Energy Efficient Cooperative LEACH Protocol for Wireless Sensor Networks

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Abstract: **We develop a low complexity cooperative diversity protocol for low energy adaptive clustering hierarchy (LEACH) based wireless sensor networks. A cross layer approach is used to obtain spatial diversity in the physical layer. In this paper, a simple modification in clustering algorithm of the LEACH protocol is proposed to exploit virtual multiple-input multiple-output (MIMO) based user cooperation. In lieu of selecting a single cluster-head at network layer, we proposed M cluster-heads in each cluster to obtain a diversity order of M in long distance communication. Due to the broadcast nature of wireless transmission, cluster-heads are able to receive data from sensor nodes at the same time. This fact ensures the synchronization required to implement a virtual MIMO based space time block code (STBC) in cluster-head to sink node transmission. An analytical method to evaluate the energy consumption based on BER curve is presented. Analysis and simulation results show that proposed cooperative LEACH protocol can save a huge amount of energy over LEACH protocol with same data rate, bit error rate, delay and bandwidth requirements. Moreover, this proposal can achieve higher order diversity with improved spectral efficiency compared to other virtual MIMO based protocols.**

Index Terms: **Cross-layer design, fading channel, low energy adaptive clustering hierarchy (LEACH), transmit diversity, virtual multiple input multiple output (MIMO), wireless sensor network.**

I. INTRODUCTION

In wireless sensor networks (WSN), a large number of low power sensor nodes jointly gather information from their surrounding environments and transmit them towards the data sink [1]–[3]. Sensor nodes typically operate with small batteries for which replacement is very difficult and expensive. Thus, in many scenarios, wireless nodes must operate without battery replacement for many years. Consequently, minimizing the energy consumption is an important criterion which encourages us to implement energy-efficient transmission schemes in WSNs. At the same time, a reliable communication over wireless channels which are highly vulnerable to path loss and fading effect is also a primary requirement.

It is well known that transmit diversity technique is energy efficient transmission protocol. To provide transmit diversity when users cannot support multiple antennas, a new method of transmit diversity for mobile users, termed as cooperative diversity, has been proposed [4]. Various cooperative transmission-protocols, their implementation issues, performance and outage analysis have been studied in literature [4]–[9]. It has been shown in [10] that virtual multi-input multi-output (MIMO) systems are more energy efficient than single-input single-output (SISO) systems in Rayleigh fading channels when both transmission energy and circuit energy consumptions are considered. Constructing a virtual MIMO environment in a distributed wireless sensor network is a great challenge for the researcher community. The major challenges are synchronization among the cooperative nodes, delay efficiency, processing overhead, exchanging information among the cooperating nodes, etc. Various cooperative MIMO protocols for clustering based WSNs have also been proposed in literature [10]–[14].

A space time block code (STBC) encoded cooperative transmission for low energy adaptive clustering hierarchy (LEACH) based protocols has been proposed in [13] and [14]. They proposed a conventional cooperative communication in cluster-head to data-sink link where the cluster-head collects information from all nodes within the cluster and transmit them towards a group of cooperative nodes (or secondary cluster-head). These cooperative nodes then transmit information to data-sink using STBC structure. A multihop LEACH protocol that incorporates multihop routing for WSNs has also been proposed in [15]. Cooperative diversity protocols can provide powerful benefits of spatial diversity at the cost of spectral efficiency due to half-duplex operation of the protocols [7]. Therefore, the spectral efficiency of the cooperative protocols proposed in [10]–[14] is half of the noncooperative protocols for long-haul transmission because these protocols requires exchanging of information between the head nodes.

In this paper, we introduce a cross layer approach to obtain higher order diversity without sacrificing any spectral efficiency. We termed our proposal as *'Cooperative LEACH'* protocol. Instead of using only one cluster-head, we propose M cluster-heads within a single cluster. Due to the broadcast nature of wireless transmission, it is possible for all cluster-heads within a cluster to receive the same transmission. After receiving data from the sensor nodes of a cluster, M cluster-heads cooperatively transmit them towards the sink or higher layer cluster-heads. The scheme proposed here is more like a multipath routing scheme which can obtain spatial diversity at the sink node. Our proposal can obtain a diversity of order M and ensures the same spectral efficiency as LEACH protocol. The goal of this paper is to design an energy efficient transmission protocol by exploiting cooperative diversity. Hence, we restrict our analysis only on the energy consumption and lifetime of the network. Simulation results are presented to show the energy efficiency of the proposal.

This paper is organized as follows. In Section II, we describe the system and channel models. Section III gives the description

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of the proposed cooperative LEACH protocol. In Section IV, we analyze the energy model and energy efficiency of our protocol. Simulation results and discussions are given in Section V and finally we conclude this paper in Section VI.

II. SYSTEM MODEL

We consider a sensor network which collects information and sends them to a sink node as shown in Fig. 1. Assume that the nodes are randomly distributed over the sensor field and they form clusters for convenience of communication. Each cluster contains a cluster-head (CH), $M-1$ cooperative cluster-heads (CCHs) and several sensor nodes (SNs). We define intra cluster transmission (SNs to CH/CCHs) as *local transmission* and CH/CCHs to sink node transmission as *long-haul transmission*. For channel propagation model, we consider both free space model and multipath fading model [16] depending on the distance between transmitter and receiver.

Local Communication: In this case, the distance between transmitter and receiver is relatively small compare to the long-haul transmission. The local communication channels are considered as additive white Gaussian noise (AWGN) channel with free space propagation model. Hence, the baseband equivalent received signal at node j due to the transmission of node i for symbol n is given by,

$$r_{ij(local)}(n) = \Gamma_{ij(local)} s(n) + \eta_j(n) \tag{1}$$

where $\eta_j(n)$ is AWGN samples at terminal j, $\Gamma_{ij(local)} = d_{ij}^{-2}$ with d_{ij} is the distance between node i and j, and $s(n)$ is the signal transmitted by node i with normalized unit transmit power.

Long-haul transmission: We consider the sink node is far away from the sensor field. Hence, for long-haul communication channel, the distance between transmitter and receiver is relatively long. We consider the channels between CH/CCHs to sink node are subjected to flat Rayleigh fading with two-ray ground propagation model plus AWGN. The baseband equivalent received signal at node j due to the transmission of node i for symbol n is given by,

$$r_{ij(long)}(n) = \Gamma_{ij(long)} h_{ij} s(n) + \eta_j(n) \tag{2}$$

where h_{ij} is the fading coefficient between node i and j and $\Gamma_{ij(long)} = d_{ij}^{-4}$. We consider flat Rayleigh fading, hence h_{ij} is modeled as independent samples of zero mean complex Gaussian random variable with variance $\sigma_{ij}^2/2$ per dimension. Assume that the fading coefficients are constant over the transmission period of a whole message block. Because of slow fading channel estimation is possible at the receivers, and we assume that perfect channel state information is available at the corresponding receivers but not in the transmitters.

III. PROTOCOL DESCRIPTION

A. Review of LEACH Protocol

Wireless sensor networks are assumed to be self organized i.e., there is no centralized control station like base station or access point. Clustering based routing protocols enable the WSNs to exploit some benefits of cellular based wireless networks. Dividing the whole sensor network in number of clusters and selecting a CH for each cluster can localize the coordination and control of the network. LEACH is well known energy efficient clustering based protocol for wireless sensor networks that can achieve as much as a factor of 8 reduction in energy dissipation compared with conventional routing protocols [1]. The LEACH protocol also outperforms classical clustering algorithm by using adaptive clustering and rotating the CH among nodes that randomize the power consumption of the CH. The LEACH protocol operates on a round to round basis and each round has three phases: Advertisement phase, cluster set-up phase, and steady-state phase. The details of this protocol are explained in [1]. In this subsection we will give a brief introduction of the above mentioned phases.

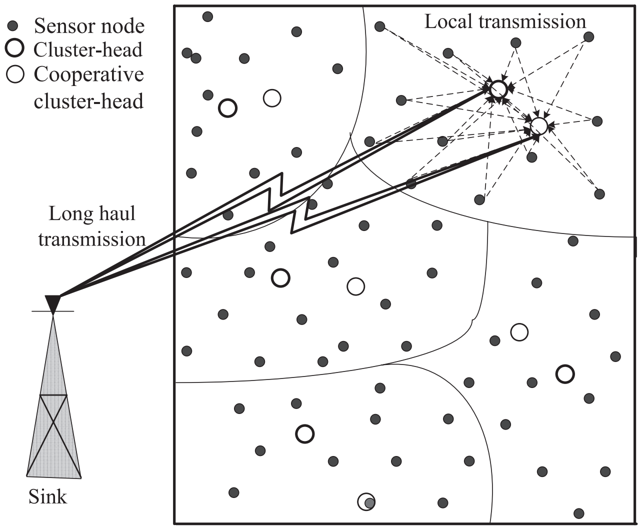

Fig. 1. System model of cooperative LEACH protocol with one CCH.

Advertisement phase: Each node decides whether or not to become a CH for current round. The decision to become a CH depends on the prior percentage of CHs and number of times the node has been a CH so far. After making this decision each node that has elected itself as a CH for the current round broadcasts an advertisement message to rest of the nodes. At the end of this phase each noncluster-head node decides the cluster to which it belongs for this round. This decision depends on the received signal strength of the advertisement message.

Cluster setup phase: Each node informs the selected CH node that it will be a member of the cluster. During this phase all CH nodes must keep their receivers on receiving messages from nodes that would like to be a member of the cluster. Depending on the number of nodes in the cluster, the CH creates a time division multiple access (TDMA) schedule and sends this schedule to all other sensor nodes.

Steady-state phase: In this phase, sensor nodes start sending data to the CH. Sensor nodes transmit their information towards the CH in their own time slot allocated by the CH. The radio of each noncluster-head nodes can be turned off except node's allocated time slot. After receiving data from all sensor nodes, cluster-head performs some signal processing prior to transmit them towards higher order cluster-head or sink node.

B. Cooperative LEACH Protocol

In this subsection, we propose some modifications of routing and scheduling algorithm of LEACH protocol to exploit spatial diversity at the physical layer. This approach can be viewed as cross-layer design among network, media access control (MAC), and physical layer. First, we will explain the modifications made in conventional LEACH protocol to exploit the cooperative diversity in long-haul data transmission. The proposed cooperative LEACH protocol also operates in round by round fashion and each round has same three phases as the LEACH protocol. We propose some modifications in second and third phase. In the cluster setup phase, we propose a scheme to select $M-1$ additional CHs termed as CCH and in the steady-state phase we incorporate virtual MIMO based cooperative transmission for the long-haul communication. The advertisement phase of our proposed protocol is same as the LEACH protocol.

Modified cluster setup phase: Each noncluster-head node decides whether it will be a CCH or not for this round. This decision is simply based on the number of times that the node has been a CCH so far, as the decision made for cluster-heads in the LEACH protocol [1]. Each node informs the selected CH node that it will be a member of the cluster. And at the same time, it informs whether it will be a CCH or not. The overhead of this procedure is just transmitting one extra bit along with the cluster joining packet. The CH node receives cluster joining packets from the nodes that would like to be included in the cluster and selects $M-1$ CCHs from the interested candidates based on the minimum communication distance equivalently with maximum received signal strength of the acknowledgement. If there are not enough candidates for becoming CCH within the cluster, then the CH will select CCHs only on the basis of the received signal strength of acknowledgement. Therefore cluster-head selects $M-1$ cooperative cluster-heads which are located in minimum communication distance from the CH node.

If a pair of CH/CCH is in the same place or very close to each other (less than the half wave length), then the system will not achieve full diversity gain. Cluster-head can avoid this situation by setting a predefined threshold value of the received signal strength while selecting CCH. Depending on the number of nodes in the cluster, the CH creates a time division multiple access (TDMA) schedule and sends this schedule to the CCHs and all other sensor nodes. At the same time, the CH informs the cooperative CH selection. As soon as the CCHs receive the schedule from the CH they will broadcast an acknowledgement signal towards all sensor nodes. Once the cluster formation is completed, the SNs always communicate with the CH and CCHs of their own cluster. Therefore, only the SNs within the cluster need to receive the acknowledgements from CCHs to adjust the transmission power. The SNs can adjust their transmission power according to the strength of the broadcast signals from CH & CCHs. Therefore, CH & CCHs can receive the local transmission reliably. The overhead of this procedure is about transmitting few extra bits along with the TDMA schedule.

Modified steady-state phase: The sensor nodes start transmitting data and due to the broadcast nature of wireless transmission, cluster-head and all the cooperative cluster-heads will receive these transmissions. Similarly to LEACH protocol, we consider all the sensor nodes transmit information in their allocated time slot. We also consider that the neighboring clusters are using different orthogonal channels to avoid the inter-cluster interference. After receiving the information from all sensor nodes, cluster-head and cooperative cluster-heads perform data aggregation and some other signal processing if necessary, prior to transmitting them to the sink node using proper signaling structure of cooperative transmission. All kinds of signal processing at the CH nodes are beyond the scope of our analysis and it is straight forward that additional signal processing does not affect our protocol when all head nodes (CH and CCHs) use the same signal processing techniques.

C. Cooperative Transmission

In conventional cooperative transmission protocols [4]–[8], relay terminals have to process their partner's received signals. However, current limitations in radio implementation preclude the terminals from full duplex operation, i.e., transmitting and receiving at the same time and frequency band [4]; thus, conventional cooperative protocols ensure half-duplex operation. Surprisingly, our cross-layer design approach overcomes this major limitation of cooperation technique. In this proposal, CH and CCHs are gathering data independently from the sensor nodes at the same time. Therefore, CH and CCHs do not require exchanging information among them for cooperation. Existing virtual MIMO based cooperative protocols, for examples [10]–[14], require exchanging information among the cooperating nodes. This fact allows us to use a full rate transmission similar to direct transmission using LEACH. We propose a virtual MIMO communication architecture with distributed space time block code (DSTBC) where CH and CCHs transmit at the same time and same frequency [8]. Hence, our proposal can offer the same diversity order as existing protocols [10]–[14] with higher spectral efficiency. In case of perfect local communication, the received signal of DSTBC has the form of M-branch maximal ratio combining (MRC). The bit error rate (BER) probability of DSTBC signaling structure for binary phase shift key (BPSK) modulation in terms of long-haul signal to noise ratio (SNR) derived in [17] and can be given as,

$$P_b = \left[\tfrac{1}{2}(1-\mu)\right]^M \sum_{k=0}^{M-1} \binom{M-1+k}{k} \left[\tfrac{1}{2}(1+\mu)\right]^k \quad (3)$$

where $\mu = \sqrt{\frac{\bar{\gamma}_{long}}{1+\bar{\gamma}_{long}}}$ with average long-haul received SNR $\bar{\gamma}_{long}$.

BER performance of cooperative LEACH ($M > 1$) and conventional LEACH ($M = 1$) is shown in Fig. 2. Numerical BER expression of (3) is also verified with simulations for different number of CCH. The solid lines represent simulation results and the points represent numerical results found from BER analysis. For all M, the simulation results perfectly matched with the numerical results of BER expression of (3). Simulation and numerical results show that proposed cooperative LEACH protocol outperforms the conventional LEACH for all values of M. For simplicity, we present the BER performance for BPSK modulation only. Similar results for other modulations are available

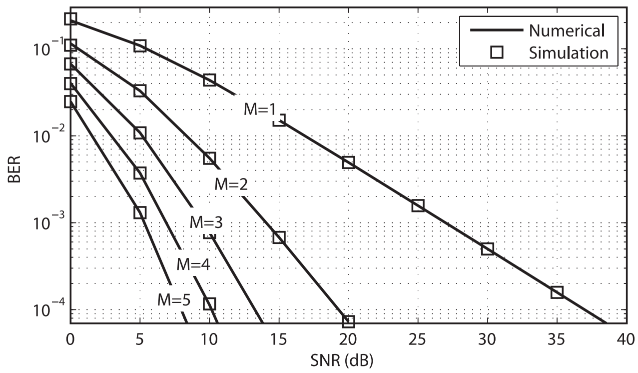

Fig. 2. BER performance comparison of LEACH and coop-LEACH protocol.

in the literature [17], [18] and can be easily adapted with our proposal.

IV. ENERGY MODEL

Wireless sensor networks are highly energy limited, therefore, we need to consider all the sources of energy consumption while comparing the protocols. The total energy consumption of our proposed cooperative LEACH protocol can be divided into three major parts: The energy consumption in cluster setup, energy consumption in local transmission, and energy consumption in long-haul transmission. For simplicity of analysis, we include cluster setup energy in local communication energy. Each of the energy components can be divided into two parts: Transmission energy and the transmitter and receiver circuit energy dissipation. The transmission energy is the energy required at the transmit amplifier to achieve an acceptable SNR and the circuit energy dissipation is the energy dissipated by the transmitter and receiver electronics. The total energy equation is given by

$$\begin{aligned} E &= E_{local} + E_{long} \\ &= E_{t\_local} + E_{c\_local} + E_{t\_long} + E_{c\_long} \end{aligned} \tag{4}$$

where the subscripts c represents circuit energy dissipation, t represents transmission energy, $long$ represents long-haul communication and $local$ represents local communication.

Local communication: A free space propagation model with AWGN is considered for local communication. The received signals at the CH and CCHs are defined by (1). According to the Friis free space equation [16], the received power at the receiver antenna can be given as

$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L} \tag{5}$$

where P_t is the transmit power, G_t & G_r are transmitting & receiving antenna gain, λ is the carrier weave length, d is the distance between transmit and receive antenna and L is the system loss factor. For the local communication, we consider that the sensor nodes can adjust their transmit power by estimating the distance. In case of LEACH, this distance d is simply the SN to CH distance and for cooperative LEACH this distance is the maximum of SN to CH/CCHs distance. If the bit rate of the system is R_b, the transmit power can be represented as

$$P_t = \varepsilon_{amp\_local} R_b d^2 \tag{6}$$

where ε_{amp_local} is the energy required at the transmit amplifier to achieve an acceptable SNR at the receiver. Now from (5) and (6), we can get

$$\varepsilon_{amp\_local} = \frac{P_{r\_th}(4\pi)^2}{R_b G_t G_r \lambda^2} \tag{7}$$

where P_{r_th} is the threshold value of the received power for error free reception at the receiver. We consider the same model proposed in LEACH protocol. In [1], the authors assumed that for error free reception destination requires a SNR of 30 dB with a noise figure of -82 dBm. Hence, $P_{r\_th\_local} > 30 - 82 = -52$ dBm $\cong 6.3$ nW. Considering the same trend of [1], i.e., $G_t = G_r = 1, \lambda = 0.328, L = 1$, and $R_b = 1$ Mbps we can calculate as, $\varepsilon_{amp\_local} = 10$ pJ/bit/m^2.

Long-haul Communication: For fair comparison with the LEACH we consider, CH and CCH of cooperative LEACH share the same total energy in long-haul transmission as

$$P_{CH}^{L} = P_{CH}^{CL} + \sum_{m=1}^{M-1} P_{CCH,m}^{CL} \tag{8}$$

where P_{CH}^{L} is average transmitting power from CH of LEACH protocol and P_{CH}^{CL} & $P_{CCH,m}^{CL}$ are average transmitting power from CH & CCHs of cooperative LEACH protocol. We avoid the optimal power allocation technique that requires channel state information (CSI) at transmitters [18] and assume equal power allocation $P_{CH}^{CL} = P_{CCH}^{CL} = P_{CH}^{L}/M$ for simplicity.

For long-haul communication, we consider a two ray propagation model and the received signals at the CH and CCHs are defined by (2). According to the two-ray ground propagation equation [16], the received power at the receiver antenna can be given as

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4} \tag{9}$$

where h_t and h_r are the height of the transmitting and receiving antenna above ground. If the bit rate of the system is R_b, the transmit power can be written as

$$P_t = \varepsilon_{amp\_long} R_b d^4 \tag{10}$$

where ε_{amp_long} is the energy required at the transmit amplifier to achieve an acceptable SNR at the sink node. Now from (9) and (10), we can get

$$\varepsilon_{amp\_long} = \frac{P_{r\_th}}{R_b G_t G_r h_t^2 h_r^2} \tag{11}$$

where P_{r_th} is the threshold value of the received power. In case of the long-haul transmission, we consider that the channels are subjected to the Rayleigh fading. Hence, the adjustment of the transmit power to achieve an error free communication requires channel state information (CSI) at the transmitting nodes (CH and CCHs) which is very difficult to obtain in practical case. In this paper, we assume that CSI is available only at the

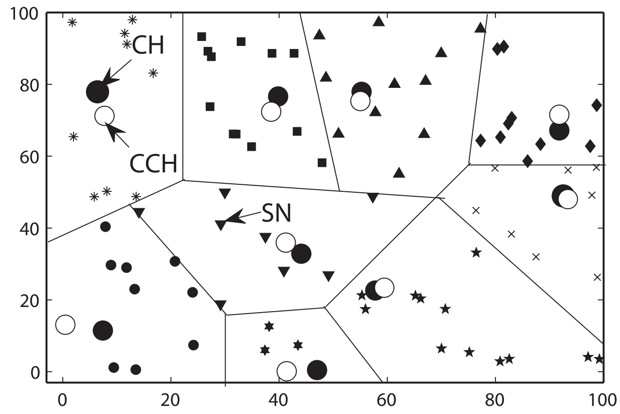

Fig. 3. Clustering of any arbitrary round for $M = 2$.

corresponding receivers. Therefore, we consider that the CH and CCHs transmit data with an average power to achieve an arbitrary small BER at the sink node. It is clear from Fig. 2 that the performance of the proposed cooperative LEACH protocol increases logarithmically as the target BER decreases. We chose a moderate value of 10^{-4} as target BER for our energy analysis. Fig. 2 shows that a BER of 10^{-4} can be achieved by the LEACH at 35 dB and the cooperative LEACH protocol at 20 dB, 14 dB, 10 dB, and 8 dB SNR for $M = 2, 3, 4$, and 5, respectively. The corresponding received power for the LEACH protocols can be given as, $P^L_{r\_th\_long} > 35 + (-82) = -47$ dBm $\cong 20$ nW.

Now considering the similar parameters of local communication along with $h_t = h_r = 1$ m, we can get, $\varepsilon^L_{amp\_long} \cong 0.02$ pJ/bit/m^4. Using the similar approach, we can calculate the energy required at the transmit amplifier for the cooperative LEACH protocol corresponding to the SNR required to achieve a BER of 10^{-4}. The values of $\varepsilon^{CL}_{amp\_long}$ for $M = 2, 3, 4$, and 5 are listed in Table 1. The circuit energy dissipation for local and long-haul communication, E_{c_local} and E_{c_long} are modeled similarly as original proposal of [1] and given in Table 1. We also consider data aggregation method at both CH and CCHs that can compress the data with a ratio of $r : 1$ [3]. We include the energy consumption for data aggregation in long-haul circuit energy.

V. SIMULATION RESULTS

In this section, we perform Monte Carlo simulation in MATLAB to evaluate the performance of both LEACH and cooperative LEACH protocol. Assume all sensor nodes have data of block size 2000 bits. We consider a 100 node network as shown in Fig. 3. Here, the nodes are randomly distributed over the area $K \times K$ and sink node is located Y meters from the nearest sensor node ($x = K/2,\ y = -Y$). The clustering shown in Fig. 3 is for any arbitrary round with $M = 2$. Table 1 summarizes the simulation parameters used for the comparison of protocols. Throughout the simulation, we consider the parameters of Table 1 unless otherwise stated. In cooperative LEACH protocol, SNs adjust their transmit power on the basis of the distance from CH and CCHs. For reliable reception at CH and all CCHs, each SN will calculate it's transmit power corresponding to the maximum one of the distances. Local communication also includes the cluster setup procedure and the proposed cooperative LEACH protocol introduces some overhead for selecting the CCHs and synchronization among CH and CCHs. To compensate this overhead, we consider cooperative LEACH protocol transmits extra 100 bits along with the data packet of 2000 bits in local communication.

Table 1. Simulation parameters.

Nodes	100
Network size ($K \times K$)	$100\ m \times 100\ m$
Sink node position $(K/2, -Y)$	$(50, -150)$
Packet size	2000 bits
Data rate	1 Mbps
Target BER	10^{-4}
Circuit energy dissipation	50 nJ/bit
Data aggregation energy	5 nJ/bit/message
Data aggregation ratio ($r : 1$)	$10 : 1$
Percentage of cluster-head	10%
$\varepsilon^L_{amp\_long}$	0.02 pJ/bit/m^4
$\varepsilon^{CL}_{amp\_long}(M = 2)$	0.00063 pJ/bit/m^4
$\varepsilon^{CL}_{amp\_long}(M = 3)$	0.00016 pJ/bit/m^4
$\varepsilon^{CL}_{amp\_long}(M = 4)$	0.000063 pJ/bit/m^4
$\varepsilon^{CL}_{amp\_long}(M = 5)$	0.0000398 pJ/bit/m^4

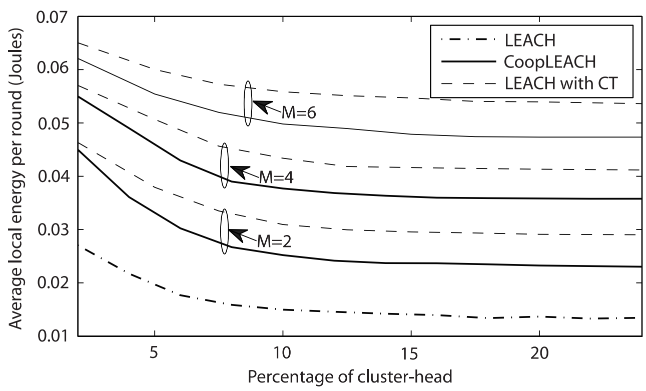

Fig. 4. Comparison of local communication energy consumption of the protocols for different number of CHs.

Fig. 4 shows the amount of energy dissipated per round in the local communication for LEACH and cooperative LEACH with the percentage of CH (percentage of nodes that elected themselves as CH). Simulation results indicate that the cooperative LEACH protocol consumes higher energy than that of the LEACH protocol in local communication. The local communication energy of the cooperative LEACH increases as the number of CCHs increases. The sources of this extra energy consumption are the increased local communication distance and the extra receiving operations at the increased number of CCHs. As the percentage of CH increases the local communication dis-

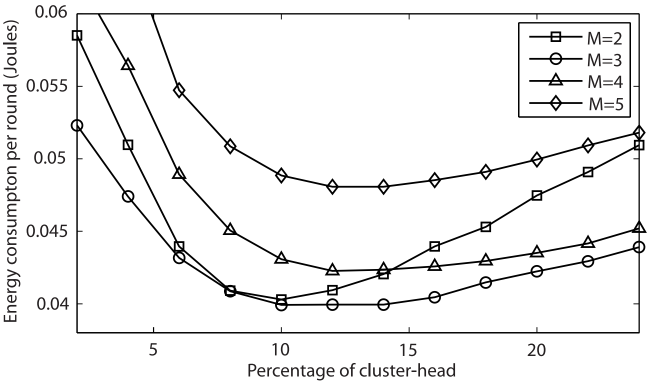

Fig. 5. Total energy consumption of cooperative LEACH protocol.

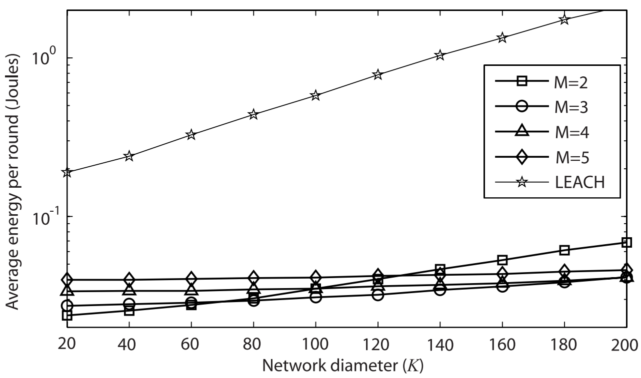

Fig. 6. Average energy dissipated per round with various network diameters (K) for LEACH and cooperative LEACH protocols.

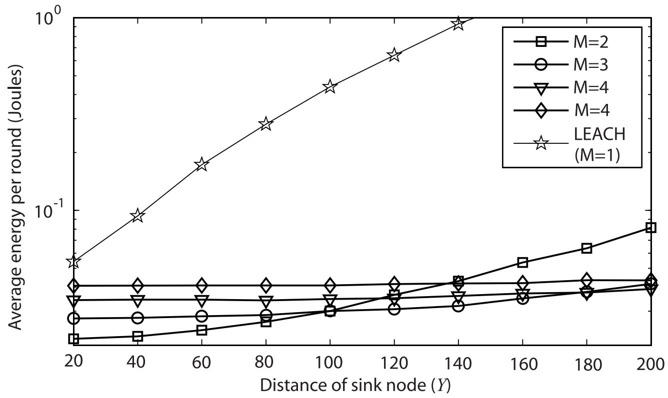

Fig. 7. Average energy dissipated per round with different position of sink node for LEACH and cooperative LEACH protocol.

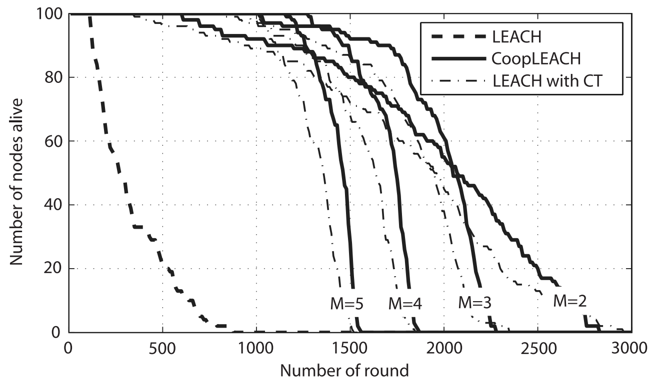

Fig. 8. System lifetime of different protocols when 1 Joule is initially given to each individual node.

tance decreases. This extra power consumption of the cooperative LEACH protocol in local communication is negligible compared with the diversity gain achieved in the long-haul communication shown in the Fig. 2.

The comparison of the local communication cost between proposed cooperative LEACH and LEACH with conventional cooperative transmission (LEACH with CT) is also shown in Fig. 4. The other clustering based virtual MIMO protocols, ex. [13] and [14], work on three-hop transmission. The first hop is local transmission, second hop is exchange of information between CH and cooperative nodes (CCHs), and the third hop is long-haul transmission. On the other hand, our proposal works on two hops by reducing the transmission between CH and CCHs. Hence, it reduces the power required for this transmission. Simulation results show that the proposed cooperative LEACH protocol significantly reduces the energy consumption of local communication compare to the LEACH with CT due to the reduction of the CH-to-CCHs transmission. We model the energy consumption of the long-haul communication using the BER curves of Fig. 2. The received SNR at the sink node for cooperative LEACH and LEACH with CT is the same because they use same transmission technique (space-time-coding). Therefore, the BER curves and the circuit energy consumptions are also same for both protocols. Hence, the long-haul communication cost is obviously the same for both LEACH-CT and LEACH-CP.

In Fig. 5, we observe the total energy consumption per round of the cooperative LEACH protocol with different percentage of CHs. This figure indicates that the energy required for the long-haul communication increases as the percentage of CHs increases; whereas, the energy consumption in local communication decreases with the increasing percentage of CHs. Therefore, the total energy consumption in cooperative LEACH decreases with the increase of the percentage of cluster-heads up to a certain limit. This characteristic of the total energy consumption suggests an optimal percentage of CHs. The optimal percentage of CH depends on several parameters, such as network topology, relative cost of consumption and communication energy, aggregation ratio, target BER, etc [1]. Simulation shows that the optimal number of CH is about 10% for $M = 2$ and 3 and 12% for $M = 4$ and 5. Fig. 5 also gives us an idea about optimal number of cooperating nodes (CH/CCHs) inside a cluster. At the optimal percentage of CHs, the energy consumption is almost same for $M = 2$ and 3 and it increases as M increases. For rest of our simulations, we consider 10% CHs for all values of M.

In Figs. 6 and 7, we investigate the effect of the network topology on our proposal. For this purpose, we change the network diameter (K) in Fig. 6 with a fixed distance of the sink node

$Y = 120$ meters. Increasing the value of K is equivalent to decreasing the node density of the network. From Fig. 6, it is clear that the energy saving in the cooperative LEACH over the LEACH protocol increases as the node density decreases, for all values of M. Fig. 7 shows the similar results for the distance of the sink node with a fixed network size of 100 $m \times 100$ m. The energy saving also increase as the distance of the sink node increases. Specifically, the proposed protocol can save a huge amount of energy when the sink node is far away from the sensor field as shown in Fig 7. Figs. 6 and 7 also indicate that the optimal number of cooperating nodes (CH/CCHs) is a function of the network size. For small network, only one CCH along with a CH ($M = 2$) is optimal. As the network size increases, the optimal number of cooperating nodes also increases. For a large network, the increment in energy saving offers by increased number of cooperating nodes is very small.

Fig. 8 shows the comparison of lifetime of a sensor networks that use cooperative LEACH (CoopLEACH), LEACH and LEACH with cooperative transmission (LEACH with CT) proposed in [13]. We consider each node initially starts with 1 Joule of energy. Fig. 8 indicates that cooperative LEACH protocol can increase the system lifetime more than ten times compare with conventional LEACH in terms of both 50% nodes to die and first node to die. This huge improvement in network lifetime is achieved due to the diversity gain of long-haul transmission. As we discussed before, the optimal number of cooperating nodes dependents on the several network parameters. Fig. 8 shows that the maximum network lifetime is achieved by $M = 2$ and 3 when 50% nodes to die is considered. If we consider first node to die as a performance parameter, $M = 4$ provides longer lifetime than that of other values of M. Importantly, the network lifetime for $M = 5$ is always worse than that of $M = 4$. Fig. 8 indicates that the proposed cooperative LEACH protocol also distributes the energy uses among the nodes in the network similar to the LEACH protocol. This distribution becomes more even when the number of cooperating nodes is high.

In Fig. 8, we compare the lifetime of our proposal with the proposal of [13]. Our proposal reduces the number of the transmission between CH and CCHs hence, it reduces the power required for this transmission as shown in Fig. 4. The proposed protocol outperforms LEACH with CT with the same CCHs selection and energy model. This extra transmission also causes to increase the end-to-end delay when time division multiplexing is used as channel access method. The protocol proposed in [14] also offers a diversity of order 2 with one primary cluster-head and one secondary cluster-head but sacrifices some performance due to synchronization error. Therefore, cooperative LEACH protocol improves the energy efficiency over [13] and [14] with reduced complexity and delay.

VI. CONCLUSION

A novel virtual MIMO based LEACH protocol for wireless sensor network is presented. Proposed cooperative LEACH protocol can reduce huge energy consumption with the same bit error rate, spectral efficiency and delay requirements compared with LEACH in Rayleigh fading environment. Saving energy equivalently prolongs the network lifetime which is a prime performance criterion of WSN. We consider all the sources of power consumption in wireless nodes- transmit and receive electronic, transmit amplifier, cluster setup etc. Analysis and simulation results show that our proposal outperforms conventional LEACH protocol with maintaining all the advantages of LEACH protocol. We also measure the performance of our proposal with various network parameters and in all cases cooperative LEACH shows better performance than the existing protocols. The optimal number of cooperating nodes (M) is also analyzed. Analysis shows that the optimal number is dependent on various network parameters.

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