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Abstract

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Keywords

BER, delay, characteristics, analysis, IEEE, 802, wireless, sensor, networks, cooperative, MIMO

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BER-Delay Characteristics Analysis of IEEE 802.15.4 Wireless Sensor Networks with Cooperative MIMO

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Abstract - This paper presents a study of the impact of transmission delay differences between co-operating nodes on bit error rate performance and energy consumption of wireless sensor networks. We consider a wireless sensor network using an Alamouti virtual MIMO (multiple-input multiple-output) configuration between collaborating nodes operating in quasi-static Rayleigh flat-fading channels. Our results show that above certain delay difference (in the range above 0.75Tb), the traditional non-cooperative approach is more energy-efficient than the cooperative strategy and that the transmission delay difference has the most significant on the transmission energy consumption in the delay range of below 0.75Tb.

Keywords: Wireless Sensor Networks, Transmission Delay Difference, BER-Delay Characteristics, Cooperative MIMO

1. Introduction

Wireless sensor networks (WSNs) have emerged as one of the dominant technology trends of this decade [1]. MIT Enterprise Technology Review [2] suggested that wireless sensor networks would be one out of the ten emerging technologies that will change the world and affect the way we live and work. One of the most important considerations in wireless sensor networks design and operation is to minimise the energy consumption and to prolong the network lifetime while satisfying the given throughput and end-to-end delay requirements. The throughput and end-to-end delay requirements are application dependant. There are three types of applications or queries; one-time (time-critical), persistent (medium-critical) and historical (non-time-critical). It is important to make sure that energy consumption is minimised while satisfying the throughput and end-to-end delay requirements for all the types of queries.

The nature of deployment of wireless sensor networks as distributed and scattered nodes in a close proximity and in high density has created many problems to the minimisation of energy consumption. The problems are even more challenging when we consider node mobility. There are three major contributors of energy consumption in wireless sensor networks; energy consumption due to packet transmissions, energy consumption due to packet retransmissions (WSNs may experience 20% to 30% frame loss rates [3]) and circuit energy consumption (DSP, MAC, memory and processor). In this paper our aim is to explore how collaborative MIMOs impact on energy consumption in wireless sensor networks. Alamouti Space-Time Codes (STCs) [8] are used to encode the data packets in order to perform virtual or cooperative MIMO schemes. The two encoded signals are transmitted from the chosen two collaborating nodes V_n. The encoding is done in space and time and the sequence of the data packet transmissions are given in Table 1 [8]. In particular, we explore the impact of the difference in transmission delay between collaborating nodes on both bit error rate (BER) performance and energy consumption of wireless sensor networks.

The remainder of this paper is organised as follows. In Section 2 we review related research reported in the literature that addresses energy consumption issues with cross layer interactions in wireless sensor networks. In Section 3, we formally describe the problem we are considering and in Section 4 we present our model. In Section 5, we present simulation results exploring the impact of transmission delay differences between collaborating nodes on BER performance and energy consumption. Finally in Section 6 we conclude our paper and propose future work in this area.

2. Related Works

Currently, one of the active research areas in WSNs with an objective to reduce energy consumption is a method of cross layer design (CLD) that considers cross interactions between layers in communication

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protocols. For the purpose of our research work, we narrow down the scope of CLD and focus only on the interactions between Medium Access Control (MAC) and Physical (PHY) layers. The CLD approach changes the concept of interaction between MAC and PHY and significantly impacts on how communication protocols work at both layers. Channel State Information (CSI) is an important parameter impacting overall network performance.

Table 1: The STC Encoding and Transmission Sequence In Wireless Sensor Network Scenario.

	Node 1	Node 2
STS 1 (t)	$s_0(0), \dots, s_0(M-1)$	$s_1(0), \dots, s_1(M-1)$
STS 2 (t+T)	$-s_1^*(0), \dots\dots,$ $-s_1^*(M-1)$	$s_0^*(0), \dots\dots,$ $s_0^*(M-1)$

CSI has been used in different ways in prior literature. However there is no comprehensive study of the impact and correlation of CSI to the higher layers especially to MAC in WSNs. Authors in [4–5] propose a method of transmission power control by each sensor node. The information of channel gain is used to control the transmission power. As long as the channel gain is above a given threshold, a sensor node continues to transmit data. Although the works in [4–5] increased the link quality, the nodes suffered higher energy consumptions due to higher transmission power usage. A method that can reduce the transmission power and increase/maintain the link quality even though the channel gain is below the threshold would be very useful to minimise energy consumption. Authors in [6] propose a method to control back-off intervals based on information from the Link Quality Indicator (LQI) parameter such as BER. When the estimated link BER gets higher, the back-off interval gets longer. Thus nodes with the lowest estimated link BER will be selected to perform data transmission with the shortest back-off interval. However the work in [6] considers the factor of BER influenced only by channel conditions such as propagation delay, attenuation and fading. In this paper we consider the factor of BER influenced not only by channel conditions but also by transmission delay differences in collaborating nodes due to different processing and scheduling times at the MAC layer. Significantly higher delays and BER increase the energy consumption of sensor nodes.

The latest trend to combat the problem of channel impairments in wireless sensor networks is by using virtual or cooperative MIMO schemes. Authors in [7-8] discuss the impact of MIMO schemes on wireless sensor network performance particularly in terms of energy consumption. Both research works show the advantages of MIMOs to reduce energy consumption by reducing the transmission power and link error rates. However the work in [9] assumes that the channels for local transmission between sensor nodes are AWGN which does not reflect the real implementation of sensor nodes in a dense and close proximity network. In this paper, we consider quasi-static Rayleigh flat-fading channels for local transmission between nodes and study the transmission delay effects in such channel conditions. The resultant transmission delay characteristics can be used to identify the required SNR for a given BER requirement. Thus the energy per bit for data transmission in a wireless sensor network can be computed in order to calculate the total energy consumption in the network. Furthermore, these results can be used to set the requirements for MAC schedulers in order to minimise the impact of the difference in transmission delay between collaborating nodes on the total energy consumption in wireless sensor networks.

3. Problem Description

In this paper, we consider the wireless sensor network scenario as illustrated in Fig. 1, where a sensor node U, needs to transmit data packets to a remote receiver, R through a multi-hop wireless network. In the intermediate hop, a data packet from the sensor is received by multiple nodes V_1 to V_N and all the nodes, V_n are within the transmission range of node U. Traditionally, one of these nodes would be chosen to forward the data packet to R. However due to channel impairment problems, several intermediate nodes may need to retransmit the data packet. In our work, we exploit the advantages of transmit diversity [9] where 2 of the N nodes are chosen to perform simultaneous transmissions with STC encoding. Thus MIMO scenario reduces to a MISO (multiple-input single-output) scenario with two inputs. In this scenario we study the transmission delay effects of transmit diversity on the wireless sensor network performance in terms of BER performance and energy consumption.

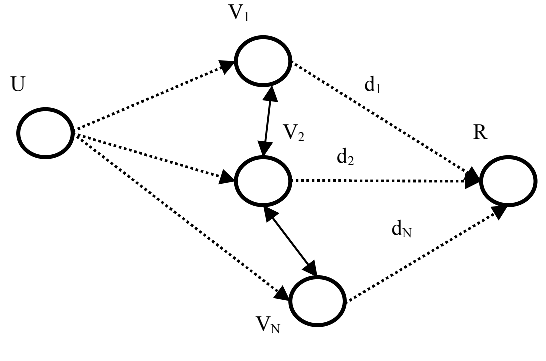

Figure 1: Multi hop wireless sensor network scenario.

The main objective of this paper is to study the transmission delay effects on BER performance and energy consumption of wireless sensor nodes with a cooperative MIMO strategy in quasi-static Rayleigh flat-fading channels. We make the following assumptions for the network settings:

a) The position of each sensor node is known and fixed (stationary) and all sensors have the same sensing range.
b) All the nodes V_n receive the same data packets at the same time from node U.
c) There is no synchronisation between nodes in order to perform the virtual MIMO operation. Hence at the receiver the data from the collaborating nodes may not arrive at the same time.

4. Problem Modelling

To model the above-described problem, we define the MIMO strategy used by nodes V_n to transmit the data packets and the channel models. We assume the following:

a) The same two data packets received by nodes V_n from node U, P_0: {$s_0(0)$, ……. , $s_0(M-1)$} and P_1: {$s_1(0)$, ……. , $s_1(M-1)$} where symbols $s_i(k)$, i = 0,1 and k = 1,..,M, are BPSK symbols with equal probability.
b) Alamouti Space-Time Code (STC) [8] is used to encode the data packets. The encoded data symbols are represented as a random matrix with the rows of the matrix defining the spatial dimension and the columns of the matrix defining the temporal dimension in our simulation.
c) The channels from nodes V_n to receiver, R are quasi-static Rayleigh flat-fading with complex coefficients α_n. Assuming that fading is constant (flat) across two consecutive symbols, we can write:

$$h_n(t) = h_n(t+T) = h_n = \alpha_n \exp(j\theta_n) \qquad (1)$$

d) Noise is modeled as a complex random vector with a circularly symmetric complex Gaussian variable with zero mean and variance σ^2 in our simulation.
e) The received symbols are combined according to the combining scheme as suggested by Alamouti [8] and then sent to the maximum likelihood detector. The combined symbols are given as:

$$\hat{s} \sim N_C\left(s, \frac{\sigma^2 I}{\|h\|^2} \right) \qquad (2)$$

Where s is the transmitted symbols, $\|h\|^2$ is the Euclidean norm of the channels coefficients.

The decision rule for maximum likelihood detection (MLD) for PSK signal is given as:

$$\hat{s} = \underset{s \in S}{\arg\min} \|h\|^2 \cdot \|s - \hat{s}\|^2 \qquad (3)$$

f) We consider the delay difference impact on the bit error probability of Alamouti transmit diversity scheme. The delay is bounded by the bit period; T_b. Consider the bit period, T_b is 4 μs for BPSK modulation in 802.15.4 system [3]. We can model the delay as:

$$\Delta T_b = T_b - \left(\frac{E_b' T_b}{E_b} \right) \qquad 0 \le \Delta T_b \le T_b \qquad (4)$$

and also,

$$E_b' = E_b \left(\frac{T_b - \Delta T_b}{T_b} \right) \qquad (5)$$

Where ΔT_b is the delay difference, E_b' is the new received energy per bit which is degrading function of the energy per bit with no delay, E_b. The average SNR per channel as a function of delay, τ is given by:

$$\bar{\gamma}_c = \frac{\bar{\gamma}_b}{L} = \frac{\tau E_b E(\alpha_n)}{L N_o} = \left(\frac{T_b - \Delta T_b}{T_b} \right) \left(\frac{E_b E(\alpha_n)}{L N_o} \right) \qquad (6)$$

Where $\bar{\gamma}_b$ is the average SNR per bit, L is the diversity order, and N_o is the power spectral density.

5. Simulation Results

We implemented our model in a simulation environment to measure BER performance as a function of transmission delay difference between the two collaborating nodes. We investigated several scenarios from our simulations:

a) BER performance of the MISO strategy as a function of SNR
b) BER-Delay Difference performance of the MISO strategy as a function of SNR

5.1. BER performance of MISO strategy as a function of SNR

We simulated our model with the transmission delay difference varied from 0 to Tb to observe the impact of transmission delay difference on BER performance. As shown in Fig. 2, BER increases significantly as the delay difference increases. To achieve BER of 1% with the delay difference between the co-operating nodes of 3 µs, 6 dB more SNR is required compared to the scenario with no delay difference between the co-operating nodes. Thus the scenario with the 3 µs delay difference consumes about 4 times more transmit energy. In addition, as can be seen from Fig. 2, that in order to achieve the same BER criteria, the SISO scheme consumes about 4.1 times more transmit energy than the MISO scheme with the 3 µs transmission delay difference. Thus the uses of co-operative nodes results in lower transmit energy than in the SISO case with the upper bound of delay difference is defined at 3 µs. However obviously when the delay difference is above the determined upper bound, SISO strategy is better than the MISO.

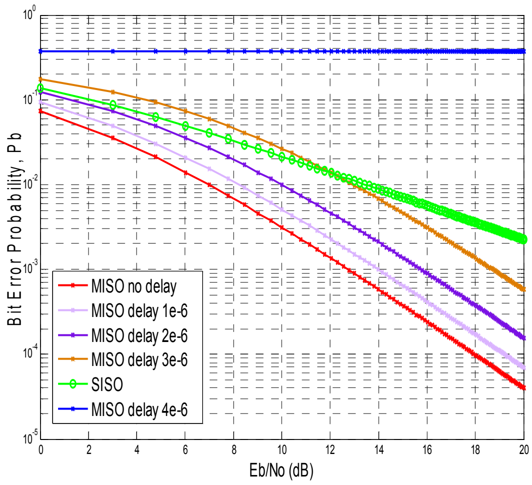

Figure 2: BER performance comparisons as a function of SNR and transmission delay difference in quasi-static flat-fading channels.

From the above results we obtained a relationship between BER and transmission delay differences.

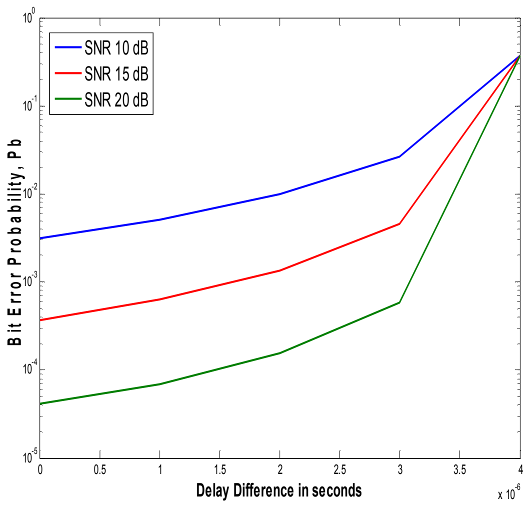

Figure 3: BER versus transmission delay difference for a given SNR.

5.2. BER-Delay Difference Performance as a function of SNR

As shown in Fig. 3 in the wireless sensor networks with cooperative transmission, there is a new constraint we need to take into consideration in the network design which is the delay difference. In order to reduce the transmission energy effectively, the lower SNR must be used and at the same time satisfy given BER and delay difference constraints. Therefore by sharing transmission delay differences knowledge between nodes in a wireless sensor network is essential to reduce the total energy usage.

6. Conclusion

In this paper we studied the impact of transmission delay differences between collaborating MIMO nodes on BER performance of wireless sensor networks. We showed that transmission delay differences between two co-operating nodes using the Alamouti scheme have a significant impact on BER performance as the SNR increases. We also showed that in certain range above 0.75Tb, the traditional non-cooperative approach is more energy-efficient than the cooperative strategy. However, the transmission delay difference has a significant impact below the range of 0.75Tb with SNR constraint. In addition, the knowledge of delay difference is essential in MAC scheduling design for cooperative nodes in wireless sensor networks.

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