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Energy Efficient Decentralized Cluster Based Protocol Using Cooperative MIMO

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Abstract

Recent development in microelectronics and signal processing enable more efficient use of wireless sensor network. The different challenges of a wireless channel are bit error rate, signal attenuation and fading that occur in a wireless channel due to its unpredictable nature. Apart from this, using sensors for data transmission lots of energy is being consumed due to various mentioned constrained of wireless channel. Thus lots of researches have been done at various layer of communication to reduce the energy consumption of a sensor during the communicating the sense data. In this paper a scheme has been proposed to implement virtual MIMO system in a decentralized weighted cluster based protocol and the impact of various cooperative communication strategies and coding schemes on energy consumption is also analysed .The results shows that cooperative communication techniques provides a significant amount of energy savings to the conventional clustering protocols.

1. Introduction

Wireless sensor networks (WSNs) have gained world-wide consideration in recent years, particularly with the proliferation in Micro-Electro-Mechanical systems (MEMS) technology which has facilitated the development of intelligent sensors. These sensors are small, with limited processing and computing resources. The sensor nodes sense information, process

the sensed data and transmit the processed data to the BS over a wireless channel.. The sensor nodes are operated by battery which has the limited energy. Recent development in wireless sensor network have increased the requirement of high data rate and increased quality of service but it is difficult to full fill these requirements in resource constrained network such as WSN [1] and due to the constraints of the wireless communication. Various researches have been done to enhance the life time of WSN. Clustering is the method which is adopted in the network to reduce the energy consumption of each individual node deployed in the network. LEACH [2] is an important clustering protocol that used to conserve the life time of sensor network. LEACH protocol follows a probabilistic approach for clustering the network based on threshold values to determine the cluster head. The weighted cluster based protocol WST-LEACH [3] follows a probabilistic approach but also take into consideration the factors such as residual energy, number of neighbours, and distance to the neighbours and the characteristics features of each node for the determination of cluster head. The weighted approach shows a significant amount of reduction in energy consumption and enhancement of network lifetime. Most of the unique advantages of WSNs are provided through wireless communication. Ease of deployment, infrastructure-free networking, and broadcast communication are some of these advantages. However, wireless communication also brings several challenges in terms of limited communication range, frequent errors, and interference. To improve the QOS of the transmission several techniques have been proposed .

With the advent of MIMO technique it has been proved that it by using multiple antennas at the transmitter and receiver side helps reduce distortion of the transmitted signal and can efficiently reduce the energy consumption in the transmission of data in a wireless fading channel this effect has been shown in [4], [5].

However it is difficult to implement this technique directly in a sensor network because a sensor node is so small that it cannot have multiple antennas and possessing multiple antennas is also a very energy draining for a sensor mote. Thus cooperative technique is used among the sensor node in which multiple nodes share their antennas for the data transfer [6] and results shows that this could be an energy efficient method for conserving the energy. Sharing antennas by the cooperative node leads to achieve spatial diversity technique at the transmitter side [7].

Implementation of cooperative communication requires a proper synchronization among the cooperative nodes. The effect of losing the synchronization among the cooperative nodes have been studied in [7], the effect of co channel interferences in MIMO based WSN and their performance is shown in [8].

MIMO technique implemented using space time block codes has been studied in [4], [9] and [10]. The clustered sensor network selects nodes from within their clusters or from the neighbouring clusters to establish the cooperative communication. The transmitting node ,relay node and the receiving nodes together acts as virtual antenna array to realize MIMO communication as virtual MIMO.

The proposed technique implements the MIMO system in a weighted clustering protocol. The cluster head select a cluster member as a relay node to implement the cooperative communication as virtual MIMO. The impact of various cooperative communication strategies such as Amplify and Forward, Decode and Forward and various diversity techniques is analysed. Alamouti STBC scheme is used to realize diversity in WSN. The results shows that inspite of the additional overheads due to cooperation among the nodes ,they provide a better energy efficiency as compared to conventional routing protocols and the QoS offered is also improved.

2. PROPOSED TECHNIQUE

The proposed scheme implements a MIMO system in a conventional clustering protocol to enhance the network lifetime of the sensor network. The system model is shown in the following figure in which nodes have joined their respective cluster head and now the cluster head will transmits its data to the base station. The clustering of the network has been done by using WST-LEACH [3] protocol .

In the conventional clustering protocols the nodes elects optimal number of cluster heads (CH) among themselves and remaining nodes joins their respective cluster heads. The next phase is data sensing by the sensors and the sensed data is sent by each of the sensor nodes to their respective cluster heads for transmitting the aggregated data to the base station by the respective cluster heads.

In the proposed scheme when all the node send their sense data to their respective cluster head, the cluster head will select one node as a cooperative node which will simultaneously send the data with the cluster head to the base station. The use of cooperative nodes for data transmission incurs additional overhead in terms of energy consumption for the local communication between the nodes at the transmitter and those at the receiver but simultaneously introduces certain gains for the long- haul communication. Two or more nodes on the transmitter side cooperate and encode their transmission sequence based on Alamouti diversity codes. The number of nodes participating in cooperative communication depends on the QoS requirement and the application for which it is used.

The selection of cooperative node is done based on received signal strength. The cluster head knows the energy status of their cluster members and the distance to itself is estimated by the received signal strength and the no of times each of the cluster members being cluster head is also taken into account. If Nt cooperative transmitting antennas are needed, CH has to choose Nt -1 secondary cluster heads (SCH), it will select Nt -1 SCHs according to the following constraint:

For node i within a cluster,

$$\text{Max}\ \{(E_{remainder}\ (i)/d_i) + (E_{remainder}\ (i)/nt_i)\}, \quad (1)$$

$$E_{remainder}\ (i) > E_{th\_sch}$$

Where the parameters d_i is the distance of node i to the cluster head, nt_i gives the number of times the node i has become cluster head. E_{th_sch} is the threshold energy over which the node has a chance to become secondary cluster head. Once a CH has found enough SCHs satisfying the constraints, it will send the message to the SCHs to inform their roles in processing STBC coding for data transmission.

After forming a complete MIMO overlay network and creating the TDMA schedule, the nodes starts to transmit data. First , the cluster members transmits the data by SISO to its CH during its allocated slot and sleeps in other slots to save energy. When a CH receives all data from its members it will execute data aggregation to remove the data redundancy which dramatically reduces transmission energy. Then the cluster head transmits the fused data to the SCHs within the cluster. The Nt cooperating antennas encode and transmit the data to the BS by cooperative MIMO

The modelling of above is being done in simple MIMO transmission and reception and with the conventional SISO for the same BER and throughput condition. Alamouti diversity code for various diversity scenario is used for data transmission in MIMO system. Binary phase shift keying (BPSK) has been consider to model the energy consumption in the network. In the results it has been shown that for the short range communication conventional MIMO system is not as much energy efficient but as the communication range increases they shows an energy efficiency.

2.1 Energy model

In this section we present an energy model for cooperative MIMO based clustered network. The model is built on a cluster based sensor network which is different from those used in [2]. The sensors are uniformly distributed and is subjected to energy constraints. The nodes are self-organized into clusters and cooperates on data transmission to the base station(BS). For simplicity it is assumed that the base station is equipped with single antenna. The nodes in the cluster and the nodes at the base station form a cooperative or virtual MIMO system.

The communication based on cooperative MIMO can be classified into two: 1) local communication and 2) long haul communication. During local communication, sensor nodes in the same cluster exchange their data with their CH or through the CH to facilitate cooperative transmission and at the same time the data is also compressed by removing the redundancy with the help of proper aggregation schemes. During long haul communication the CH and the SCHs concurrently transmits the compressed data over the wireless channel to the base station by using a space time block coding (STBC) scheme.

A square law path loss with additive white Gaussian noise (AWGN) is assumed for local communication, whereas for long haul communication, a Rayleigh fading channel with square–law path loss is assumed. We adopt orthogonal STBC (OSTBC) in long haul cooperative communication and the channel is assumed constant during the transmission. The channel gain of the Rayleigh fading channel between a transmitting node and the receiving node is a scalar. Therefore, the fading factors of the cooperative MIMO channel can be represented as scalar matrix. In other words, the signal is attenuated further on top of the square –law path loss by a scalar fading matrix H, in which each entry is a zero-mean circulant symmetric complex Gaussian (ZMCSCG) random variable with unit variance[11].

2.2 Energy consumption for SISO scheme.

The energy consumption with in a cluster can be divided into two: 1) the energy dissipated by the CH and 2) the energy dissipation by non – cluster head nodes. The total energy consumed with in a cluster for SISO scheme is given by E_{SISO}

$$E_{SISO} = E_{CH} + E_{non\text{-}CH} \qquad (2)$$

The energy dissipated in a cluster head node during a single round with the assumption that each round has one frame:

$$E_{CH} = ((N/K_{OPT}) - 1)\, P_{RX}*(L/R_{INTRA}) + E_{DA} + P_{TX}*(L/R_{INTRA}) + P^d_{SISO}\,(L/R_{INTRA}) \qquad (3)$$

where L is the number of bits transmitted ,N is the total number of nodes, K_{OPT} is the optimum number of cluster heads depends on the protocol employed , R_{INTRA} is the transmission data rate, P_{TX} and P_{RX} are the power consumption of the circuit blocks at the transmitter and receiver side ,respectively. The transmission data rate is given by R_{INTRA} =b. B, with b being the constellation size and B being the modulation bandwidth. The power consumption of the power amplifier P^d_{SISO} is calculated based on the link budget relationship [12], [13]. For a channel that experience a square law path loss, we have

$$P^d_{SISO} = \frac{(1+\alpha)\, E^b_{INTRA}\, R_{INTRA}\, ((4\pi)^2 d^n M_l N_f)}{G_t\, G_r\, \lambda^2} \qquad (4)$$

Here , d represents the transmission distance, G_t and G_r represents the transmitter and the receiver antenna gains, respectively, n is the path loss exponent can take values 2 or 4 depends on the transmission distance, M_l is the link margin and N_f is the receiver noise level. The energy per bit requirement for a given BER requirement is represented by E^b_{INTRA}

$$E^b_{INTRA} = (\gamma_{INTRA})\, No\,, \qquad (5)$$

Where γ_{INTRA} denotes the instantaneous received signal to noise ratio (SNR).

The energy dissipated by the non-cluster head members during a single round is given by

$$E_{non\text{-}CH} = P_{TX}\,(L/R_{INTRA}) + P^d_{SISO}\,(L/R_{INTRA}) \qquad (6)$$

The total energy consumption in a cluster during a single round

$$E_{SISO} = E_{CH} + E_{non\text{-}CH} \qquad (7)$$

2.3 Energy consumption for MIMO scheme

The energy consumption with in a cluster for MIMO scheme can be divided into three; 1) the energy dissipated by the CH 2) the energy dissipation by non – cluster head nodes and 3) energy dissipated by the secondary cluster heads. Thus the energy consumed with in a cluster for MIMO scheme is given by E_{MIMO}

$$E_{MIMO} = E_{CH} + E_{non\text{-}CH} + E_{SCH} \qquad (8)$$

The energy dissipated in a cluster head node during a single round with the assumption that each round has one frame

$$E_{CH} = ((N/K_{OPT}) - 1)\, P_{RX}*(L/R_{INTRA}) + E_{DA} + P_{TX}*(L1/R_{INTRA}) + P^d_{SISO}*(L/R_{INTRA}) + P_{TX}*(L1/R_{LH}) + Pd_{MIMO}\,(L1/R_{LH}) \qquad (9)$$

Where L1 is the number of bits transmitted after performing the encoding scheme, R_{LH} denotes the transmission bit rate defined as $R_{LH} = R_S\, b\, B$, with

R_S being the spatial rate of the encoding scheme. Here R_S =1/2 ,because we use an OSTBC with a code rate of 1/2.

The power consumption of the power amplifier P^d_{MIMO} is calculated based on the link budget relationship [12],[13]. For a channel that experience a square law path loss, we have

$$P^d_{MIMO} = \frac{(1+\alpha)\, Eb_{LH}\, R_{INTRA}\, ((4\pi)^2\, d^{\,n}\, M_l\, N_f)}{G_t\, G_r\, \lambda^2} \quad (10)$$

Here , Eb_{LH} is the average energy per bit required for a given BER requirement.

$$E^b_{LH} = \frac{(\gamma_{LH})\; n\, No}{\|h\|^2} \quad (11)$$

Where γ_{LH} is the instantaneous received SNR for the cooperative MIMO system ,n represents the number of cooperative nodes and h represents the channel gain

The energy dissipated by the non-cluster head members during a single round is given by

$$E_{non\text{-}CH} = P_{TX}\,(L/R_{INTRA}) + P^d_{SISO}\,(L/R_{INTRA}) \quad (12)$$

The energy dissipated by the SCH during a single round is given by:

$$E_{SCH} = P_{RX}(L1/R_{INTRA}) + P_{TX}(L1/R_{LH}) + P^d_{MIMO}(L1/R_{LH}) \quad (13)$$

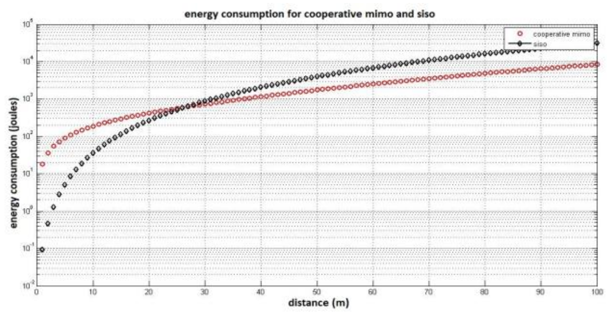
The total energy consumption in a cluster during a single round

$$E_{MIMO} = E_{CH} + E_{non\text{-}CH} + E_{SCH} \quad (14)$$

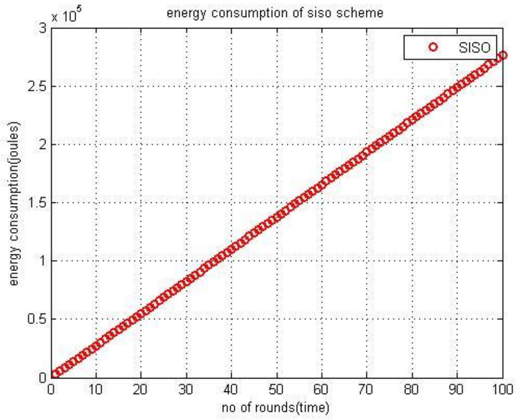
For the cooperative MIMO based scheme to be energy efficient than SISO scheme, the requirement is the energy consumed by the cluster in the MIMO scheme should be less than the SISO scheme.

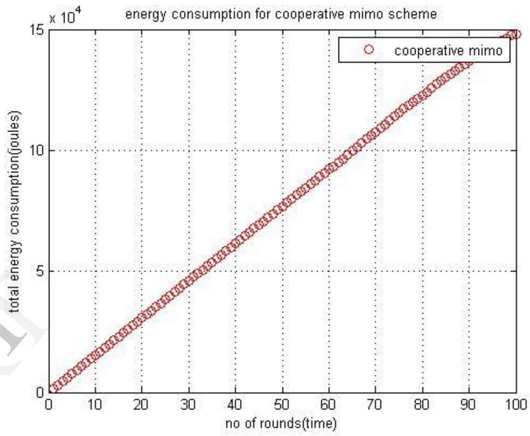
$$E_{MIMO} < E_{SISO} \quad (15)$$

Analysis of the above equation shows that it is a function of the transmission distance and depends on the number of cooperative nodes involved. As shown in the figure below the cooperative MIMO communication provides a significant energy saving above a certain threshold distance. The fig was obtained for two cooperative node scenarios.



The energy consumption of the above two schemes during each rounds is shown in fig:

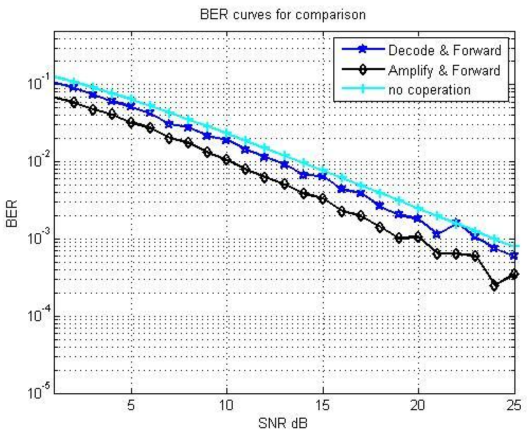




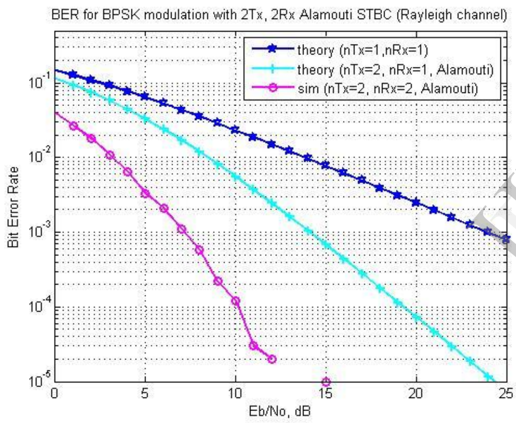
3. Evaluation of various cooperative selection strategies and the diversity techniques

The cooperative communication involves the transmitting node ,the relay node and the receiving node. Various strategies can be employed to realize the cooperative communication. The two schemes are: 1) Amplify and Forward and 2) Decode and Forward.

Amplify and forward technique the relay node receives the STBC encoded transmission data sequence. The relay node amplify the received signal and transmit it to the base station. The noise associated with the signal also get amplifies and gets transmitted it to the base station. Decode and forward technique the relay node decodes the encoded transmission sequence and retransmit after encoding to the base station. The propagation of error decreases but incurs additional overheads to the resource constraint nodes for encoding and decoding. The fig shows the BER of various cooperative selection strategies and that without any cooperation. The cooperation shows a significant improvement in the SNR values for a given BER requirement, reducing the optimal transmitting energy per bit. The cooperative communication provides a significant energy savings for a higher BER requirement .



The use of various Alamouti STBC code for various diversity order provides a better BER . The figure shows the BER for various diversity orders with and without coding and for a single input single output scheme. The use of higher order diversity helps combat the wireless channel impairments and improves the QoS of the transmission. For a given BER requirement the diversity scheme shows a significant improvement in the SNR values.



Better BER reduces the number of retransmission and reduces the energy per bit requirement, providing a significant amount of energy efficiency. The cooperative selection strategies , the diversity techniques in a clustered wireless environment provides additional energy savings , thus improving the network lifetime of the sensor network.

4.CONCLUSIONS AND FUTURE WORK

The results show that MIMO technique is more energy efficient than a SISO technique in a Rayleigh fading channel but this could be contradictory if considering the circuit energy consumption. The results also shows that the for the short range communication the SISO is more energy efficient than MIMO but as the communication range increases MIMO system will become energy efficient. Thus for a long range communication, proposed technique will be more energy efficient than a SISO technique. The use of optimal cooperative communication strategies and diversity techniques helps combat the constraints of the wireless communication channel and enhances the QoS of the communication also provides an improved energy efficiency thus improving the network lifetime.

The use of ultra wide band(UWB) communication is not being considered, this could help further reduce the energy consumption of the network.

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