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Delay Efficiency Analysis of Turbo Coded Cooperative Communication in Wireless Sensor Networks

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ABSTRACT

Delay efficiency is one among the main issues in Wireless Sensor Network (WSN). In this paper, a Cooperative Multiple-Input-Single-Output (C-MISO) scheme based on turbo codes with Multi level-Quadrature Amplitude Modulation (M-QAM) is proposed, which overcomes the delay constraint in WSN. Also, delay analysis of turbo coded C-MISO scheme is compared with the traditional uncoded cooperative scheme and turbo coded Single-Input-Single-Output (SISO) scheme. The simulation results show that significant delay efficiency can be obtained through the proposed turbo coded cooperative communication.

INTRODUCTION

Wireless sensor networks (WSNs) are composed of a number of sensor nodes equipped with small batteries. So, there is a strict energy limitation and also the replacement of batteries for these devices is impossible or difficult. In order to overcome this limitation, the data transfer between the nodes in WSN should be carried out efficiently within less time and also the nodes should consume less energy. Multiple antenna systems enable communication at high data rate over multipath fading channels using Multiple-Input-Multiple-Output (MIMO) technology. However, it is impractical to apply MIMO technology to small WSN devices since small sensor nodes may only be able to have a single antenna. Therefore, through collaboration of several single-antenna-equipped devices, a multi-device virtual MIMO technique called cooperative MIMO (C-MIMO) has been proposed in (Li, X., 2003).

Using this approach, WSNs can configure several virtual topologies including Cooperative Single-Input-Multiple-Output (C-SIMO), Cooperative Multiple-Input- Single-Output (C-MISO) and C-MIMO which are collectively called C-MIMO technology (Ahmad Hasan Khan and K.C. Roy, 2013; Shuguang Cui, A.J. Goldsmith and Ahmad Bahai, 2004; Sudharman, K. Jayaweera, 2006) and (Shuguang Cui, A.J. Goldsmithand A. Bahai, 2006).

In addition to the C-MIMO technology, the concept of error correction using turbo codes is used in this paper to minimize the time delay of the WSN communication system. The advantage in using turbo codes for error correction is that, it reduces the bit error rate. Though, there are many coding schemes available only turbo codes and Low Density Parity Check (LDPC) codes are most successful (Ahmad Hasan Khan and K.C. Roy, 2013). LDPC coding technique outperforms turbo coding at high code rate. On the other hand turbo code is more efficient than LDPC at low code rate. The use of LDPC codes in cooperative communication as an error control code is proposed in (Mohammad Rakibul Islam and Y.S. Han, 2011). In this paper, turbo code is

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incorporated in cooperative communication as an error control code. The delay model for the proposed turbo coded C-MISO scheme is developed. Later, the proposed scheme is compared with turbo coded SISO communication to analyze the delay efficiency.

Multi-hop C-MISO Scheme:

A. ***System Model:***

In wireless sensor network, to apply C-MISO scheme the nodes need to be equipped with Space Time Block Codes (STBC) (Paulraj, A., R. Nabar and D. Gore, 2003; Proakis, J.G., 2000) and (Alamouti, S.M., 1998) encoding and decoding capability as well as basic relaying capability. Consider a homogeneous two hop C-MISO network. “Homogeneous” refers to a multi-hop configuration with the same configuration applied to all hops (Jong - Moon Chung, *et al*., 2012).

The considered network model shown in Figure 1 includes a total of 11 nodes- SN, DN, n1, n2, n3,n4, n5, n6, n7, n8 and n9. It is a two hop model, where the first hop is from the source node (SN) to node n5 and the second hop is from n5 to the destination node (DN). In the first hop, SN is the upstream node and n5 is the downstream node. Likewise, in the second hop n5 is the upstream node and DN is the downstream node. As the node n5 connects two hops it is referred as the inter-hop node. Here, C-MISO networking starts with SN sequentially distributing packets to its cooperating nodes n1 and n2 in level L1 (short-haul transmission at the transmitter end).

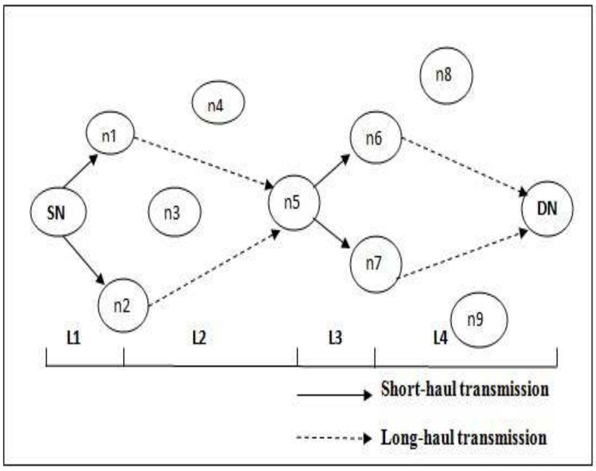

Fig. 1: Two hop C-MISO network model

In level L2, the nodes n1 and n2 encode the received packets and simultaneously transmit to node n5 (long-haul transmission at the transmitter end). Node n5 decodes the two space diversifying signals and in level L3 it repeats the actions of SN in level L1. Similarly, in level L4 the nodes n6 and n7 repeats the actions of nodes n1 and n2 in level L2 (long-haul transmission at the receiver side) and finally the packets reach the destination node (DN).

B. ***Delay Model:***

The total time delay (T) required for a system with M_t transmitting nodes and M_r receiving nodes each with one antenna can be calculated as the sum of transmission delay (T_{tr}), propagation delay (T_{pr}) and processing delay (T_{pc}) [13]. The total time delay is given by Equation (1) as,

$$T = T_{tr} + T_{pr} + T_{pc} \tag{1}$$

For an uncoded cooperative MISO system with $M_t=2$ nodes and M_r =1 node, the total time delay (T_{C-MISO}) can be calculated as the sum of transmission delay (T_{tr_MISO}), propagation delay (T_{pr_MISO}) and processing delay (T_{pc_MISO}), which is given by Equation (2) as,

$$T_{C-MISO} = T_{tr\_MISO} + T_{pr\_MISO} + T_{pc\_MISO} \tag{2}$$

The transmission delay of uncoded C-MISO system (T_{tr_MISO}) is given by Equation (3) as,

$$T_{tr\_MISO} = T_s\left(\frac{\sum_{i=1}^{M} N_i}{b_i^t} + \frac{\sum_{i=1}^{M} N_i}{b_m}\right) \quad (3)$$

where b_i^t represents the constellation size (bits per symbol) used during the local transmission on the transmitter side, b_m represents the constellation size used in the alamouti code, T_s is the symbol period which is assumed to be approximately equal to $T_s \approx \frac{1}{B}$ for a fixed transmission bandwidth B and N_i is the number of bits to be transmitted, where $i = 1,\ldots M_t$. The first term in Equation (3) is the local delay value contributed by the transmitter side, and the second term is the delay caused by the long-haul C-MISO transmission.

The propagation delay of uncoded C-MISO system (T_{pr_MISO}) is given by Equation (4) as,

$$T_{pr\_MISO} = \frac{d^L}{c} + \frac{d^l}{c} \quad (4)$$

where c is the velocity of light, d^L and d^l represents the long-haul transmission distance and local transmission distance at the transmitter side.

The processing delay of uncoded C-MISO system,

(T_{pc_MISO}) is given by Equation (5) as,

$$T_{pc\_MISO} = T_{mod} + T_{demod} \quad (5)$$

where T_{mod} is the time taken for modulation and T_{demod} is the time taken for demodulation.

Similarly, for the turbo coded C-MISO ($T_{turbo\_C\text{-}MISO}$) system with $M_t=2$ nodes and $M_r=1$ node, the total time delay can be calculated as the sum of transmission delay ($T_{turbo\_tr\_MISO}$), propagation delay ($T_{turbo\_pr\_MISO}$) and processing delay ($T_{turbo\_pc\_MISO}$), which is given by Equation (6) as,

$$T_{turbo\_C-MISO} = T_{turbo\_tr\_MISO} + T_{turbo\_pr\_MISO} + T_{turbo\_pc\_MISO} \quad (6)$$

The transmission delay of the turbo coded C-MISO system ($T_{turbo\_tr\_MISO}$) with the turbo code rate r_t and $M_t=2$ nodes, $M_r=1$ node is given by Equation (7) as,

$$T_{turbo\_tr\_MISO} = T_s\left(\frac{\sum_{i=1}^{M_t} N_i}{r_t b_i^t} + \frac{\sum_{i=1}^{M_t} N_i}{r_t b_m}\right) \quad (7)$$

The propagation delay of the turbo coded C-MISO system ($T_{turbo\_pr\_MISO}$) with $M_t=2$ nodes and $M_r=1$ node is given by Equation (8) as,

$$T_{turbo\_pr\_MISO} = \frac{d^L}{c} + \frac{d^l}{c} \quad (8)$$

The processing delay of the turbo coded C-MISO system ($T_{turbo\_pc\_MISO}$) with $M_t=2$ nodes and $M_r=1$ node is given by Equation (9) as,

$$T_{turbo\_pc\_MISO} = T_{mod} + T_{demod} + T_{encode} + T_{decode} \quad (9)$$

where T_{encode} and T_{decode} is the time taken for turbo encoding and decoding respectively.

SISO can be treated as a special case of C-MISO with $M_t = M_r = 1$. A SISO differs from C-MISO as it does not have local transmission on the transmitter side, it only has long-haul transmission between the source and destination node. Thus, the total time delay of uncoded SISO system (T_{SISO}) can be calculated as the sum of transmission delay (T_{tr_SISO}), propagation delay (T_{pr_SISO}) and processing delay (T_{pc_SISO}), which is given by Equation (10) as,

$$T_{SISO} = T_{tr\_SISO} + T_{pr\_SISO} + T_{pc\_SISO} \quad (10)$$

The transmission time of the uncoded SISO system (T_{tr_SISO}) is defined by Equation (11) as,

$$T_{tr\_SISO} = T_s\left(\frac{N_i}{b_n}\right) \quad (11)$$

where N_i is the number of bits to be transmitted and b_n is the constellation size used in the SISO long-haul transmission. The propagation time of the uncoded SISO system (T_{pr_SISO}) with long-haul transmission distance d is given by Equation (12) as,

$$T_{pr\_SISO} = \frac{d}{c} \tag{12}$$

The processing time of the uncoded SISO system (T_{pc_SISO}) is given by Equation (13) as,

$$T_{pc\_SISO} = T_{mod} + T_{demod} \tag{13}$$

Similarly, for the turbo coded SISO system the total time delay (T_{turbo_SISO}) can be calculated as the sum of transmission delay ($T_{turbo\_tr\_SISO}$), propagation delay ($T_{turbo\_pr\_SISO}$) and processing delay ($T_{turbo\_pc\_SISO}$), which is given by Equation (14) as,

$$T_{turbo\_SISO} = T_{turbo\_tr\_SISO} + T_{turbo\_pr\_SISO} + T_{turbo\_pc\_SISO} \tag{14}$$

The transmission delay of the turbo coded SISO system ($T_{turbo\_tr\_SISO}$) with turbo code rate, r_t is given by Equation (15) as,

$$T_{turbo\_tr\_SISO} = T_s\left(\frac{N_i}{b_n r_t}\right) \tag{15}$$

The propagation time of the turbo coded SISO system ($T_{turbo\_pr\_SISO}$) with long-haul transmission distance d is given by Equation (16) as,

$$T_{turbo\_pr\_SISO} = \frac{d}{c} \tag{16}$$

The processing time of the turbo coded SISO system ($T_{turbo\_pc\_SISO}$) is given by Equation (17) as,

$$T_{turbo\_pc\_SISO} = T_{mod} + T_{demod} + T_{encode} + T_{decode} \tag{17}$$

The delay difference (*DD)* is a measure of the performance of the system. Delay difference is calculated by the equation (18) as,

$$DD = T_{turbo\_SISO} - T_{turbo\_MISO} \tag{18}$$

Positive value of delay difference from Equation (18) depicts that the proposed turbo code based C-MISO networking is delay efficient in WSN.

Performance Analysis:

The performance analysis of the delay efficient cooperative communication in WSN using turbo codes is carried out using MATLAB. The performance of turbo coded and uncoded C-MISO systems are compared and the system with significant delay efficiency is analyzed. Table 1 summarizes the simulation parameters used in the analysis. The optimized constellation size for M-QAM modulation is listed in Table 2 (Shuguang Cui, *et al*., 2005).

Table 1: Simulation parameters

PARAMETER	VALUE
Modulation	M-QAM
Fading channel	Rayleigh
Noise	AWGN
Number of transmit antenna	2
Number of receive antenna	1
Bandwidth	10 KHz
Target Bit Error Rate (BER)	10^{-3}
Number of bits to transmit	20 Kbits

Table 2: Optimized constellation size for M-QAM modulation

Distance (m)	1	5	10	20	40	70	100	150	200
MISO	14	10	8	6	5	4	3	2	1
SISO	12	6	5	4	4	2	2	1	1

Figure 2 shows the BER performance of uncoded and turbo coded system for Binary Phase Shift Keying (BPSK) and QAM modulations. From the Fig. 2, it can be observed that for a target BER of 10^{-3}, the SNR required for the uncoded system is higher than the turbo coded system. Therefore, it is clear that turbo coding reduces the required signal power and thus it is energy efficient. On considering the modulation technique, turbo code with BPSK requires less SNR when compared to turbo code with QAM modulation. But, on analyzing with respect to delay efficiency, the number of symbols to be transmitted is 20,000 in BPSK; on the other hand, it is only 10,000 symbols for QAM modulation (4-QAM). Thus, it can be concluded that turbo code with BPSK modulation is efficient in terms of energy and not delay. On the other hand, QAM modulation achieves significant energy saving when compared to the uncoded system and is also delay efficient. Therefore, QAM modulation technique is used for further analysis.

Figure 3 shows the delay performance comparison between the turbo coded C-MISO and SISO systems. The total time delay of the turbo coded C-MISO system with optimal constellation size for various distances is computed. Similarly, the total time delay of the turbo coded SISO with optimal constellation size for various distances is computed. With the computed delay values, the Delay Difference (DD) is calculated and plotted with respect to distance. From the Fig. 3, it can be observed that the delay difference is negative for distance less than 50 m. The delay difference becomes positive after a distance of about 50 m. The positive values of delay difference indicate that the turbo coded C-MISO system is delay efficient when compared to the turbo coded SISO system.

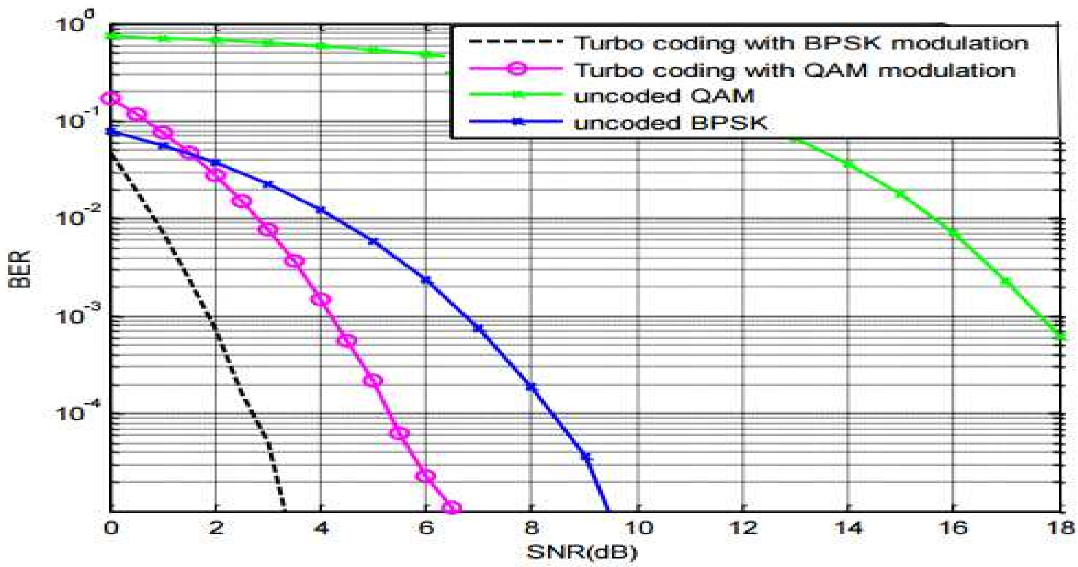

Fig. 2: BER Performance comparison of uncoded system with turbo coded system for various modulation techniques

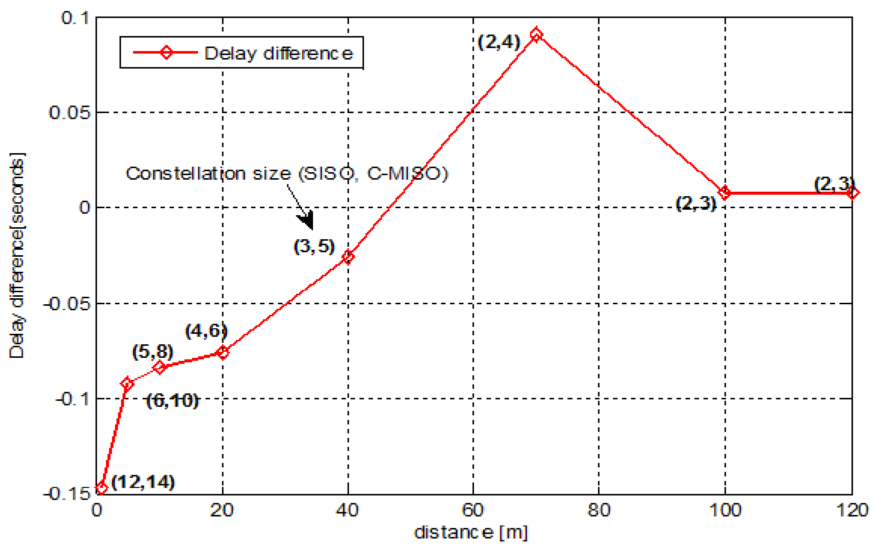

Fig. 3: Delay difference analysis of turbo coded SISO and C-MISO system

Conclusion:

Delay efficient data transmission is one of the key factors for delay constraint wireless sensor network. In this paper, a delay model for cooperative communication with M-QAM modulation using turbo codes is proposed. Simulation results show that turbo coded C-MISO communication system achieves significant delay efficiency when compared to turbo coded SISO system. Thus, it can be concluded that turbo coded cooperative MISO system is delay efficient.

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