information up to 80ns RMS delay. And also, we have shown the BER performance of space-time coded WPAN system with the proposed channel estimation scheme. The simulation result shows that the system performance can be increased by using the STBC algorithm and proposed channel estimation scheme.

Acknowledgement

This work is financially supported by the Ministry of Education and Human Resources Development (MOE), the Ministry of Commerce, Industry and Energy (MOCIE) and the Ministry of Labor (MOLAB) through the fostering project of the Lab of Excellency and is supported by MIC Frontier R&D Program in KOREA.

References

1. J.Karaoguz, "High-Rate Wireless Personal Area Networks" *IEEE Communication Magazine*, vol. 39, no. 12, pp.96-102, Dec. 2001.
2. B. A. Bjerke and J. G. Proakis, "Multiple-antenna diversity techniques for transmission over fading channels" *IEEE WCNC'99*, Italy, pp.1038-1042, Sept. 1999.
3. Hashemi, H., Tholl, D., Morrison, G., "Statistical modeling of the indoor radio propagation channel-part I," *IEEE Vehicular Technology Conference*, vol.4, pp.338-342, May 1992.
4. S.M. Alamouti, "A simple transmit diversity scheme for wireless communications" *IEEE J. Select. Areas Commun.*, vol. 16, no. 8, pp. 1451-1458, Oct. 1998.
5. S.M. Alamouti, "Trellis-coded modulation and transmit diversity: design criteria and performance evaluation" *IEEE Universal Personal Communications.*, vol. 1, pp.703-707, Oct. 1998.
6. V. Tarokh, H. Jafarkhani, and A. R. Calderbank, "Space-time block codes from orthogonal designs," *IEEE Trans. On Info. Theory*, vol. 45, no. 5, pp.1456-1467, July 1999.
7. V. Tarokh, H. Jafarkhani, and A. R. Calderbank, "Space-time block coding for wireless communications: Performance results," *IEEE J. Select. Areas Commun.*, vol. 17, no.3, pp.461-471, March 1999.
8. G. J. Foschini Jr. and M. J. Gans "On limits of wireless communication in a fading environment when using multiple antennas" *Wireless Personal Commun.*, March 1998.
9. IEEE Std P802.15.3-2003, 2003.