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MIMO 시스템에서 ALAMOUTI 기법과 IEEE 802.15.4의 BER 성능 개선

Improving BER Performance of IEEE 802.15.4 with Alamouti Scheme in MIMO System

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요　약

본 논문은 IEEE 802.15.4 표준 기반의 Multiple Inputs Multiple Output (MIMO) 시스템에 space-time block coding (STBC) - Alamouti scheme을 적용하는 기법을 제안한다. 제안된 기법은 IEEE 802.15.4 표준을 기반으로 하는 2x1 MISO와 2x2 MIMO에 적용되었다. Matlab을 이용한 모의 실험을 수행하였고, 그 결과를 기존의 IEEE 802.15.4 Single Input Single Output (SISO) system과 switching diversity 1x2 Single Input Multiple Output (SIMO)와 비교하였다. 모의 실험 결과 제안된 기법은 IEEE 802.15.4 SISO 및 switching diversity 방식에 비해 더 나은 Bit Error Rate (Ber) 성능을 보이는 것을 입증하였다

☞ 주제어 : IEEE 802.15.4, Alamouti scheme, 비트 오류율 성능, 다중 입력 다중 출력

ABSTRACT

This paper proposes a technique for applying space-time block coding (STBC) - Alamouti scheme on Multiple Inputs Multiple Output (MIMO) system based on IEEE 802.15.4 standard. It is applied to IEEE 802.15.4 standard in 2x1 MISO and 2x2 MIMO systems. Simulation is performed using Matlab and the results are compared with conventional IEEE 802.15.4 approaches, Single Input Single Output (SISO) system and switching diversity 1x2 Single Input Multiple Output (SIMO) system. The simulations show that applied Alamouti scheme gave better Bit Error Rate (BER) performance compared to combined IEEE 802.15.4 with switching diversity and SISO system.

☞ keyword : IEEE 802.15.4, Alamouti scheme, BER performance, MIMO

1. 서　론

IEEE 802.15.4 Low Rate Wireless Personal Area Network (LR-WPAN) is a network designed for low-power, low-cost, and short-range wireless communications among inexpensive fixed, portable and moving devices [1], [2], [3]. This standard is focusing on home and industrial automation and it is specifiedfor high level communication protocols using low-power digital radios for personal area networks. One of the major problems of IEEE 802.15.4 is the error-prone performance in harsh environment such as industrial applications. Many techniques are used to overcome this problem such as increasing the transmit power, however it cannot be solution due to the limitation of maximum transmit power and power-hungry operation of transmission will shorten the lifetime.

The advance of hardware technology allows more signal processing functionality to be integrated into a single chip. It has made wireless sensor network devices become smaller and more complex, but still manage the ability to preserve low power consumption. The concept of multiple transceivers is born, where two antennas are implanted into a single device and it can handle multiple input and multiple output transmission, known as MIMO system. The usage of dual antennas in a single IEEE 802.15.4 device has already been common and commercialized such as in[4], [5], and [6]. In [7], they introduced a study of energy efficiency of MIMO

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techniques in WSN based on its power consumption and they assumed Alamouti diversity codes are used for the MIMO and cooperative MIMO system. It shows that the power consumption of MIMO system-based WSN devices can be more efficient compare to SISO system - based WSN devices in certain distance transmission. But they did not consider how the usage of MIMO system in WSN affects the enhancement of transmission performance.

The explained aspects become our consideration to apply Alamouti - STBC as one of diversity method with IEEE 802.15.4 standard in MIMO system. The goal of this paper is to study the effect of applied Alamouti scheme with IEEE 802.15.4 in MIMO system by considering the enhancement of BER performance, compared to switching diversity and conventional approach of IEEE 802.15.4 in SISO system.

This paper is organized as follows. Several related works and basics information related to Alamouti scheme is presented in next section. The applied Alamouti scheme in IEEE 802.15.4 is explored in section III. Section IV provided simulation results, followed by conclusion in section V.

2. RELATED WORKS

Several related works considering the performance of IEEE 802.15.4 in MIMO system and basic information related to Alamouti scheme are discussed in this section. Switching diversity was proposed in [8], [9] as a method to overcome the problem with limited transmit power. They introduced a way to choose or combine the best transmission channel from n antennas (n=2), so it can improve the BER performance in the harsh environment. However, re-synchronization may occur when the quality of one antenna degrades and another antenna is establishing link which will create delay and more power consumption. As proved in [10] each time the receiver switches, a switching transient corrupts the receiver filters and data signal chain causes an "internal outage" condition; if the switching rate is high, data lost will be increased and switching diversity becomes unreliable. The other problem is their assumption that using known channel at the receiver, where IEEE 802.15.4 standard based commercial products only support the switching diversity without the channel estimation [4], [5], [6].

Cooperative MIMO is another solution to deal with harsh environment problem [11]. By cooperating with the neighboring relays, it can improve BER performance. The problem is that cooperative MIMO scheme cannot be established when there is no neighboring relay. Cooperative MIMO also requires extra energy for the local cooperative data exchange and extra power consumption of the cooperative nodes [12]. Cooperative MIMO also has a problem of inability to improve the performance of one hop link.

Alamouti [13] presents a remarkable spatial and time diversity scheme for transmission with two transmit antennas that improves quality of the received signal by using simple processing scheme at the transmitter and linear decoding at the receiver. The Alamouti - STBC is known as one of the most effective diversity methods in MIMO system used to combat the effect of channel fading in wireless communication. In [7], Alamouti code based on MIMO system and modulation has been introduced to minimize power consumption under constraint throughput for sensor networks. But they did not investigate the enhancement of BER performance. As it is shown in [14], [15], Multiple Input Multiple Output (MIMO) system with Space Time Block Coding (STBC) can become an effective way to reduce the fading effect in the wireless channel by providing diversity and to increase the BER performance in receiver side.

Performance of Alamouti scheme itself has been evaluated in many scenario such as in [16], [17] and [18]. L. Yang and J. Qin in [16] have conductedperformance analysis of Alamouti scheme to maximized the instantaneous received signal-to-noise ratio (SNR) for M-ray signals, while the focus in [17] is performance analysis considering the case of cooperative MIMO relaying system with a single relay. Author in [18] is considering the performance analysis in analytical approach concerning multi-level quadrature amplitudemodulation (M-QAM) system when Alamouti scheme transmit diversity transmission is performed in Rayleigh fading channel.

Alamouti scheme in diversity method utilizes the repetition sending process of transmitted signals in different time slots by using 2 or more transmitters. Each transmitted signal encounters independent fading as it is transmitted separately. Assuming the usage of M-ary modulation scheme in the encoding part with m information bits is modulated, where $m = log_2 M$. The encoder works by taking two modulated symbol S_1 and S_2 in each encoding process and maps them to transmitter according to code matrix given by

$$S = \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} \quad (1)$$

The Alamouti code with two transmitters uses two different symbols S_1 and S_2 transmitted simultaneously during the first symbol period from antennas 1 and 2, respectively, followed by signals $-S_2^*$ and S_1^* from antennas 1 and 2, respectively, during the next symbol period (* denotes complex conjugate). The encoding part is done in both time and space domains and we can denote the transmit sequence from both antennas by S^1 and S^2.

$$s^1 = \begin{bmatrix} s_1 & -s_2^* \end{bmatrix} \quad (2)$$

$$s^2 = \begin{bmatrix} s_2 & s_1^* \end{bmatrix} \quad (3)$$

If the Alamouti channel is symbolized as h_1 for channel 1 and h_2 for channel 2, and both are experiencing Rayleigh fading. The received signal can be expressed as

$$r_1 = h_1 s_1 + h_2 s_2 + n_1 \quad (4)$$

$$r_2 = -h_1 s_2^* + h_2 s_1^* + n_2 \quad (5)$$

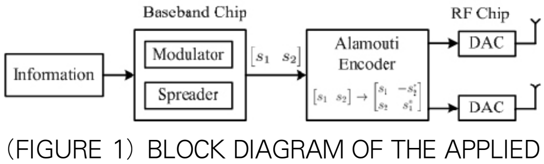
where r_1 and r_2 are received signals and n_1 and n_2 are independent complex variables representing receiver noise and interference at time t and $t+T$, respectively.

3. IEEE 802.15.4 WITH ALAMOUTI SCHEME

Our proposed approach of applying Alamouti scheme on IEEE 802.15.4 standard will be summarized in this section. Applied Alamouti scheme on IEEE 802.15.4 MIMO system model includes the following major blocks: spreader and de-spreader, Binary Phase-Shift Keying (BPSK) / Offset Quadrature Phase-Shift Keying (OQPSK) modulator and de-modulator, Alamouti encoder and decoder, and Rayleigh fading channel.

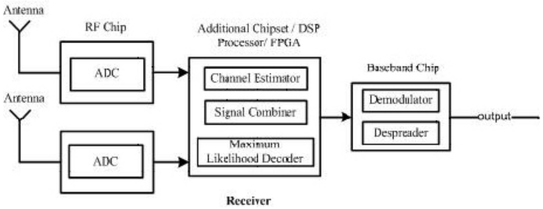
Assuming that in the transmitter side, a random integer generator block generates some number of samples. Those samples are taken as input to the spreader block, which will spread every 4 bits data symbol into 32 sequences for the 2.4 GHz model and will spread every 1 bit input into 16 sequences for the 868/915 MHz model, according to chip mapping tables like shown in [19]. Then those integers are taken as input to the BPSK/OQPSK modulation block depends on model used. The output is then encoded with Alamouti encoder. As it is shown in Figure 1, the encoder works by taking two modulated symbol s_1 and s_2 in each encoding process and maps them to transmitter according to code matrix in Alamouti scheme. The additive Gaussian noise block is then added to the encoded stream as interference that experienced while transmission on progress. The encoded data is the converted into analog signal and send through all available antennas.

Considering the receiver part, OQPSK modulation supports both 16 and 32 sequences for the received data. Those sequences are sent to the de-spreader which is converted back to an integer, contain 4 bits symbol. Those 4 bits are compared with the original one and the BER is calculated. BPSK modulation only supports modulation of 16 sequences data.



(FIGURE 1) BLOCK DIAGRAM OF THE APPLIED ALAMOUTI SCHEME ON IEEE 802.15.4 TRANSMITTER

The received 16 sequences data are de-spread into 1 bit symbol and compared with the original one to calculate the BER. Receiving process can be operated by one or two antennas, where the incoming signals are passed through Alamouti decoder. Inside the Alamouti decoder, channels are estimated; received signals are combined; and the results are estimated with Maximum Likelihood method. Finally, the estimated results are passed through the BPSK/OQPSK demodulation block. Figure 2 shows a receiver design of applied Alamouti scheme on IEEE 802.15.4 device.

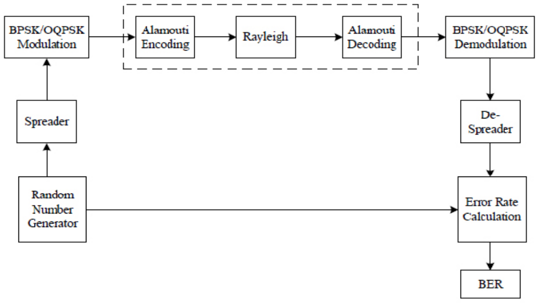


(FIGURE 2) RECEIVER DESIGN OF APPLIED ALAMOUTI SCHEME ON 802.15.4

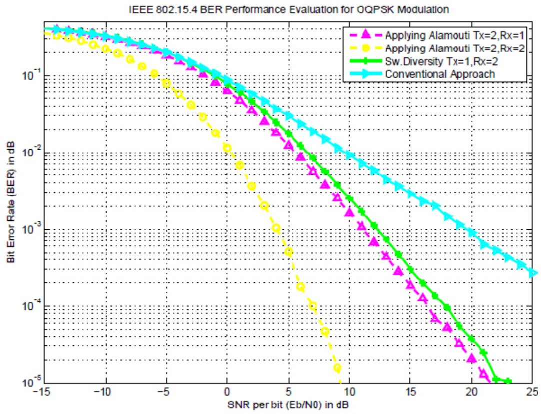
4. SIMULATION

The capabilities of the proposed Alamouti scheme that is applied on IEEE 802.15.4 standard will be demonstrated in this section via simulations using Matlab. Simulations in Matlab are performed with number of samples equal to 10^7, where the environment of transmission channel is experiencing Rayleigh fading and all transmission are suffer from noise. Both BPSK and OQPSK modulation cases are considered as it is used as modulation method in the standard. BER performance is considered as the performance metric and simulations scenario are considering conventional IEEE 802.15.4 in SISO system, switching diversity in SIMO system, and applied Alamouti scheme in MISO and MIMO system. The proposed simulation model of applied Alamouti scheme on IEEE 802.15.4 is shown in Figure 3.

The BER performance using OQPSK modulation for combined method of applied Alamouti scheme on IEEE 802.15.4 standard is presented in Figure 4. Simulation results shown that for OQPSK modulation, switching diversity can achieve the same BER of 10^{-3} with 4 dB smaller Eb/N0 compared to conventional one. Second comparison is performed among switching diversity 1x2 SIMO, applied Alamouti scheme 2x1 MISO and 2x2 MIMO systems. Because of switching diversity cannot estimate its channel, it



(FIGURE 3) PROPOSED SIMULATION MODEL OF APPLIED ALAMOUTI SCHEME ON IEEE 802.15.4

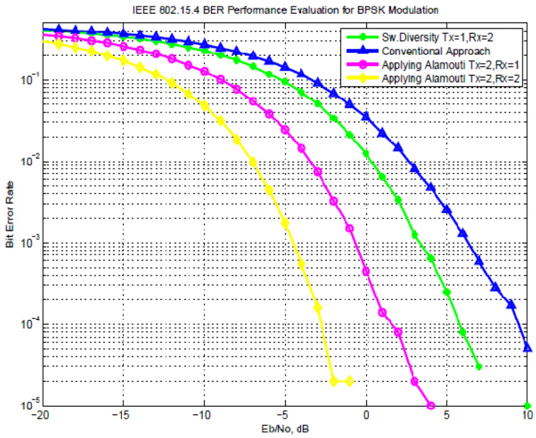


(FIGURE 4) COMPARATIVE SIMULATION RESULTS OF APPLIED ALAMOUTI IN OQPSK MODULATION

shows that applied Alamouti scheme 2x1 MISO and 2x2 MIMO system can achieve the same BER of 10^{-3} with 1 dB and 8 dB smaller Eb/N0.

On the contrary with switching diversity, Alamouti scheme exploits channel estimation based on Maximum Likelihood which increases the BER performance. At last, applied Alamouti Scheme 2x1 MISO and 2x2 MIMO system can achieve the same BER of 10^{-3} by using 9 dB and 15 dB Eb/N0, respectively compared to conventional IEEE 802.15.4 approach of 1x1 SISO System.

In Figure 5, the BER performance in BPSK modulation of applied Alamouti scheme is presented. The simulation results shown that switching diversity for BPSK modulation can achieve the same BER of 10-3 with 3 dB smaller Eb/N0, compared to conventional one. Second comparison isperformed among switching diversity, 2x1 MISO and 2x2 MIMO systems. Comparison shown that applied Alamouti scheme 2x1 MISO and 2x2 MIMO can achieve the same BER of 10-3 with 4 dB and 7 dB smaller Eb/N0, respectively. At last, conventional IEEE 802.15.4 approach of 1x1 SISO needs 6 dB and 10 dB higher Eb/N0 to achieve BER of 10-3 compare to 2x1 MISO and 2x2 MIMO system, respectively.



(FIGURE 5) COMPARATIVE SIMULATION RESULTS OF APPLIED ALAMOUTI SCHEME IN BPSK MODULATION

The enhancement of BER performance in applied Alamouti scheme MISO and MIMO system cases are affected by the ability of Alamouti scheme in achieving full diversity gain without sacrifice the data rate. In this case, applied Alamouti scheme is able to send multiple symbols within one time slot. With the high enhancement of BER performance achieved from applied Alamouti scheme in IEEE 802.15.4 MISO and MIMO system, the transmission in point-to-point between 2 IEEE 802.15.4 devices will resulting higher probability of packet received successfully in the error-prone network environment. If this method is applied to network system, it is expected to be able to enhance the overall performance of IEEE 802.15.4.

5. CONCLUSION

This paper proposed a study to apply STBC - Alamouti scheme on IEEE 802.15.4MISO and MIMO system, for the purpose of improving the BER performance. Simulation is conducted by using Matlab in the BPSK and OQPSK modulations for the transmission of 2x1 MISO and 2x2 MIMO antenna system, where conventional approach of IEEE 802.15.4 SISO and switching diversity 1x2 SIMO are used as comparison. The simulation results shown that applied Alamouti scheme on IEEE 802.15.4 with 2x2 MIMO system is able to enhance Eb/N0 gain by 15 dB at BER of 10^{-3} in OQPSK modulation compared to conventional IEEE 802.15.4 and Eb/N0 gain by 8 dB compared to switching diversity. Considering BPSK modulation, applied Alamouti scheme in 2x2 MIMO system is able to enhance Eb/N0 gain by 10 dB at BER of 10^{-3} compared to conventional IEEE 802.15.4. Therefore, it is concluded that the applied Alamouti scheme on IEEE 802.15.4 standard with MISO and MIMO system give Eb/N0 performance gain compared to conventional IEEE 802.15.4 approach (1x1 SISO) and switching diversity 1x2 SIMO system.

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