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Design and Analysis of Energy Efficient Wireless Sensor Networks Using Data Aggregation Techniques

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Abstract

Energy optimization is a crucial issue in designing wireless sensor networks (WSNs) where nodes are powered by batteries .In this paper data aggregation technique is the most efficient technique to reduce the energy consumption in wireless sensor networks. Cooperative multi-input-multi-output (MIMO) and data aggregation techniques are jointly adopted to improve energy efficiency of the point-to-point communication system. We compare the total energy consumption at critical distances at which cooperative MIMO outperforms the SISO system for different redundant data for both local and long-haul distance is analyzed. Simulations provide better results of energy saving achieved by data aggregation techniques. It is shown that data aggregation into cooperative MIMO techniques optimizes the total energy consumption.

Keywords: Alamouti diversity schemes,Cooperative multi-input-multi-output, Data Aggregation, Energy efficiency, Wireless sensor networks.

1. Introduction

Wireless sensor network extends our capability to explore, monitor and control the physical world. Wireless sensor networks consist of sensor nodes with sensing and communication capabilities. As sensor nodes are battery driven, energy efficiency is one of the most critical factors to extend the lifetime of the wireless sensor networks

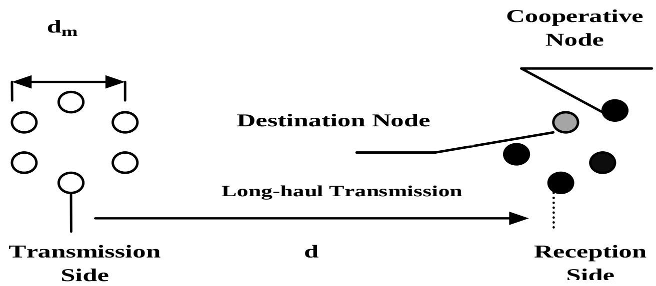
.Recently, a multiple antenna communication has been proposed to offer enhanced energy savings in WSNs depending on channel conditions and transmission distance. Long range wireless communications in WSNs are affected by factor like fading of channel, interference and radio irregularity. To mitigate the effect of fading in wireless channel, multiple-input-multiple-output (MIMO) scheme is utilized for wireless sensor network [1], [2].Cooperative MIMO is a kind of MIMO technique where multiple inputs and outputs are formed via cooperation in a wireless sensor networks. Under the same bit-error-rate and throughput requirements, the diversity using multiple-input-multiple-output (MIMO) technique in a wireless network that required less transmit power than single-input-single-output (SISO) [3]. Data aggregation has been considered an essential tool for integrating such data to reduce redundancy and to reduce energy consumption by minimizing number of transmission [4]. The energy efficiency of cooperative transmission under space-time block code (STBC) is analyzed in [5].Variable rate M-ray quadrature amplitude modulation (M-QAM) scheme is used for both long-haul communication and local communication to increase the transmission rate and reduce the circuit energy consumption. In a sensor node, energy is consumed by the power supply, the sensor, the computation unit and the radio unit. Transmission energy efficiency is especially important because wireless transceivers usually consume a major portion of battery energy. Sensor node lifetime, therefore, shows strong dependence on battery life. An energy efficient communication technique is required so that energy consumption must be minimized while satisfying given throughput and delay requirements. Following energy-efficient communication techniques for maximizing lifetime and for delay reduction of wireless sensor networks are discussed in this paper.

The remainder of this paper is organized as follows. In Section 2, the energy model for cooperative MIMO with data aggregation is explained. Section 3, summarizes our conclusion.

2. Data Aggregation with cooperative communication

To prolong network lifetime is the main concern in wireless sensor networks. Since sensor networks are mainly designed to cooperate on some joint task where per node fairness is not emphasized, the design intention is to minimize the total energy consumption of individual nodes [6]. In this section, we propose a strategy to minimize the total energy consumption of multiple nodes from network perspective.

In a typical sensor network, information collected by multiple local sensors need to be transmitted to remote central processor. If the remote processor is far away, the information will be first transmitted to relay node, then multihop based routing will be used to forward the data to the final destination. Within local sensors, if the maximum separation is d_m meter and for long-haul communication distance is d meter, as shown in Fig.1.



However, in order to allow cooperative transmission possible local data exchange is necessary before long-haul transmission .Since the communication based on cooperative MIMO with data aggregation can be divided into two steps: 1) local communication and 2) long-haul communication. During local communication, sensor nodes intra cluster (local sensors) exchange their data with each other or through a central node for the preparation of cooperative transmission in the next step, and the same time ,data are compressed during the exchange using appropriate aggregation schemes and then are distributed to individual nodes. During long-haul communication, individual nodes at the same time transmit the compressed data over the wireless media to active sensor by using Alamouti's space-time block coding schemes.

For cooperative MIMO approach. In this context, we assume there are N sensor nodes and each of which has N_i bits to transmit, where i = 1, 2… N. Within local sensors, if the maximum separation is d_m meter and for long-haul communication distance is d meter, as shown in Fig.3, energy consumption for Cooperative MIMO can be divided into four steps. In the first step, collected data transmitted to the cluster head for data aggregation. At the second step, cluster head transmits the collected data to M_t-1 nodes. After each node receives all the information bits, these M_t nodes encode the transmission sequence according to the Alamouti diversity codes [3]. In third step, since each node has a preassigned index i, they will transmit the sequence which the ith antenna should transmit in an Alamouti MIMO system. On the receiving side, there are M_r nodes joining the cooperative reception. Finally in the fourth step, the (M_r-1) assisting nodes first quantize each symbol they receive into n_r bits then transmit all the bits using uncoded MQAM to the destination node for the joint detection.

The total energy consumption for the cooperative MIMO approach can be calculated as

$$E_{DF+MIMO} = \sum_{i=1}^{N-1} N_i\, E_i^t + E_{bf} \sum_{i=1}^{N} N_i + \sum_{j=1}^{M_t-1} E_j^{t0} \sum_{i=1}^{N} N_i\, \gamma_i + E_b^r \sum_{i=1}^{N} N_i\, \gamma_i + \sum_{h=1}^{M_r-1} E_h^r\, n_r N_s \tag{1}$$

Where the energy cost per bit for local transmission on the TX side, denoted as E_i^t , i = 1,2,……, N-1.For local transmission the energy cost per bit for cooperative communication, denoted as E_j^{t0}, j=1,2,3….M_t-1 and the energy cost per bit for local transmission on the Rx side, denoted as E_h^r , h = 1, 2,……,M_r -1 for joint detection and. $N_s=\sum_{i=1}^{N} N_i \gamma_i / b_m$ is the total number of symbol received at the receiver by each node with constellation size b_m as used in space-time code. Note that E_i^t , E_j^{t0} and E_h^r can be calculated according to the results for SISO Communication link as a special case of MIMO links where $M_t=M_r=1$. And the energy cost per bit for MIMO long haul transmission, can be denoted as E_b^r. For non cooperative approach, each transmitting node uses a different time slot to transmit the collected data to the remote node with uncoded MQAM without any cooperation. So the total energy consumption for the non-cooperative approach is

$$E_{DF+SISO} = \sum_{i=1}^{N-1} N_i E_i^t + E_{bf} \sum_{i=1}^{N} N_i + E_0 \sum_{i=1}^{N} N_i \gamma_i \qquad (2)$$

3. Alamouti Scehmes Based Data Aggregation Into Cooperative MIMO

Two different communication schemes with data aggregation are illustrated in Fig.1 to estimate the energy consumption of cooperative communication. In the transmission process, N1 node will firstly transmit its data to the N_2 node to do data aggregation to eliminate redundancy. Both nodes should have aggregated data to do cooperative communication. Although N_1 does not have the data of N_2.N_1 receives have same aggregated data from N_2. The value of the critical distance is crucial in determining whether to use cooperative MIMO or SISO system. Where the critical distance is d for justifying the use of MIMO schemes is higher where the value of local transmission distance is d_m is small.

3.1 Scheme A

In Scheme A, after data aggregation N_2 needs not to transmit it all data to N_1 where N_2 knows which datum is redundant and does not transmit the overlapped data to save energy. Total energy consumption of this scheme with gama = 80%,70% and 60% .The data of the two nodes are insignificant with gama = 80% at critical distance shown in Fig.2.However,critical distance increases as gama decreases from 80% to 60%. The total energy consumption is given by

$$E_A = N_1 E_1^t + E_{bf} \sum_{i=1}^{2} N_i + E_2^{t0}\big(N_2 - (1-\gamma)(N_1 + N_2)\big) + E_b^r \sum_{i=1}^{2} N_i \gamma \quad (3)$$

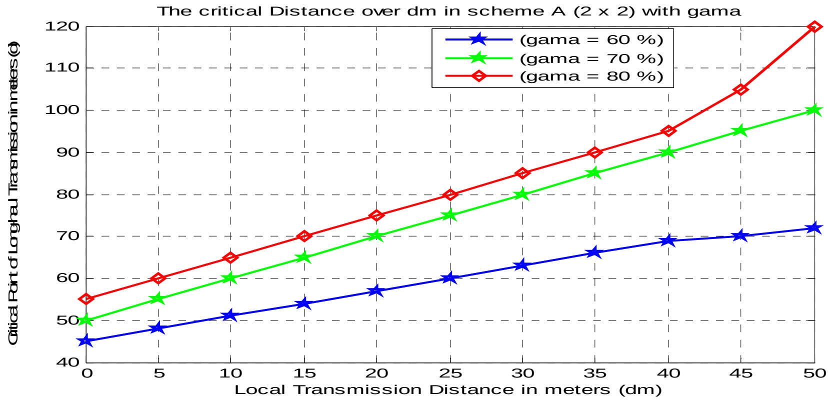


Figure 2: Critical distance over dm in scheme A (2×2) with gama.

3.2 Scheme B

In scheme B, N2 will transmit all its data to N_1 to meet critical delay requirements where data aggregation algorithm is complex and time consuming in a real-time system. The total energy consumption of this scheme with gama = 80%, 70% and 60% .The data of the two nodes are insignificant with gama = 80% at critical distance shown in Fig 3. However, in scheme B, critical distance increases as gama decreases from 80% to 60%.The total energy consumption is given by

$$E_B = N_1 E_1^t + E_{bf} \sum_{i=1}^{2} N_i + E_2^{t0} N_2 + E_b^r \sum_{i=1}^{2} N_i \gamma \qquad (4)$$

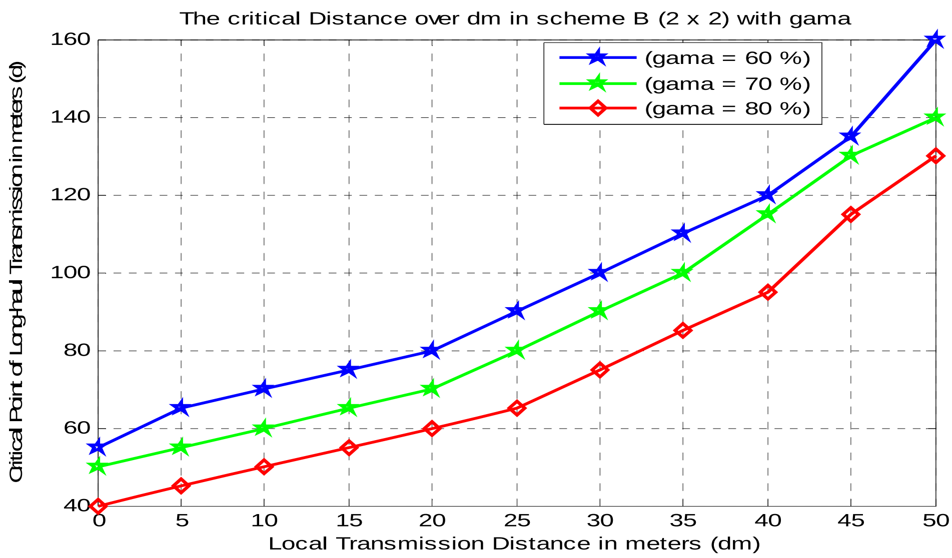


Figure 3: Critical distance over dm in scheme B (2×2) with gama.

4. Conclusion

In this paper energy model of data aggregation into cooperative MIMO schemes exploits energy saving in WSNs has been investigated. The proposed strategy has demonstrated its performance excellence in terms of energy efficiency. Simulation results show that comparisons of the critical distances with respect to local distance d_m at which cooperative MIMO system outperforms the SISO system for different redundant data.

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