Performance Optimization in Wireless Sensor Networks: A Novel Collaborative Compressed Sensing Approach

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***Abstract*—In this paper, we present need-based clustering (NbC) with dynamic sink mobility (DSM-NbC) scheme for WSNs using a collaborative compressed sensing approach. The scheme incorporates dynamic sink mobility in a way that mobile sink moves from dense regions towards sparse regions. Intelligently moving the sink to high density regions ensure maximum collection of data. As more number of nodes are able to send data directly to the mobile sink, therefore, significant amount of energy is saved in each particular round. However, there is a certain limitation to this approach. Nodes which are far from sink have to wait much for their turn. So, there are chances of buffer overflow that is not desirable. To overcome this issue, our scheme includes NbC. Clustering (communication via cluster heads) becomes the part for those regions which are away from mobile sink. Most importantly, we deploy a collaborative communication scheme that significantly reduces the energy consumption and increases network lifespan. Simulation results show that DSM-NbC outperforms other protocols in terms of stability period, network lifetime and computational complexity.**

Keywords*—cluster heads (CHs), compressed sensing (CS), coverage holes, energy holes, wireless sensor networks (WSNs)

I. Introduction

Wireless sensor networks (WSNs) consist of tiny, portable and energy limited nodes that are capable of transmitting the data of interest using wireless communication. Such development of a sensor network offers great promise for a number of real time applications including, but not limited to, capturing information and processing it for military application such as battlefield surveillance [1], [2], target tracking and remote environmental monitoring [3], and an amazingly increasing interest towards applications like refineries, petrochemicals, underwater development facilities and oil and gas platforms [4].

The sensor nodes are usually deployed in a field to monitor various signals of interest. The nodes being small in size and limited in energy open floors for novel approaches to optimize their performance. This problem can be tackled by efficient energy utilization which ultimately prolongs the network lifetime. A number of possible ways to solve this problem have been proposed in the literature for reducing the energy consumption. Out of these, clustering [5] has proved to be the most significant one. Such cluster-based techniques, where a single node serves as the cluster head (CH) throughout the network life time, ensure efficient distribution of nodes and thus control redundant transmissions. The clustering technique is used to perform data fusion i.e, combines the data from source nodes into a small set of meaningful information. Moreover, it reduces the number of messages transmitted and thus saves energy. An enhanced performance is obtained when dynamic clustering is used instead of static clustering, where in each round a different CH is selected based on specified measure. Many dynamic clustering-based energy efficient routing protocols are proposed to optimize energy consumption (e.g., see [6], [7]).

Another performance dependent factor is the type of communication and base station (BS) being used in the underlying network. Different communication schemes such as direct and multihop are used for data transmission in small and large scale networks. When the network size is large, nodes near the BS or sink act as a relay for data transmission of the other nodes far from the sink. Therefore, these nodes die quickly due to more energy consumption. This creates the bottleneck which is removed by introducing a mobile sink (MS) in the network. MS is responsible for effective load balancing, reducing hotspot problem (energy depletion of near-sink nodes) and hence, improving network lifetime. It moves in the network and collects data directly from the nodes saving their energy i.e, nodes send data to MS when it comes in the predefined sensing range. In this way, the multi-hop transmission between nodes is avoided and energy usage is optimized.

A. Sparse Reconstruction

Recently, compressive sensing (CS) based approaches have been used widely by mathematicians, computer scientists and engineers for a variety of applications in astronomy, biology, medicine, radar and seismology, to name a few [8]. Due to the inherent sparse nature of many natural signals, CS has gained tremendous attention over the past few years. The idea is that a signal can be represented by fewer components in a transformed-domain. However, successful recovery of the sparse coefficients is always a challenging task especially in case of generally introduced AWGN noise. For this, having known that the observed signals are always sparse abundant, modified CS algorithms can be used to recover such sparse signals from under-determined model of linear equations having the form

$$\chi = \Theta \upsilon + \omega, \tag{1}$$

where $\chi \in \mathbb{C}^M$ and $\upsilon \in \mathbb{C}^N$ are observed signal and unknown sparse signal that a node will collect. Moreover, $\Theta \in \mathbb{C}^{M\times N}$ is a known dictionary matrix and $\omega \in \mathbb{C}^M$ is i.i.d

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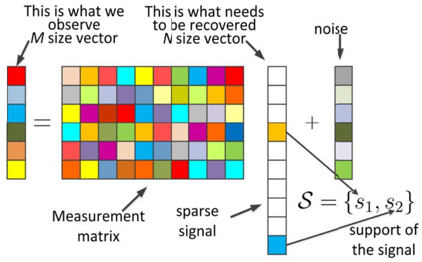

Fig. 1. Sparse Model

zero mean Gaussian noise vector with variance $\boldsymbol{\sigma_\omega^2}$ i.e., $\omega(.) \sim \mathcal{N}(\mathbf{0}, \boldsymbol{\sigma_\omega^2} \mathbf{I})$.

The objective is to restore a degraded data signal, denoted by $\hat{\mathbf{f}}_{denoised}(n)$, collected by sensor nodes as close as possible to its original form. For this, we use the model of (1), a depiction of which is shown in Fig. 1. As we can see, the number of unknown elements N in such a scenario is much larger than the number of observations M i.e., N $\gg$ M. With CS, a true signal can be reconstructed by linear projections of the sparse signal using ℓ_1-optimization with high probability [9].

$$\hat{\upsilon} = \underset{\upsilon}{\mathbf{argmin}} \|\upsilon\|_1 \text{ such that } \|\chi - \boldsymbol{\Theta}\upsilon\|_2 \leq \zeta), \quad (2)$$

where $\zeta = \sqrt{\boldsymbol{\sigma_\omega^2}(M + \sqrt{2M})}$.

B. Contribution

In light of the above discussion, we propose to use a dynamic clustering and sink mobility based collaborative sparse recovery framework to optimize the energy usage and prolong network life. For this, once the nodes are deployed in the network field area, node density is calculated in different regions of the field. MS moves from denser area towards areas of lower node density. This is because demand for data collection is high in dense regions. Now, apart from the region in which MS lies, nodes from other regions communicate with MS via CHs. As a consequence, nodes do not have to wait much for MS to come in their region, thus, assuring less data loss and efficient communication.

For the collected data itself, we transmit the sparse coefficients and use a pre-defined dictionary to recover the original signal at the receiver end. To ensure successful recovery of the sparse coefficients, and hence the data, we collaborate between the data of adjacent sensors. This is done by calculating the probability of active components of the coefficients in the transformed domain. Once we have the probability vectors, we get enhanced sparse vectors by collaborating between the adjacent sensors. This ultimately leads not only in increasing network throughput[1] but also helps reducing the energy usage by only transmitting fewer sparse components. To the best of our knowledge, such a collaborative CS based approach using sink mobility has never been used in the literature. This motivates us to name our algorithm DSM-NbC: dynamic sink mobility and need-based clustering (NbC). The key features of our proposed algorithm are as follows:

- Our approach compute support-agnostic sparse estimates giving us probability of active taps. So the algorithm don't have to compute any distribution and is independent of the signal support distribution.
- Refining sparse estimates via the collaboration step tremendously improves performance.
- The algorithm lends itself low computational complexity.

Rest of the paper is organized as follows: section II provides related work with motivation. A detailed description of the proposed algorithm is presented in section III. Section IV takes into consideration the discussions of simulation results, and section V ends the research work with conclusion.

II. Related Work

This section provides the readers with comprehensive literature review including papers on clustering and sink mobility in WSN.

A. Clustering Protocols

LEACH [5] is the clustering protocol for homogeneous WSNs which targets to reduce global communication by the formation of local clusters of nodes based on minimum distance or received signal strength. In each cluster, CH is selected randomly, which is responsible for data aggregation and fusion. CH then further transmits data to base station (BS), thus saving energy (number of transmissions and distance is reduced). BS and sink are interchangeably used in this work.

In [10], authors have proposed a routing protocol, TEEN, with the capability to react immediately after the detection of changes in the sensed attribute of interest. The CHs selection and nodes' association techniques are similar to those of LEACH. The difference lies in data transmission only. In LEACH there is no check on transmission of data. However, in TEEN there is hard and soft threshold based transmission.

Considering nodes heterogeneity, SEP [11] defines two energy levels. Based on these energy levels, nodes are categorized into two types i.e., the first type of nodes are normal while the second type are advanced. Advanced nodes carry α times more energy than that of the normal ones. Therefore, advanced nodes are more preferred for the selection of CHs due to their assigned probability weights. Rest of the protocols operation is same as LEACH.

The authors in [12] proposed a new routing protocol for heterogeneous WSNs called DEEC. In this protocol, different sensors are given different levels of energies as the network operation begins. The CH selection is based on the ratio of node's residual and network's average energy. For CHs selection in a particular round, any node with higher residual energy is selected as CH. This results in even energy distribution among the nodes. DEEC prolongs stability period as the nodes with increased residual energy become CHs more frequently. The CH formation in DEEC is similar as in LEACH. However, the probability for nodes to become CHs is different.

[1]The collaboration among different sensors will take care of the added noise and will produce a clean estimate of the signal sent by the normal nodes.

B. Sink Mobility in WSN

Authors in [13] proposed adaptive mobility solution for WSNs. According to this solution, MS moves inside the network according to the current events. This significantly reduces energy consumption acquired by the multi-hop transmission of event-driven data.

In [14], authors have explored sink mobility in WSNs to extend the network lifetime. Distance constrained MS problem is being formulated to find an optimal sojourn tour (complete trip by considering all stop locations) by using mixed integer linear programming (MILP) model.

M. Gatzianas, et al. presented a distributed algorithm in [15] for calculating the maximum lifetime of a WSN which routes data to the MS. The problem is further reduced into a simpler equivalent form and solved via dual decomposition.

In [16], authors have proposed a method based on the Set Packing Algorithm (SPA) and Travelling Salesman Problem (TSP). The goal is to achieve high efficiency in terms of gathering data from the sensor nodes by using MS.

Framework for improving the network lifetime by utilizing sink mobility in delay-tolerant applications (applications which tolerate delayed information delivery to the sink) is proposed in [17]. Authors of this paper have formulated optimization problem to maximize the network lifetime, subject to constraints of delay bound, energy and flow conservation.

Waleed Alsalih, et al. proposed a mobile data collector placement scheme in [18] for extending the lifetime of the network. Placement problem is formulated as MILPs and its solver is used to find near-optimal placement (of data collector) and routing paths to deliver data.

Authors in [19] have proposed a biased adaptive sink mobility scheme. Based upon local network conditions such as surrounding density and residual energy, adaptive mobility is defined. According to which the sink moves probabilistically in the areas less visited (to cover the entire network field in less time) and adaptively stopping in the regions of high density (to collect more amount of data). Both randomized mobility and optimized deterministic traversals are being proposed in this work. This method achieves significantly reduced latency without compromising the energy efficiency and delivery success.

Jin Wang, et al. considered mobile sink based uneven clustering algorithm in [20] to improve network performance for WSNs. The behavior of uneven clustering algorithm is studied with fixed sink node and a mobile sink node respectively. In clustering algorithm, CHs selection is mainly based on competition range and residual energy to guarantee data collection and transmission. The sink movement is defined along a predetermined path with sojourn at some special locations to communicate with nodes. The proposed algorithm greatly improves energy efficiency and extends network lifetime.

In direct transmission [21], each node in the sensor network communicates directly to BS. In the aforementioned protocol, farthest nodes die faster than the nearest nodes. In minimum transmission energy routing protocol [22], each node transmits to its nearest node so the nearest nodes die at a faster rate because they receive data from the farther nodes. In the current body of research going in the field of WSNs, clustering based protocols have attained significant attraction. In clustering based routing protocols, the sensor nodes form clusters. In these clusters, one node is selected as CH. The nodes sense data and send it to their respective CHs which aggregate and fuse the data, thus saving the energy since global communication is reduced due to local compression.

Authors in [23] work on the investigation of compressed sensing in wireless sensor networks. They propose to reduce the energy consumption by CS and joint routing using a greedy heuristic. The extra usage of energy is taken care of by using an optimization problem followed by proving its NP-completeness.

C. Motivation

Most of these proposed schemes create execution overhead of the nodes in the dense network and this overhead is directly proportional to the number of nodes in the field (network density). More number of nodes will require the mobile sink(s) to take large number of pauses increasing the waiting time of the farther nodes to transmit (critical) data.

Furthermore, all of these rely on transmitting the data in its original form. Most importantly, the data compressed using CS techniques yield very corrupt data especially in case of noise. So energy is conserved at the cost of lost data. In this paper, we propose and implement DSM-NbC protocol, which targets to reduce the energy by reducing the waiting time using NbC. Further, the data is successfully recovered using a novel collaborative approach.

III. Proposed Protocol Design

In this section, detailed description of proposed routing protocol is provided.

A. Radio Model

We assume the commonly used simple first order radio model [24]. The radio parameters for our model are shown in table 1. We also take into account d^2 energy losses due to channel transmission. Thus, to transmit a k-bit message at distance d, the mathematical expressions are:

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{mp}}} \quad (3)$$

$$if d < d_o \qquad E_{Tx}(k,d) = E_{elec} \times k + \epsilon_{fs} \times k \times d^2 \quad (4)$$

$$if d \geq d_o \qquad E_{Tx}(k,d) = E_{elec} \times k + \epsilon_{mp} \times k \times d^4 \quad (5)$$

$$Reception\ Energy: \qquad E_{Rx}(k) = E_{elec} \times k \quad (6)$$

B. Network Model

We consider a WSN with different number of nodes deployed randomly in a network field. The area under observation is divided in four quadrants Q_1, Q_2, Q_3 and Q_4, with each quadrant further subdivided into four regions i.e., total 16 regions. Sink is placed in center of the field at (x_1, y_1).

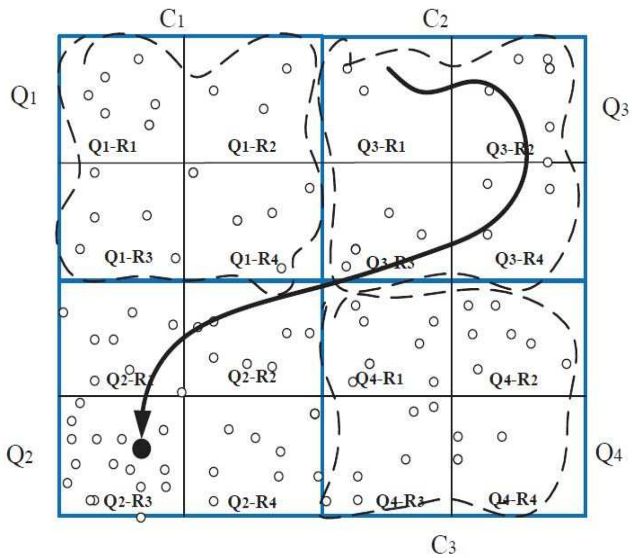

Fig. 2. Deployment of Nodes

1) Cluster Formation: Firstly, the network is divided into Z equidistant concentric squares. In our case, the entire network field is divided into $Z = 16$ regions. Nodes are deployed randomly and distributed uniformly in each region. Following equations divide network field into concentric squares:

$$T_r^{I_s}(x_2, y_2) = (x_1 + \beta, y_1 + \beta), \tag{7}$$

$$B_r^{I_s}(x_2, y_2) = (x_1 + \beta, y_1 - \beta), \tag{8}$$

$$T_l^{I_s}(x_2, y_2) = (x_1 - \beta, y_1 + \beta), \tag{9}$$

$$B_l^{I_s}(x_2, y_2) = (x_1 - \beta, y_1 - \beta), \tag{10}$$

where I_s is a reference square and β is the distance from the center of network field to the boundary of I_s. $T_r^{I_s}$,$T_l^{I_s}$,$B_r^{I_s}$ and $B_l^{I_s}$ are the top right, top left, bottom right and bottom left corners of square I_s, respectively. Using equations (7)-(10), square regions can be formed for any concentric square.

2) Dynamic Sink Mobility based on Node Density: Sink moves towards the region of highest density in each round. Therefore, maximum coverage of data gathering is ensured. In this way our protocol incorporates dynamic/adaptive sink mobility.

3) NbC: At any point (regarding sink position), the nodes which are not in the close range (sinks quadrant) of sink become the part of clusters. The basic mechanism of clustering is involved i.e., nodes send data to CHs and then CHs communicate with sink. The whole scenario is shown in Fig. 2.

TABLE I. **RADIO PARAMETERS**

Operation	**Energy Dissipated**
Transmitter/Receiver E_{elec}	$50nJ/bit$
Data Aggregation Energy	$5nJ/bit/signal$
Transmit Amplifier ϵ_{fs} ($d_{BS} < d_o$)	$10pJ/bit/4m^2$
Transmit Amplifier ϵ_{mp} ($d_{BS} \geq d_o$)	$0.0013pJ/bit/m^4$

C. Protocol Operation

DSM-NbC operates in number of steps or phases. These steps are discussed in detail in the following subsections.

1) Phase 1 - Node Deployment: Initially, nodes are randomly deployed in the network field. This means sensor network is formed with non-uniform node distribution.

2) Phase 2 - Regions Formation: After the deployment of nodes, field is divided into four quadrants named as Q_1, Q_2, Q_3 and Q_4. Each quadrant is further sub-divided in four regions (Q_1-R_1, Q_1-R_2, Q_1-R_3, Q_1-R_4, Q_2-R_1...).

3) Phase 3 - Calculating Node Density: The third step is to calculate node density (nodes per unit area) of each region. Finding the region with maximum number of nodes and then moving the sink to that region (at a particular round) is of a key interest since maximum data can be retrieved i.e., demand for data collection in the respective region is high.

4) Phase 4 - Adaptive Sink Mobility: MS provides energy efficient direct data collection in WSNs. This allows the nodes to reduce their transmission range to the lowest value required to reach the mobile device, thus saving energy. In our case, we propose biased sink mobility with adaptive approach for efficient (with respect to both energy and latency) data collection in WSNs. Sink moves in the direction of dense region in each separate round (shown by the spiral motion in Fig. 2 that point towards most dense region). This movement of sink is beneficial as it allows more number of nodes to transmit data directly to the sink when it lies in the dense region over the shortest route i.e., the sink lies closest to the nodes in such particular region.

5) Phase 5 - NbC: Sink mobility alone is not desirable in most of the cases. This is because the nodes which are far from the sink have to wait much for their turn (considering direct or even multi-hop communication). So to overcome this problem, DSM-NbC involves clustering in those regions which are far from sink. As sink moves to next location in each round, therefore, apart from this quadrant (including four regions), in all of the other quadrants our technique involves clustering. As shown in Fig. 2, C_1, C_2, and C_3 are the clusters formed in the quadrants in which the sink is absent (assuming sink has moved). In each cluster, CHs are selected based on maximum residual energy. Cluster heads, responsible for data aggregation and fusion, in LEACH are randomly rotated over time to balance the energy consumption of nodes. A given node i generates a random number, and compares it with a threshold value; $Th(i)$, given as:

$$Th(i) = \frac{\rho}{1 - \rho \times mod(r, 1/\rho)} \tag{11}$$

Where, ρ is the probability of CHs which is defined initially and $mod(r, 1/\rho)$ returns the modulus after division of r by $1/\rho$. When the value of threshold is greater than the random number, node is selected as CH. In (11), r represents the round in progress. Optimal number of CHs is suggested to be 10% of the total nodes in the network. We termed it as NbC, as clustering is done according to the need. It also ensures energy-efficient communication.

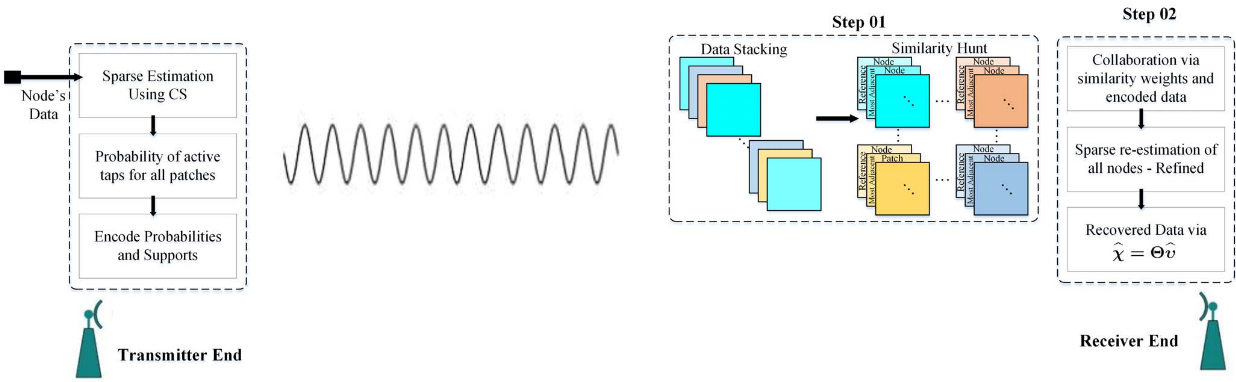

Fig. 3. Communication Block Diagram

6) Phase 6 - Communication: Once the scheme is devised according to which a technique works, then comes the part of data exchange i.e., how to receive data from nodes at sink. In DSM-NbC, nodes communicate directly with sink when it comes in the respective quadrant. However, nodes from all other quadrants transmit the data to the CHs which then transmit it to the sink. The main objective behind direct communication is reduced distance as the sink and the nodes are located in the same quadrant.

Most importantly, the significant contribution towards energy reduction and network throughput lies in the CS based collaborative communication scheme block diagram of which we have shown in Fig. 3. At the transmitter end, we find the sparse representation of the data a node collects and then find the taps on which has active coefficients. This gives us the support as well the probabilities of the active locations. Since this is sufficient enough to represent the data, we encode and transmit it. To find the sparse representation, we use [9] since this algorithm is capable of taking any *apriori* information as well that we take advantage of at the receiver end.

On the other hand, the receiver end has two main steps to process the data. For any node's data received at the receiver end, we first of all hunt for similarity based on adjacency. Once we have a certain number of most adjacent neighbors, we collaborate among the probabilities using weights. The most adjacent neighbor has higher weight and vice versa. This gives us refined probability vector for a reference node [25]. Finally, we recover the original data using the refined probabilist and a pre-defined dictionary composed of wavelet and DCT basis.

7) Phase 7 - Repetition of phases $\mathbf{1-7}$ till last round: The entire functionality of protocol is repeated in each round till the network ends.

IV. Simulations, Results and Discussions

In this section, we evaluate the performance of DSM-NbC. We consider different scenarios with a WSN with $\mathbf{100, 1000}$ and $\mathbf{10000}$ nodes randomly deployed in a field. Initially, we assume the sink outside the field at $(\mathbf{120}, \mathbf{120})$. In comparing the performance of DSM-NbC with other protocols, we ignore the effects of channel interference on the propagation of radio waves. The comparison of proposed protocol is done with LEACH, TEEN, DEEC and SEP protocols. Along with

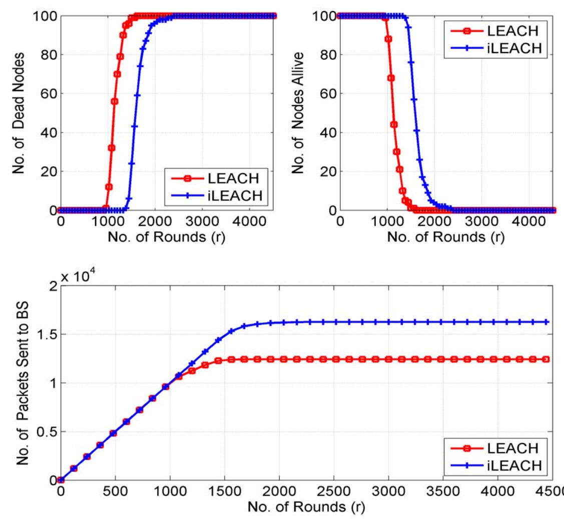

Fig. 4. iLEACH vs. LEACH

implementing the proposed protocol as independent, we also present the improved versions of the existing methods by incorporating our key steps on these and call these iLEACH, iTEEN, iDEEC and iSEP. The parameters of first radio model [26] used in our simulation are shown in Table I. In subject to system's performance, the following metrics are used for evaluation purpose:

1) Stability period: It is defined as time interval from the start of the network till the death of first node. It is measured in units of time (sec) or number of rounds (time period in which network completes its one operation). In our scenario, stability period is taken in terms of rounds. During this period, network remains stable as all nodes are alive and operational. Hence, maximum efficiency is achieved.

2) Network lifetime: Time duration from the start of first round till the death of last node is known as network lifetime. It depends upon the number of nodes and the initial energy assigned to nodes. Moreover, balancing energy consumption of nodes in a better way results in longer network lifetime.

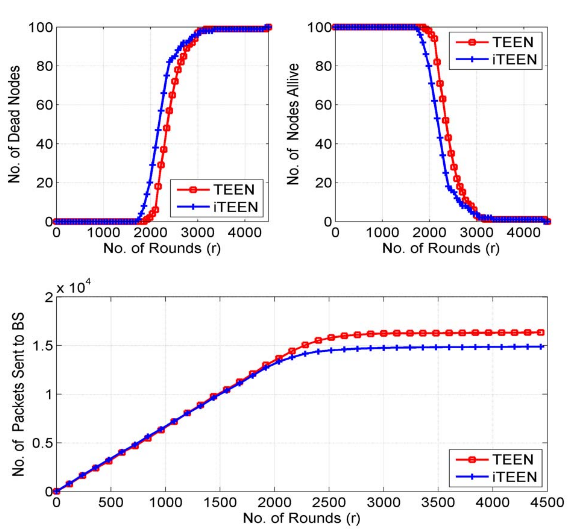

Fig. 5. iTEEN vs. TEEN

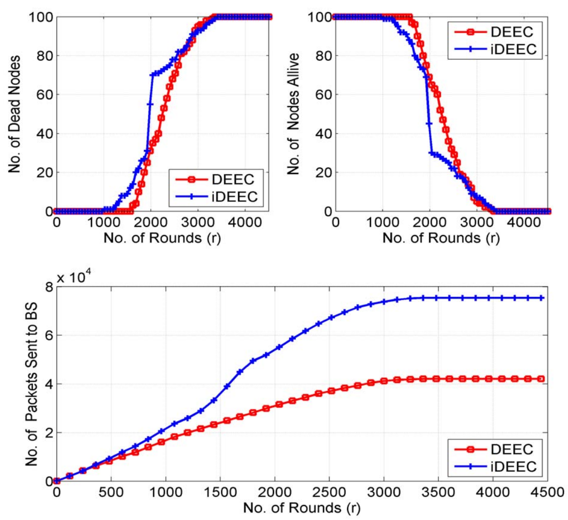

Fig. 6. iDEEC vs. DEEC

3) Number of packets sent to BS: This is the number of packets that are sent directly to sink. The total of all packets (dropped or successfully received) are counted for this number.

4) Number of packets dropped: Sum of all the packets dropped due to bad status of link.

5) Network throughput: This is the number of data packets successfully received at BS. We can say:

Throughput = Number of packets sent to BS -

Number of packets dropped

Generally, throughput has a direct relation with network lifetime i.e., increased lifetime means more throughput and vice versa. Moreover, if number of transmissions increase with

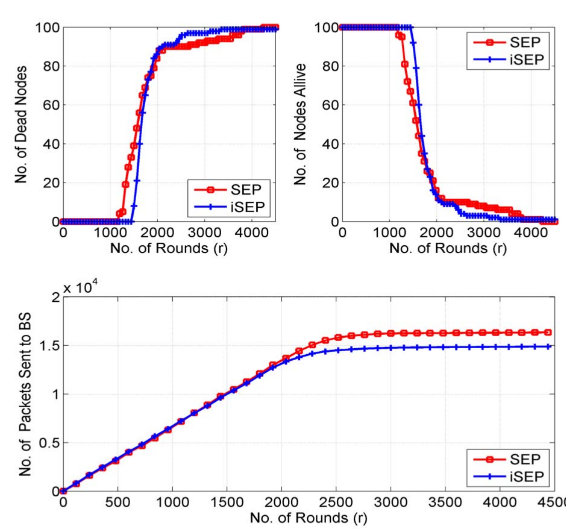

Fig. 7. iSEP vs. SEP

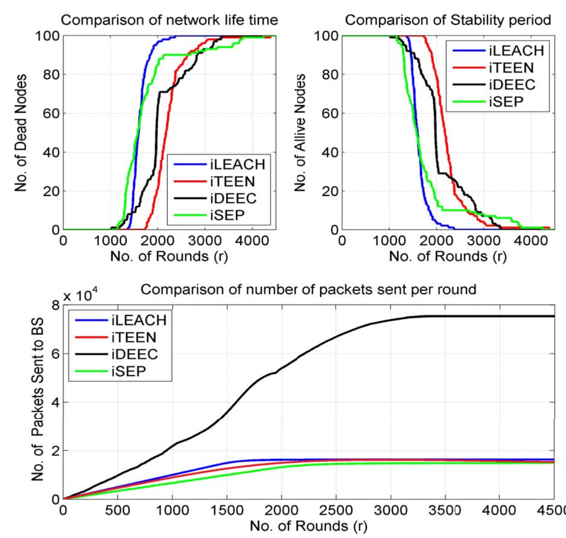

Fig. 8. Comparison of iLEACH, iTEEN, iDEEC and iSEP

the increase of number of nodes, more will be the network throughput.

6) Propagation delay (per packet): Delay encountered during the transfer of packet from source to destination. It is measured in seconds and computed by the given formula; $t = s/v$ where s is the distance between source (node) and destination (CH/sink) and v is the radio propagation speed which is approximately $3 \times 10^8 m/s$. It depends upon the distance and channel conditions.

Fig. 4 shows a comparison of system's lifetime using iLEACH versus LEACH with each node initially given 0.5J of energy. iLEACH shows improved stability period as compared to LEACH since the first node dies at later period. It also

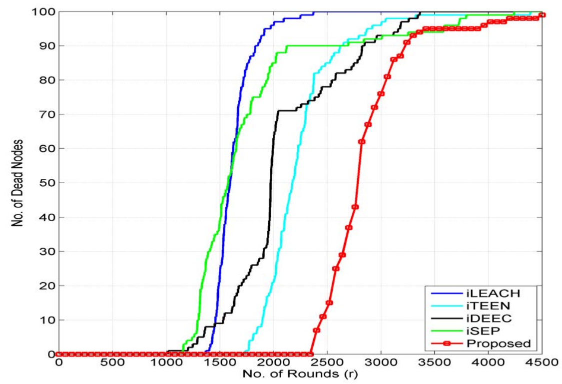

Fig. 9. Network Lifetime Comparison

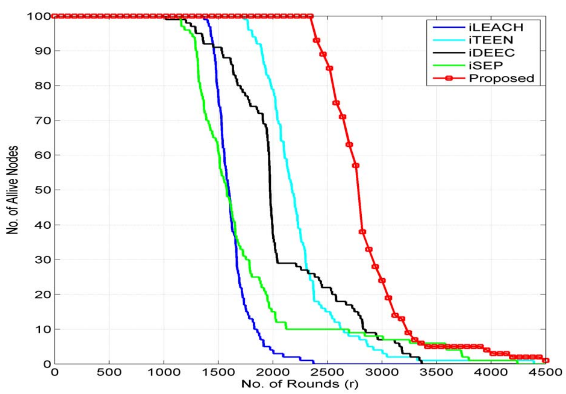

Fig. 10. Stability Period Comparison

depicts enhanced network lifetime because large number of nodes continue their transmission session till more number of rounds. This is due to the provision of sink mobility that facilitate the nodes to communicate over short distance thereby allowing them to save their energy to a significant level.

It is immediate to see that moving the sink always improves the lifetime compared to fixing it. We also see sharpness (slop) in the graph line as the sink moves from denser towards less dense area. This indicates much faster decay of nodes from 900 rounds onwards. iLEACH further prolongs the stability period as it allows more number of nodes to transmit their data directly to the sink when it lies in the denser region over the shortest route i.e., the sink lies closest to the nodes in such particular quadrant. While for other regions, the nodes transmit data to CHs which are responsible for further communication towards sink i.e., according to the need, clusters are formed in the regions which are far from the current position of sink. Clustering ensures energy-efficient communication across the network. Based on these phenomenon, network remains operational till about 3200 rounds. It depicts that sink has arrived to a central point of field by which the node density has been equalized in all regions. So, the nodes transmit data to CHs which then transmit to sink. Hence for such duration, the network appears to be more stable (no node decay).

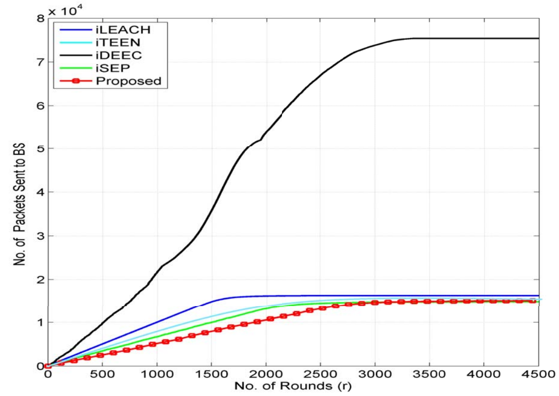

Fig. 11. Number of Packets Sent Comparison

In Fig. 5, we present comparison of iTEEN vs. TEEN, while in Fig. 6 we compare the performance of iDEEC vs. DEEC. We see that due to the nature of the original protocols, there is a difference in how the protocols adapt to the proposed method. For this reason, we observe that iTEEN is not able to outperform TEEN. This is also associated to the reactive nature of the TEEN protocol.

Similarly in Fig. 7, it can be observed that our protocol depicts varying performance due to the original protocol's methodology. Fig. 8 presents a comparison of all the protocols. In this figure, we show the efficiency achieved in the improved versions of the existing methods. Using the efficient transmission of the data, the energy is utilized efficiently. From this figure, it's clear that the proposed methodology optimize the use of energy.

The comparison of network lifetime is shown in Fig. 9, while Fig. 10 presents the comparison of stability period. Here we show that even the improved versions of the original protocols depict varying performance, the network in the proposed standalone protocol DSM-NBC exists for a longer period and has the capability to transmit the data for a longer time. The nodes in LEACH send data packets directly to sink while it moves from dense to sparse region. As initially more number of nodes send data packets, therefore, it results in reduced network lifetime and consequently in lower throughput. Same is the case with iLEACH, iTEEN, iSEP and iDEEC. Comparing the performance of DSM-NbC, as shown in Fig. 9, we can see that DSM-NbC is much more efficient then even the improved versions of the original protocols. Clustering along with sink mobility further enhances the network lifetime and thus improves the data throughput.

Moreover, Fig. 11 shows packets sent to BS. Taking the benefits of sink mobility (allows nodes to communicate at shorter distances and also ensures full coverage of data gathering) and NbC (nodes which are far, communicate with sink via CH), DSM-NbC send less packets to sink as compared to LEACH, TEEN, DEEC and SEP.

In Fig. 12, we compare the computational burden of the proposed scheme over different scenarios. We show that our method is not only energy efficient but is also equipped with low cost making it performance efficient. As can be seen in this figure, the time it takes to complete the task is lower than competing state-of-the-art methods over different number of nodes thereby outperforming the existing schemes uniformly.

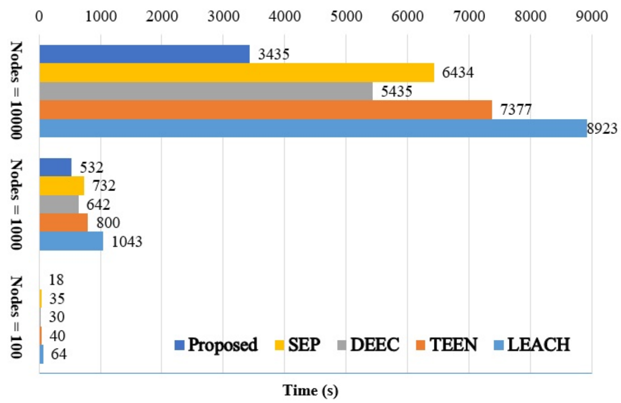

Fig. 12. Computational Overhead Comparison

V. Conclusion

The proposed scheme jointly considers adaptive sink mobility and NbC for lifetime maximization. The idea is to move the sink in the sensor network based on a strategy (moving from dense to sparse region) that minimizes the total energy usage. Furthermore, clustering is done to minimize the time for collecting data or the consumed energy of the nodes which are far from sink. The CS based collaborative communication scheme is a significant step to further reduce the energy consumption and optimize the complexity as well as the lifetime performance. From simulation results, we conclude that DSM-NbC prolongs the network lifetime and optimizes the computational burden in comparison with LEACH, TEEN, SEP and DEEC. An interesting future direction can be to monitor the network under the scenario of deploying mobile sensors along with provision of multiple mobile sinks (MMSs) in the same network dimensions.

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