Performance Analysis of SM-MISO with Q-CSIT in Wireless Sensor Network

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***Abstract*—In this paper, we investigate the role of Q-CSIT in SM-MISO for wireless sensor networks system. The SN are connected to the CH, it is modeled as a MISO system. Spatial modulation has an advantage over a conventional MIMO system which does not require multiple radio frequency chains as many as the number of transmit antennas. The Q-CSIT is aimed to estimate the faded wireless channel with a limited/finite number of bits. The finite number of feedback bits trigger the SN adapt automatically its AMC modes. Adaptation of the AMC modes causes a changing of transmit power and transmission rate, these changes will make a better probability of error. The numerical results show that bigger the number of feedback bits yields better SER. Furthermore, lower spatial correlation generates a better probability of error. The last, quality of wireless channel that is stated in SNR also dominantly influences the performance of SM – MISO system.**

***Keywords*—spatial modulation, Q-CSIT, WSN**

I. INTRODUCTION

A wireless sensor network (WSN) consists of a large number of spatially random deployed self-processing device nodes. Each node has limited computing capabilities, narrow wireless communication coverage and equipped with non-rechargeable battery-limited lifetime. On the other hand, sensor networks are required to be able to self-configure based on changing environmental conditions. A large number of sensor nodes (SN) are directly or indirectly connected to the cluster head (CH) node. These links are very sensitive to reflection, diffraction, scattering and thus faded wireless channel communication [1]. Wireless channel performance in the WSN is extremely degraded. Some techniques are developed to mitigate the adverse effects of faded links. One of the promising techniques is rate-transmission adaption. Changing of rate-transmission level is automatically adapted to channel conditions. Information that represents the channel properties of the communication link is well-known as channel state information (CSI). This information depicts how a signal travels from CH to SN and influenced by diffraction, reflection, scattering, fading, and power loss due to distance. This method is called channel estimation. The CSI creates to adapt rate-transmissions to current wireless channel conditions. It is important for achieving a robust and reliable wireless communication link. This CSI is estimated and quantized at CH, as a result of limited-rate feedback from SN. This limited-rate feedback is robust to delay channel, error channel and jamming. It is a quantized-channel state information at the transmitter (Q-CSIT). Antenna beamforming, adaptive transmission rate are based on Q-CSIT to maximize transfer rate through adaptive modulation coding (AMC) technique and increase the received-signal to noise ratio (SNR) in multiple input multiple output (MIMO) system. In addition, one of the most promising modulation technique in a MIMO system is spatial modulation (SM). Spatial modulation has a specific index of the transmit antenna (TA). MIMO system with m_t transmit antennas, there are $\log_2 m_t$ bits transferred by the indexed TA and the number of bits these are contained on M constellation modulation, producing a total rate-transmission of $(\log_2 m_t + \log_2 M)$ bits per channel link. The SM performance can be improved by involving the CSI at the transmitter. Minimizing error probability using channel-link adaptation has been discussed in paper [2]. Improvement of spectral efficiency by applying of an optimal-modulation order was investigated in [3]. Increasing the attainable coding and diversity of modulation scheme by exploiting the channel links phase information was discussed in [4],[5]. In [6], optimizing of the beamforming MIMO antenna under Q-CSIT system. Authors in [7] considered the joint estimation of phase shifting and amplitude scaling in power inefficient. Several modifications of SM-CSIT has been explored. In this paper, we analyze the performance of SM with limited rate feedback and quantized CSI. This system uses a multiple input single output (MISO) antenna, multiple SN which is equipped with a single antenna connect to single CH with a single antenna. Weighting is used to overcome a shift phase or fading at the wireless channel. We assume that the Q-CSIT is obtained through a limited rate feedback channel from SN to CH. The SN transmits $(m_t -1)$ B bits of information about the properties of channel link to the CH (transmitter).

In this work, we use Q-CSIT with SM-MISO system over Rayleigh fading channel. Furthermore, we also simulate the system performance which the Q-CSIT is available via a limited/finite rate feedback and consider the probability of error (P_e)/bit error rate (BER) as the metric. Performance analysis of the probability of error (P_e) due to limited/finite feedback bits. We organize this paper as follows, section I is an introduction, Section II explains the basic theory of SM-MISO with limited/finite rate feedback bits. The system model will be presented in section III. Section IV provides the numerical results and the last section we draw the conclusions.

II. QUANTIZED-CHANNEL STATE INFORMATION TRANSMITTER & SPATIAL MODULATION – MULTIPLE INPUT SINGLE OUTPUT

A. Spatial Modulation – Multiple Input Single Output

Recently, using several antennas at a single transmitter or receiver is a promising technique to increase the data rate and spectral efficiency capabilities. It is well-known as a MIMO system. Some works have used 64 or more antennas at a single transmitter/receiver. Using extra antennas give great improvements in both transmission-reception signal and throughput. In consequence, it needs a large number of radio frequency equipment chains that is a big challenge in the MIMO system [8]. Starting with this major drawback, researchers developed a new technique that uses SM. Spatial modulation was first introduced in [9]. SM uses an index of transmit antenna as additional source information to improve data rate and spectral efficiency. In SM, the information bits are grouped into two categories: a spatial modulation constellation to encode the index of transmit antenna and a signal constellation based on the digital modulation scheme. Unlike the conventional MIMO antenna system, the SM does not need multiple radio frequency equipment chains at the transmitter. There is a low complexity computational decode at the receiver. Firstly, the receiver decodes the index of the transmit antenna, and then the second decode is to estimate the transmitted symbol. The SD (spatial demodulation) uses these two decodes to recover the transmitted information bits. According to this formula ($\log_2 m_t + \log_2 M$) to determine the number of information bits, consider an example when we use 4 transmit antennas (it means that there is four SN inside the WSN system – $m_t = 4$), $\log_2 4 = 2$ bits. When M = 4 as a constellation of QAM digital modulation, based on a formula $\log_2 M$, we get $\log_2 M = \log_2 4 = 2$ bits, a spectral efficiency system is 4 bits/s/Hz (2 bits for an index of transmit antenna and 2 bits per symbol in QAM modulation).

B. Quantized-Channel State Information Transmitter

In general, there are three types of CSIT, the first is deterministic CSIT (D-CSIT), the second is perfect CSIT (P-CSIT), and the last is quantized CSIT (Q-CSIT). D-CSIT can be used in a wireless channel with slow fading condition. Several works use D-CSIT to minimize the power consumption at the SN (receiver). A perfect channel state information at the transmitter generates a great capacity system, dirty-paper coding reaches the whole capacity region of the MIMO antenna system, but both D-CSIT and P-CSIT may not be realistic due to feedback delay, channel estimation error, and jamming. However, perfect CSIT is difficult to obtain in the implementation system. This consideration, as stated earlier, encourages a finite/limited feedback system which only quantized channel state information is available at the CH via a few of bits of feedback from the SN.

III. SYSTEM MODEL

We consider a WSN configuration with m_t sensor nodes equipped a single antenna, these SN connect to the CH which is also equipped a single antenna. This configuration is depicted as a MISO system. In this work, we use SM – MISO system. The wireless channel link can be described by the vector $h = [h_1\ h_2\ \dots\ h_{m_t}]$ with $h_i \in \mathbb{C}$ which states the wireless channel signaling from the i^{th} transmit antenna SN to the CH (receiver). $r \in \mathcal{M}^{m_t}$ with $r = [0, \dots, 0, r_i^j, 0, \dots, 0]^T$ where r_i^j expresses the j^{th} symbol in the modulation constellation that transmitted from the i^{th} transmit antenna of SN. In CSIT, the data symbol r is multiplied by a weighting matrix Q = diag (q) to generate the channel input x = Q r. The channel output y can be formulated as $y = \sqrt{\beta}\, h\, x + z$ with z is the AWGN with zero mean and variance, β is the SNR of channel. For the detail of the system model is depicted in Fig. 1.

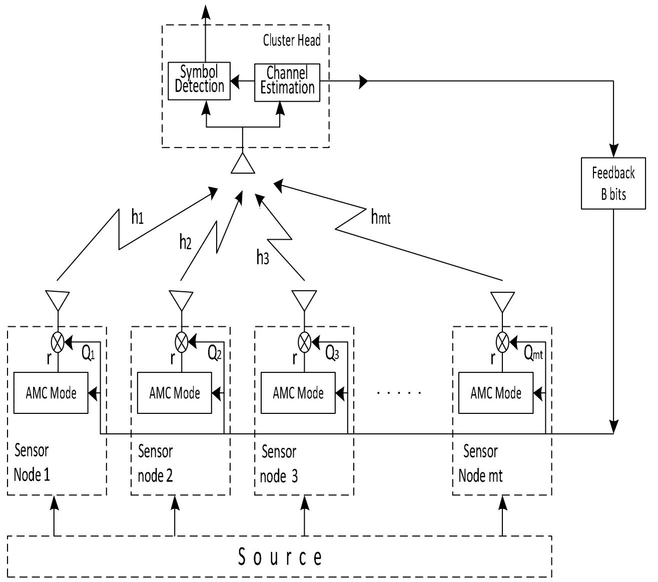

Fig. 1. A system model of multiple input single output in wireless sensor networks.

We suppose that each SN has a finite AMC mode index, $k \in \{1, 2, \dots, m_t\}$. Each mode has a constellation size M_k and transfer rate $T_k = \log_2(M_k)$. To overcome the effect of fading. Using AMC mode system, the m_t^{th} SN transmits the symbol r that multiplied by a weighting Q_k. With $Q = [Q_1\ Q_2\ \dots\ Q_{m_t}]^T$ expresses the weighting vector, and $h = [h_1\ h_2\ \dots\ h_{m_t}]^T$ is the MISO channel response. The received signal at the CH can be formulated as follows,

$$y = Q^T h\, x + z = \sqrt{P} u^T\, h\, x + z \qquad (1)$$

where $\sqrt{P} = \|Q\|$ and $u = Q/\|Q\|$. Changing of the weighting Q (phase and modulus) can have an impact on the power transmit allocation, and beamforming which greatly affects the transmission rate at each h condition. Define f is a B-bit of the Q-CSIT codeword which the CH transmits back to the SN. The SN automatically adapts their transmit power to one of 2^B AMC modes determining the transmission rate, and transmit power. In this work, we design the optimal channel quantizer / channel weighting that generates quantized-CSIT (B bits) for optimal transmission rate and transmit power, so the total power transmitted by all SN in WSN system is minimized parameter to BER and transmission rate. The CH will quantize a channel response h to find optimal B bits Q-CSIT. The B bits Q-CSIT consists of B_i bits for an index of transmit antenna and B_m bits for signal constellation based on digital modulation. Next, the SN will use B bits CSIT determining AMC modes to adapt optimal transmission rate, and minimized transmit power.

IV. RESULTS AND DISCUSSION

In this section, we show several numerical results. Using the weighting scheme for reducing the number of feedback bits. The weighting can be filled by phase compensation. In addition, we also use the M-PSK modulation signal constellation which has a $\frac{2\pi}{M}$ rotational phase. It is adequate to rotate the channel to the nearest modulo $\frac{2\pi}{M}$ phase compensation. It is sufficient to quantize a phase angle compensation in the range $\left[0,\frac{2\pi}{M}\right]$ which reduces the feedback rate for a specific quantization with $\log_2 M$ bits. According to the probability of error (P_{el}) or BER formula as stated in equation (2)-(3), we can derive the relation between P_{el} / BER and the number of feedback bits in equation (4). C is a constant which depends on the signal constellation and $N = 2^B$, then we get the formula as follows:

$$P_{el} = C\left[1-\left(\frac{N}{2\pi}\right)^2\left(2-2\cos\left(\frac{2\pi}{N}\right)\right)\right] \qquad (2)$$

$$C = \frac{1}{M\,n_t}\sum_{(l,i)}\sum_{(l'i')\neq(l,i)} C_{l_i,l'_{i'}} \qquad (3)$$

$$P_{el} = \frac{\pi^2 c}{3}\,\frac{1}{N^2} \qquad (4)$$

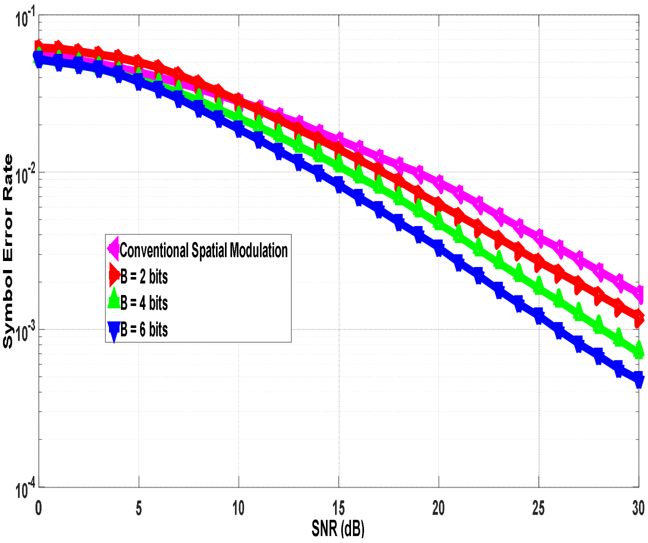

Fig. 2. Performance of symbol error rate versus SNR as a variation of the number of B bits.

This work simulates four SN and one CH using QPSK modulation. The wireless channel is modeled with Rayleigh fading. The weighting channel (Q) compensates the shifted-phase due to the channel decay. Fig. 2 shows the symbol error rate as a function of the SNR. There are fours graphs that explain the performance of the symbol error rate in Q-CSIT and conventional spatial modulation MISO system. We can see that the Q-CSIT with limited/finite feedback using six bits gives about 5 dB gaining over the conventional spatial modulation MISO at the specific 10^{-2} of symbol error rate. In general, the Q-CSIT using limited/finite feedback (2,4,6 bits) yields better performance than the conventional spatial modulation MISO. Theoretically, the upper bound of SM-MISO is limited by perfect channel state information-transmitter (P-CSIT).

Next, Fig.3 plots the probability of error versus the finite feedback B bits with specific SNR. Calculation of the probability of error can be shown in equation (4). The probability of error is getting better with increasing the number B bits of finite feedback on SM-MISO system. In addition, the increasing level of SNR also improves the probability of error. Higher SNR value indicates a good wireless channel condition. At specific 5 bits, the channel quality with SNR 3 dB creates 2.24 10^{-3} probability of error while SNR 8 dB generates 9.5 10^{-4} probability of error and the last, SNR 14 dB yields 1.54 10^{-4} probability of error.

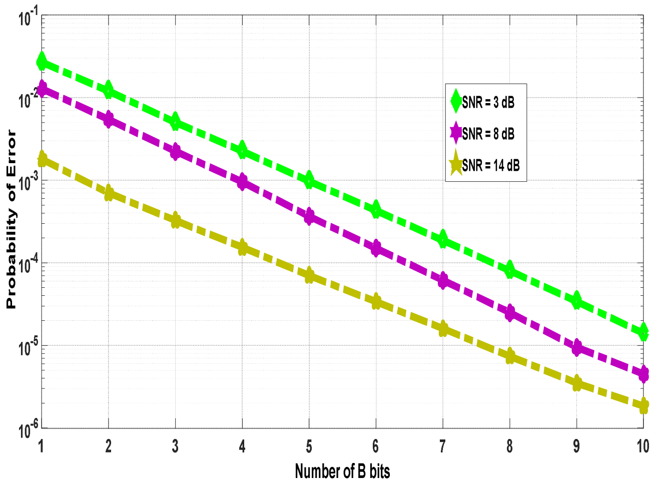

Fig. 3. Probability of error varies in SNR and the number of B bits.

Based on Fig. 4 below, we can see the performance of the probability of error versus SNR with a variation of the number of receive antenna at the receiver. Fig. 4 consists of four graphs, each graph illustrates a different number of the antenna at the receiver. The more number of receive antenna gives a better probability of error performance. At the specific BER 10^{-3}, four receive antennas need about 18 dB of SNR while one receive antenna requires about 24 dB of SNR. There is about 6 dB improvement. Furthermore, four antennas generate 2.4 10^{-4} probability of error whereas one antenna gives 4.8 10^{-3} probability of error, respectively.

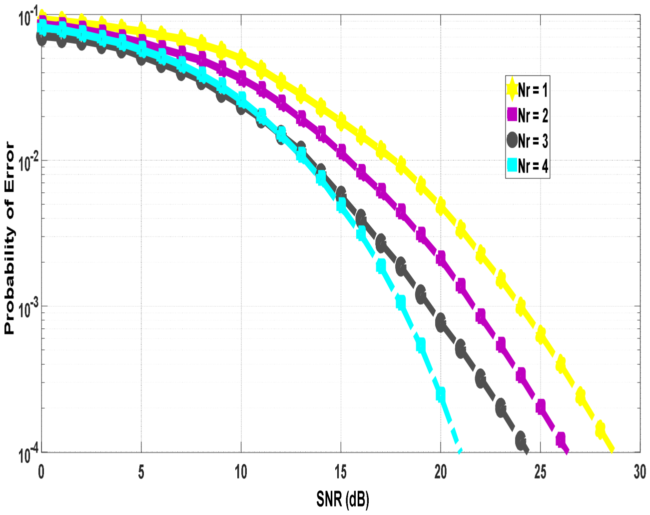

Fig. 4. Variation of the number of receive antenna in performance of the probability of error.

The last, Fig. 5 informs us of the effect of spatial correlation between the antenna index at the transmitter. It is denoted $\rho^{|ij|}$ with $\rho \in [0,1]$. The performance of the SM-

MISO system wiil decrease by increasing the spatial correlation ($\rho > 0$). The existence of a weighting system with phase compensation will help to improve the system performance. The robustness of the SM-MISO system increases significantly with the weighting.

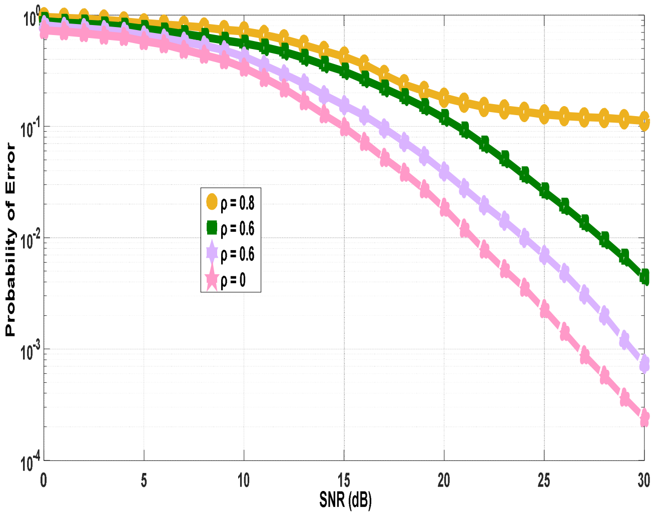

Fig. 5. Variation of spatial correlation affects the performance of the probability of error.

CONCLUSIONS

The existence of CSIT is very useful in estimating wireless channel conditions. However, the perfect-CSIT condition is very difficult to be realized. With a limited number of bits, Q-CSIT plays an important role in improving the performance of SM-MISO in the WSN system. The numerical results show that bigger the number of Q-CSIT bits produces better SER. In addition, the performance of Q-CSIT in SM MISO is also influenced by wireless channel conditions which are expressed as SNR values, the greater of SNR value indicates better wireless channel condition. Furthermore, smaller spatial correlation value has an impact on the improvement of the probability of error.

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