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Lifetime Maximisation of Multihop WSN using Cluster-based Cooperative MIMO Scheme

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***Abstract*— Wireless sensor network (WSN) requires robust and energy efficient communication protocols to minimise the energy consumption as much as possible. However, the lifetime of sensor network reduces due to the adverse impacts caused by radio irregularity and fading in multihop WSN. A cluster-based cooperative multi-input and multi-output (MIMO) scheme is proposed as a solution for this problem. The proposed scheme extends low energy adaptive clustering hierarchy (LEACH) protocol and enables multihop transmissions among the clusters by incorporating cooperative MIMO scheme through the selection of cooperative sending and receiving nodes. The performance of the proposed MIMO system is evaluated interms of energy efficiency and reliability. Simulation results show that tremendous energy savings can be achieved by adopting cooperative MIMO scheme among the clusters. The proposed cooperative MIMO scheme prolongs the network lifetime with 75% of nodes remaining alive when compared to LEACH protocol.**

***Index Terms*— Cooperative MIMO, LEACH protocol, multihop communication, network lifetime, wireless sensor network**

I. Introduction

Wireless sensor network comprises of hundreds to thousands of small nodes employed in a wide range of data gathering applications such as military, environmental monitoring and many other fields [1]. Due to limited energy and the difficulty in recharging a large number of sensor nodes, energy efficiency and maximising the network lifetime are the most important design goals of a sensor network. Channel fading, interference and radio irregularity further pose big challenge on the design of energy efficient communication protocols in wireless network.

MIMO systems can dramatically reduce the transmission energy consumption in wireless fading channels [2,3]. Cooperative transmission and reception of data among sensors is known to diminish the per-node energy consumption, increasing the network lifetime [4]. In these schemes, multiple individual single antenna nodes cooperate on data transmission and reception for energy efficient communication.

Cooperative multi input single output (MISO) transmission scheme based on LEACH protocol is analysed in [5,6]. However cooperative MISO performs only single hop transmission and does not prolong the network lifetime. To overcome these draw backs, the proposed model modifies the LEACH protocol [7,8] and allows cluster heads to form a multihop backbone and incorporates the cooperative MIMO scheme on each single hop transmission by utilising a set of sending and receiving cooperative nodes in each cluster. For the proposed model, the energy consumed and the number of nodes alive for each round of data transmission is evaluated.

The remainder of the paper is organized as follows: section II describes the proposed cluster based multihop MIMO scheme. The energy consumption model of proposed scheme is analysed in section III. Simulation results are discussed in section IV and conclusions are drawn in section V.

II. Proposed Cluster- Based Multihop Cooperative MIMO Scheme

Consider a wireless sensor network with N sensing nodes distributed randomly in a square area of side M meters. All sensor nodes are assumed to be stationary, heterogeneous and energy-constrained, where each node can transmit data to any other node and sink. The sink node is assumed to have no energy constraints and is equipped with one or more receiving antennas. The sensor nodes are geographically grouped into clusters consisting of a head node, cooperative sending and receiving nodes and non-cluster head nodes that sense the data from the sensing field. The cluster heads are reelected after each round of data transmission as in LEACH protocol [7]. The proposed multihop cooperative MIMO transmission model is illustrated in Fig.1. The transmission procedure of the proposed scheme is divided into multiple rounds. Each round has three phases:

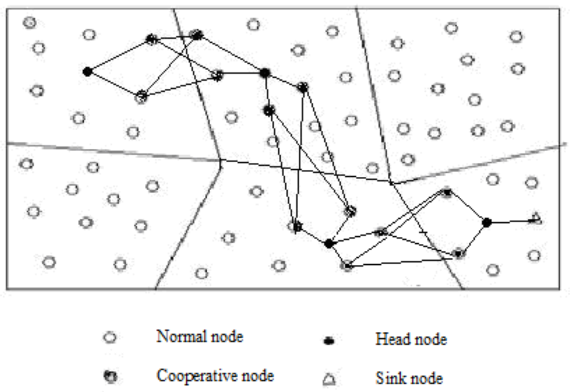

Fig.1 Multihop cooperative MIMO transmission model

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A. Cluster formation phase

In this phase, clusters are organized and cooperative MIMO nodes are selected according to the steps described below:

1) Cluster head advertisement

Initially, when clusters are being created, each node decides whether or not to become a cluster head for each round as specified by the original LEACH protocol. Each self-selected cluster head, broadcasts an advertisement (ADV) message using non-persistent carrier sense multiple access (CSMA) protocol. The message contains the header identifier (ID).

2) Cluster setup

Each non-cluster head node chooses one of the strongest received signal strength (RSS) of the advertisement as its cluster head, and transmits a join-request (Join-REQ) message back to the chosen cluster head. The information about the node's capability of being a cooperative node, i.e., its current energy status is added into the message. If a cluster head receives the advertisement message from another cluster head y, and if the received RSS exceeds a threshold, it will mark cluster head y as the neighbouring cluster head and it record y's ID. If the sink receives the advertisement message, it will find the cluster head with the maximum RSS, and sends the sink-position message to that cluster head marking it as the target cluster head (TCH).

3) Schedule creation

After all the cluster heads has received the join-REQ message, each cluster head creates a time division multiple access (TDMA) schedule and broadcasts the schedule to its cluster members as in original LEACH protocol. This prevents collision among data messages and allows the radio of each non-cluster head node to be turned off until its allocated transmission time to save energy.

4) Cooperative node selection

After the cluster formation, each cluster head will select J cooperative sending and receiving nodes for cooperative MIMO communication [5] with each of its neighbouring cluster head. Nodes with higher energy close to the cluster head will be elected as sending and receiving cooperative nodes for the cluster. At the end of the phase, the cluster head will broadcast a cooperative request (COOPERATE-REQ) message, which contains the ID of the cluster itself, the ID of the neighbouring cluster head y, the ID of the transmitting and receiving cooperative nodes and the index of cooperative nodes in the cooperative node set of each cluster head to each cooperative node. The cooperative node on receiving the COOPERATE- REQ message, stores the cluster head ID and sends back a cooperate-acknowledgement (ACK) message to the cluster head.

B. Routing table construction

Each cluster head will maintain a routing table which contains the destination cluster ID, next hop cluster ID, IDs of cooperative sending and receiving nodes. The cluster heads will update the route cost and advertise their neighbouring cluster heads about the modified routes. The TCH will flood a target announcement message containing its ID to each cluster head to enable transmissions to the sink node.

C. Data transmission phase

During this phase, the data sensed by sensor nodes are transmitted to the cluster head and forwarded to the sink using multihop MIMO scheme according to the routing table.

1) Intra cluster transmission

In this phase, the non-cluster head nodes send their data frames to the cluster head as in LEACH protocol during their allocated time slot. The duration and the number of frames are same for all clusters and depend on the number of non-cluster head nodes in the cluster.

2) Inter cluster transmission

After a cluster head receives data frames from its cluster members, it performs data aggregation and broadcasts the data to J cooperative MIMO sending nodes. When each cooperative sending node receives the data packet, they encode the data using space time block code (STBC) and transmit the data cooperatively. The receiving cooperative nodes use channel state information to decode the space time coded data [6,9]. The cooperative node relays the decoded data to the neighbouring cluster head node and forwards the data packet to the TCH by multihop routing.

III. ENERGY CONSUMPTION MODEL OF PROPOSED SCHEME

The energy consumed during each round of data transmission results from the following sources such as: cluster members transmitting their data to the cluster head, routing table constructed by the cluster head, cluster head transmitting the aggregated data to the cooperative nodes [8], cooperative node transmitting the data to the receiving cooperative nodes and to the receiving cluster head.

A. Energy consumption of cluster member

The energy consumed by the source nodes to transmit one bit data to the cluster head node is given by

$$E_{bs}(k_c) = -\frac{1}{\pi k_c}(1+\alpha)N_f\sigma^2\ln(P_b)G_1M^2M_l + \frac{P_{ct}+P_{cr}}{B} \quad (1)$$

where

k_c is the number of clusters

α is the efficiency of radio frequency (RF) power amplifier

N_f is the receiver noise figure

$\sigma^2=N_o/2$ is the power density of additive white Gaussian noise (AWGN) channel

P_b is the bit error rate (BER) obtained while using phase shift keying

G_1 is the gain factor

M_1 is the gain margin

B is the bandwidth

P_{ct} is the circuit power consumption of the transmitter

P_{cr} is the circuit power consumption of the receiver

The total number of bits transmitted to the cluster head of each cluster in each round is given by

$$S_1(k_c) = \left[\frac{N}{k_c}\right] F_n Ps \quad (2)$$

where
F_n is the number of symbols in a frame
P is the transmit probability of each node
s is the packet size

The energy consumed by a cluster member to transmit data to the cluster head is given by

$$E_s(k_c) = k_c S_1(k_c) E_{bs}(k_c) \quad (3)$$

B. *Energy consumption of cluster heads*

To construct the routing table, the energy consumed by the cluster head node is given by

$$E_r(k_c) = k_c R_{ts} R_{bt} \left((1+\alpha) M_1 N_f \frac{N_0 (4\pi)^2 (2M)^k}{P_b G_t G_r \lambda^2 (\pi k_c)^{k_c/2}} + \frac{P_{ct} + 4P_{cr}}{B} \right) \quad (4)$$

where
R_{bt} is the time required for exchanging routing information
R_{ts} is the routing table size
G_t is the gain of transmitting antenna
G_r is the gain of receiving antenna
λ is the wavelength of transmission

The energy per bit consumed by the cluster head node to transmit the aggregated data to J cooperative nodes is given by

$$E_{bc0}(k_c, J) = -\frac{1}{\pi k_c}(1+\alpha) N_f \sigma^2 \ln(P_b) G_1 M^2 M_l + \frac{P_{ct} + JP_{cr}}{B} \quad (5)$$

The amount of data after aggregation for each round by cluster head node is given by

$$S_2(k_c) = \frac{S_1(k_c)}{([N/k_c]Pagg - agg + 1)} \quad (6)$$

where
agg is the aggregation factor

The energy consumed by cluster head node to transmit the aggregated data to J cooperative nodes is given by

$$E_{c0}(k_c, J) = k_c S_2(k_c) E_{bc0}(k_c, J) \quad (7)$$

C. *Energy consumption of cooperative nodes*

The transmitter cooperative nodes of the cluster will encode and transmit the sequence according to orthogonal STBC [3] to the cluster head node. Consider the block size of the STBC code is F symbols and in each block pJ training symbols are included and are transmitted in L symbol duration. The actual amount of data required to transmit the $S_2(k_c)$ bits is given by

$$S_e(k_c, J) = FS_2(k_c)/R(F - pJ) \quad (8)$$

where
R is the transmission rate

The energy consumed by J cooperative sending nodes to transmit MIMO data to the J cooperative receiving nodes is given by

$$E_{cs}(k_c, J) = S_e(k_c, J) \left((1+\alpha) M_1 N_f \frac{JN_0 (4\pi)^2 (2M)^k}{P_b^{1/J} G_t G_r \lambda^2 (\pi k_c)^{k_c/2}} + \frac{JP_{ct} + JP_{cr}}{B} \right) \quad (9)$$

Similarly, the energy consumed by J receiving cooperative nodes to transmit data to the neighbouring cluster head is given by

$$E_{cr}(k_c, J) = S_e(k_c, J) \left((1+\alpha) M_1 N_f \frac{JN_0 (4\pi)^2 (2M)^k}{P_b^{1/J} G_t G_r \lambda^2 (\pi k_c)^{k_c/2}} + \frac{JP_{ct} + P_{cr}}{B} \right) \quad (10)$$

D. *Overall energy consumption for a round*

The energy consumption for each round of cooperative multihop MIMO data transmission can be obtained from Equations (3), (4), (7), (9) and (10) and it is given by

$$E(k_c, J) = E_s(k_c) + E_r(k_c) + n_k E_{c0}(k_c, J) + n_k E_{cs}(k_c, J) + n_k E_{cr}(k_c, J) \quad (11)$$

where
n_k is the average number of hops

IV. SIMULATION RESULTS

The analysis of the proposed cooperative multihop MIMO scheme is carried out using MATLAB to evaluate the energy consumption and maximise the lifetime of the sensor network. A sensing field of dimension M x M (M =100 m) with a population of N= 100 nodes is considered for simulation. A heterogeneous network consisting of 80 normal nodes and 20 advanced nodes are deployed over the region randomly. The initial energy of a normal node is set to 0.5 J and the energy of the advanced node is 2J. Sink node is assumed to be located at the centre of the sensing field (50, 50), provided with sufficient energy resources. The system parameters used for the simulation is listed in Table 1.

Table I. COMMUNICATION SYSTEM PARAMETERS

Parameter	Value
Efficiency of RF power amplifier (α)	0.4706
Link margin (M_1)	40 dB
Gain factor (G_1)	30 dB
Power density of AWGN channel (σ^2)	-134 dBm /Hz
Receiver noise figure (N_f)	10 dB
Path loss(k)	3-5
Carrier frequency (f_c)	2.5 GHz
Bandwidth (B)	20 KHz
BER performance (P_b)	10^{-3}
Circuit power consumption of transmitter (P_{ct})	98.2 mw
Circuit power consumption of receiver (P_{cr})	112.6 mw
Antenna gain of transmitter and receiver (G_t, G_r)	5 dB
Time for exchanging routing table for each round (R_{bt})	5
Routing table size (R_{ts})	100
Transmission rate (R)	0.75
Packet size (s)	2 kbits
Number of frames per round (F_n)	2
Transmission probability of each node (P)	0.8

The performance of the proposed multihop cooperative MIMO LEACH scheme is compared with that of the original LEACH scheme interms of energy. The results obtained are shown in Fig.2. As the number of cooperative nodes is increased, the energy consumption of the network is decreased due to the diversity gain. From the graph it is clear that the proposed scheme utilising 3 cooperative sending and receiving nodes can achieve 50% of energy savings than the LEACH protocol.

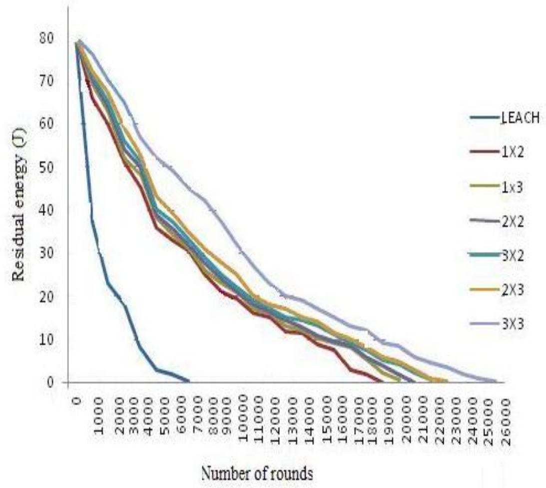

Fig.2 Comparison of energy consumption and number of rounds

Fig.3 shows the percentage of nodes alive in the network with the increase in number of rounds. It is vivid that the lifetime of WSN using multihop MIMO scheme is 75% more when compared to the LEACH protocol. Furthermore, with the increase in the diversity order from 1x2 to 3x3, 30% more nodes are alive contributing to the increase in network life time with the exploitation of diversity gain and multihop communication among cluster head nodes.

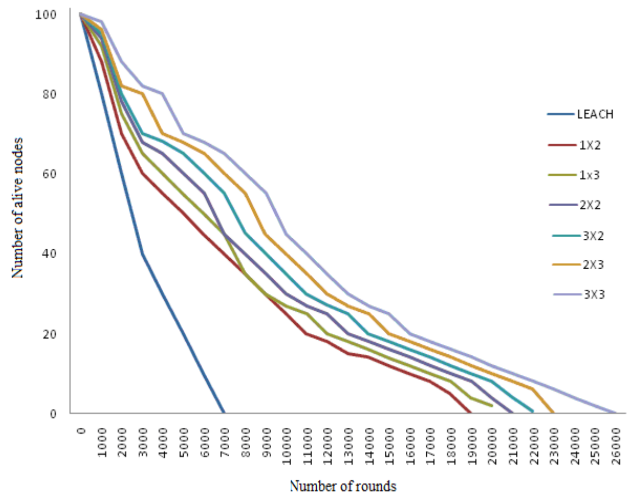

Fig.3 Comparison of network lifetime with number of rounds

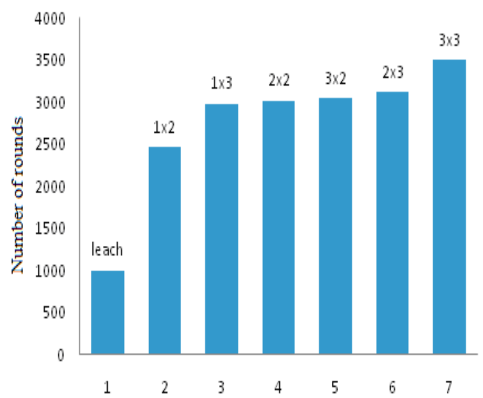

Fig.4 10% of node death with number of rounds

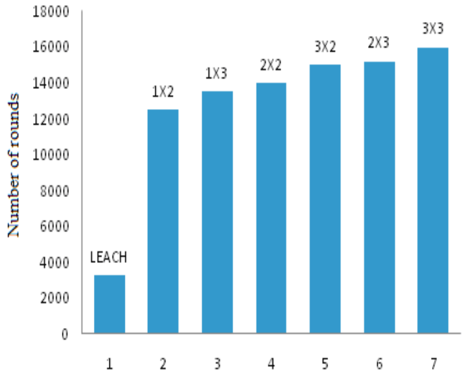

Fig.5 80 % of node death with number of rounds

The number of rounds possible for data transmission with 10%, 80% and last node death (100%) are illustrated in Figs. 4, 5 and 6. 10% of node death occurs at 1000 rounds with LEACH protocol. For the proposed multihop MIMO configurations, as the order of diversity increases, the number of rounds for which the nodes are alive also increases. 3x3 MIMO configuration can transmit data for about 3500 rounds and is approximately about 2500 rounds better in data transmission compared to the LEACH protocol. Similar analysis is presented in Fig.5 showing 80% node death. In LEACH protocol 80% of node death occurs at 3254 rounds whereas for MIMO configurations 1x2, 2x3, 3x2, 1x3, 2x2, 3x3 node death occurs at 12489, 13520, 14001, 14999, 15221 and 15998 respectively. Thus 3x3 MIMO scheme can provide lifetime of 12000 rounds more when compared to the LEACH protocol.

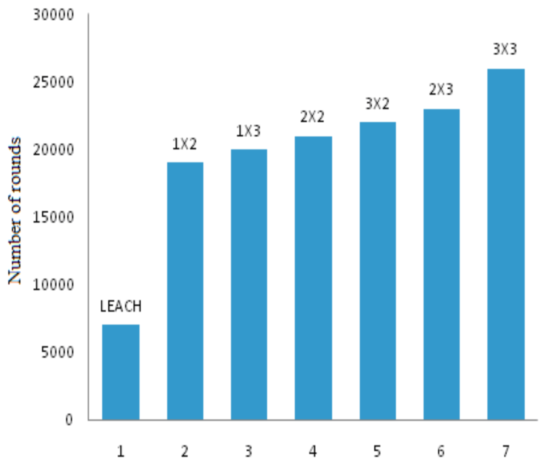

Fig.6 100% of node death with number of rounds

Fig.6 shows the time during which the last node dies in the network. From the results it is evident that the lifetime of LEACH protocol is limited to 7000 rounds and the proposed MIMO scheme extends upto 26000 rounds. The proposed 3x3 multihop MIMO scheme provides an enhanced life time of about 3.5 times more than the LEACH protocol.

V. Conclusion

A cluster-based cooperative MIMO scheme for multihop WSN has been explored and the performance of the system is evaluated to minimise the energy consumption and increase the lifetime of sensor nodes. The simulation results reveal that the LEACH protocol consumes more energy and has shorter lifetime of 7000 rounds due to the adverse channel fading effects. The proposed cooperative 3x3 MIMO scheme performs better and extends 19000 rounds more than the LEACH scheme for data transmission and saves upto 50% energy by the exploitation of the diversity gain and multihop communication among the cluster head nodes.

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References

[1] L. Akyildiz, W. Su, Y. Sankarasubramanian and E. Cayirci, "A survey on sensor networks", *IEEE Communications Magazine*, vol. 40. no. 8, pp. 102-114, 2002.

[2] G. N. Bravos and G. Efthymoglou, "MIMO-based and SISO multihop sensor network: Energy efficiency evaluation", *Proceedings of IEEE International Conference on Wireless and Mobile Computing, Networking and Communications*, 2007

[3] S. Cui, A. J. Goldsmith and A. Bahai, "Energy-efficiency of MIMO and cooperative techniques in sensor networks", *IEEE Journal on Selected Areas in Communications*, vol.22, no.6, pp. 1089-1098, 2004.

[4] S. K. Jayaweera, "Energy analysis of MIMO techniques in wireless sensor networks", *Proceedings of Annual Conference on Information Sciences and Systems*, Princeton, NJ, 2004

[5] X. Li, M. Chen and W. Liu, "Application of STBC-encoded cooperative transmissions in wireless sensor networks", *IEEE Signal Processing Letters*, vol.22, no.2, pp.134-137, 2005.

[6] Y. Yuan, Z. He and M. Chen, "Virtual MIMO- based cross-layer design for wireless sensor networks", *IEEE Transactions on Vehicular Technology*, vol. 55, no.3, pp. 856 -864, 2006.

[7] W.R. Heinzelman, A. Chandrakasan and H. Balakrishnan, "An application-specific protocol architecture for wireless microsensor networks", *IEEE Transactions on Wireless Communications*, vol.1, no .4, pp. 660 - 670, 2002.

[8] W. Cheng, K. Xu, Z. Yang and Z. Feng, "An energy-efficient cooperative MIMO transmission scheme for wireless sensor networks", *Proceedings of International Conference on Wireless Communication, Networking and Mobile Computing*, pp. 1-4, 2006.

[9] V. Tarokh, H. Jafarkhani and A. R. Calderbank, "Space-time block codes from orthogonal designs", *IEEE Transactions on Information Theory,* vol. 45, no.5, pp. 1456-1467, 1999.

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