Energy Saving Scheme for Compressed Data Sensing Towards Improving Network Lifetime for Cluster based WSN

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Abstract

Extensive research approaches have offered wireless sensor networks (WSN) is being used across wide range applications for wireless data collection, communication and smart computing. Sensor nodes are tiny, battery operated and integrated with smart computing functions to sense the physical environment, convert digital data and forward it to data collection node. However, sensor nodes have restricted resource and limited battery, continuous sensing of physical environment consumes more power and drains sensor node battery which may cause node to go dead very fast. Thus, energy conservation in WSN is considered as primary concern to withstand the node for prolonged period. Compressive sensing (CS) based WSN optimises large number of transmissions, balance the traffic load and promise to provide robust solution. Cluster based approaches have been proven energy efficient to extend network lifetime which has always been a bottleneck for WSNs. This paper aims to propose energy saving scheme for cluster based compressive data gathering to improve energy efficiency of WSN and increase network lifetime. In this scheme, existing LEACH is modified to energy saving improved LEACH (ESI-LEACH) for cluster structure and the features of compressive sensing and optimal tree-based data aggregation is combined to provide QoS requirement. The ESI-LEACH scheme is simulated using event driven simulator tool, performance results are evaluated in terms of QoS metrics.

Keywords: Compressive Sensing, Network Lifetime, Clustering, Energy Saving, Data Aggregation, WSN.

1 Introduction

Greater flexibility of wireless communication has been significantly exploited in recent years for data transmission. Wireless communication provides better connectivity and can be easily configured (Lin et al., 2006). Sensor network plays an important role in wireless communication network. WSN (wireless sensor network) consists of tiny electro mechanical sensor device distributed within an area randomly or uniformly and has been used for many applications such as military, unmanned aerial vehicle (UAV), environment monitoring, health care and mission critical networks (I. Akyildiz et al., 2002; Lay et al., 2017; Palopoli et al., 2011; Singh et al., 2016; Zheng et al., 2011). Sensor node can continuously sense the environment, process and report multiple information about various events happened by exchanging

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and transmitting of sensed data over wireless communication channel to sink or base station (BS) (Gheisari et al., 2019). However, sensors are resource and energy constrained having low bandwidth, small storage and battery operated (T. Kwon et al., 2013). It has been shown that sensor node utilizes more energy for wireless data transmission and drains its battery very fast reducing its lifetime and makes it difficult to replace sensor battery. Optimizing the energy consumption of sensor node and harvesting nodes energy to extend nodes lifetime is a challenging issue. Hierarchal cluster-based routing approach offers a reliable solution in saving nodes energy and communication efficiency for large scale networks (Nam, 2020). In hierarchal cluster-based communication, entire network is segmented into various groups of small clusters and assigning task to CH. Cluster head (CH) is chosen based on the high residual energy, other sensor nodes will be cluster members (CM). Cluster head is responsible to collect data from CM, aggregates data and forwards it to base station (BS) or sink (Heinzelman et al., 2000; Hosen et al., 2018; Roy et al., 2018; Zhao et al., 2018). Low energy adaptive clustering hierarchy (LEACH) protocol was proposed to application specific, protocol randomly selects cluster head but failed to achieve rotation of cluster head which had a major drawback (Singh et al., 2017). In recent trends data is consider to be crucial part of life, however generation of huge data traffic becomes more complex for computation as it requires more energy to process. Compressive sensing (CS) is employed for cluster-based architecture during data gathering, CS can reduce size of data and number of transmissions and provides robust solution for energy saving (El et al., 2019). In this paper we propose energy saving scheme for cluster based compressive data gathering to extend network lifetime and achieve energy efficient routing. Main contributions are:

- To overcome the drawbacks of LEACH, we modify the existing LEACH by retaining important parameters in each round like threshold energy, initial energy, residual energy and total energy of the network such that optimal clusters are formed. We name it as energy saving improved LEACH (ESI-LEACH).
- ESI –LEACH balance the energy load of sensors and not letting nodes nearer to sink in cluster formation other than CH
- Efficient data gathering integrating compressive sensing (CS) at CH and tree-based routing approach to forward the data using optimal route to sink

2 Problem Definition and Motivation

Large number of nodes equipped with sensors forms a network and continuously sense the physical environment, collects data such as object tracking, temperature, pressure and so on. Node operates on battery which is not replaceable, data exchange and transmission over a communication channel depends on the amount power consumed from battery. Energy is consumed in sensing, sending, receiving and processing of data but intense energy is consumed in communication. More power consumption reduces nodes lifetime and results in node death making network isolation for large scale sensor network. To minimize energy consumption cluster based with data aggregation techniques have been proposed to guarantee the network lifetime. However, clustering methods experiences limitations, conventional LEACH does not guarantee the ideal CH selection and fails to provide sensor location in the network. LEACH influences all CH to connect with BS, causing nodes energy wastage. LEACH does not determine the appropriate distance across cluster heads and base station (BS). Random selection of cluster head and keeping on the CH round the clock drains energy faster and results in node death. Node with the lower energy is also selected as CH in LEACH which does not ensures extended lifetime. Therefore, it is necessary to consider the energy parameters of the node and rotation of CH to balance energy among nodes. Integration of compressive sensing in data aggregation and optimal tree-based data routing enhances the QoS requirements. Therefore, motivates to layout energy saving scheme that extends network lifetime with low communication overhead.

The structure of the entire paper is as follows: Introduction is presented in section-I, problem statement and motivation are discussed in section-II, related works is described in section-III, proposed ESI-LEACH is presented in section-IV, performance results and analysis is discussed in section-V, conclusion is drawn in section-VI

3 Related Works

In 2000, Heinzelman et al. (2000) have proposed low energy adaptive clustering hierarchy (LEACH) a prominent clustering protocol for energy saving in WSN. LEACH consists of setup and steady phase. Cluster formation and cluster head (CH) selection is done in setup phase. Aggregated data is routed to sink in steady phase. However, this protocol is not suitable for large scale networks, CH selection is done on random basis which does not balance nodes energy. Further LEACH uses single hop communication to sink making long-haul communication nodes to deplete energy faster making it as major drawback. To counter LEACH in 2002, Heinzelman et al. (2002) and in 2017, Al-Baz et al. (2017) have proposed centralized LEACH and rank based LEACH, in centralized LEACH sink selects optimal clusters head and best fit nodes. Rank based LEACH aims to balance nodes energy load and considers optimal path and links between sensor nodes to select CH based on ranks, which overcomes random selection of CH adopted in LEACH. For reliable communication sink must have accurate location information of sensor node and their residual energy causing limitation of these protocols. In 2017, Mazumdar et al. (2017) have proposed algorithm to solve hotspot problem for cluster-based routing know as distributed unequal cluster-based routing (DUCR). DUCR aims to construct optimal cluster's size towards direction of sink and balances the relay load among cluster heads. However, author failed to put attention on sensor nodes not able to find cluster head within its transmission range causing disadvantage of DUCR. In 2017, Wang et al. (2017) have proposed distributed cluster based compressed data collection on compressive sensing theory. Quantization factor is considered as critical criteria for energy efficient communication. The energy cost reduction is done by using sub-nyquist sampling rate and quantization configuration reduces the amount of energy consumption. In 2017, Lan et al. (2017) by integrating compressive sensing and cluster method have proposed compressibility-based cluster algorithm (CBCA) that enables lower transmissions. CBCA was employed in power efficient gathering is sensor information system (PEGASIS) converting logical chain and spatial correlation among nodes was employed to get compressive sensing readings. In 2018, Qiao and Zhang (2018) have proposed compressive data gathering scheme for uniform and uneven deployment of nodes. For uniform distribution of even cluster formation was done considering spatial location and density of nodes. However, this scheme had hotspot problem due to multihop communication and consumed more energy. In 2018, Tirani and Avokh (2018) have proposed energy aware and energy balanced data aggregation scheme based on compressive sensing (ECDA) to enhance the network lifetime. This scheme considers Euclidean distance and network remaining energy for cluster head selection, these two parameters are inefficient to increase network lifetime and regulate nodes energy. Summary of the related works discuss about energy efficient clustering methods and compressive sensing-based clustering methods targeting to achieve lifetime extension. However, existing scheme considers single hop communication by which nodes extends its transmission range for data transmission to base station, which consume more energy compared to multihop communication and adopted optimal cluster head selection to avoid early death of nodes. In this work we consider nodes energy parameter metrics for rotation of CH considering initial energy, total network energy, residual energy and tree-based routing.

4 Assumptions and Network Model

Nodes are organized in hierarchical design deployed in a network area, WSN performs better in terms of energy consumption, communication overhead and high packet deliver in hierarchical network than flat networks (Y. Cheng and Agrawal 2007). Hierarchical network consists of sink or base station (BS) placed at the top level, sensor nodes are divided into cluster. In each cluster the cluster head (CH) monitors and serves all the sensor nodes or cluster members (CM) in its cluster. The BS is placed at top hierarchy and CH at next level. CH is elected relying on significant residual energy and is responsible to collect information or data from CM then aggregates data and forwards it to BS through inter cluster communication. Figure 1 illustrates network architecture.

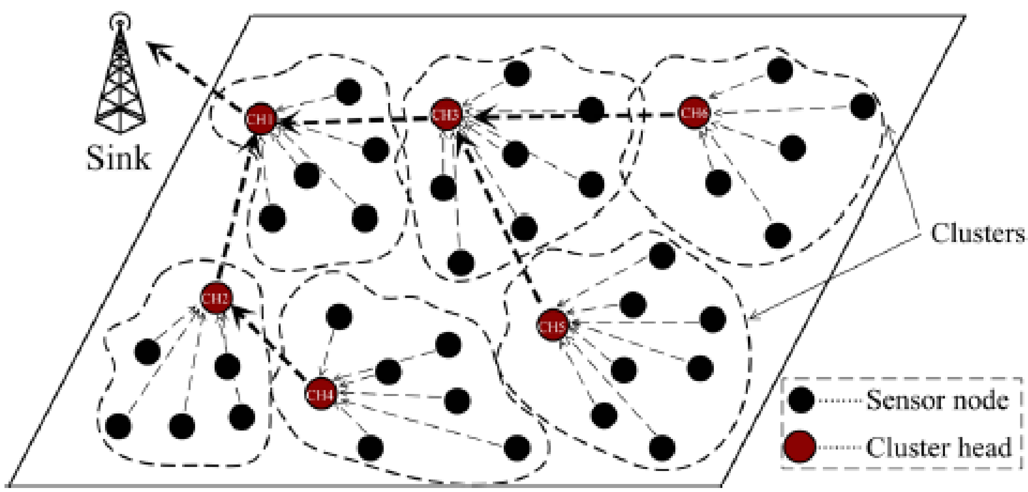

Figure 1: Network Architecture

Assumptions

Network assumptions taken during node deployment are as follows:

- Sensor nodes are randomly deployed in a network area, nodes update their location via GPS and are kept static throughout the simulation.
- Data collection node called sink is place out of network and it is static, without any energy and resource constrain.
- Sensor nodes are assigned with same amount of initial energy and are homogeneous with unique Ids
- Transmission power can be adjusted by sensor nodes depending on situation.
- Battery of sensor nodes are not replaceable and are termed as dead node upon exhausting their energies.
- The cluster formation is adopted through (Y. Cheng and Agrawal 2007) as setup and steady phase
- Euclidean distance $D = \sqrt{(y_i - y_j)^2 + (x_i - x_j)^2}$ is computed to find the distance between nodes.
- Nodes sense the environment and sense data is compressed which implies block diagonal matrix (BDM) (Nguyen et al., 2016) and it is immune to noise.

5 Proposed Energy Saving Improved Leach (ESI-Leach)

LEACH aims to save energy and plays a major role in WSN (Heinzelman et al., 2002; Tümer et al., 2010). Cluster head (CH) collects data from cluster members (CM) compress it and forwards towards sink node (Cheng et al., 2016). Selection of CH is done based on energy value $Th_e(n)$ and random function. The sensor generates random number$R(0 \leq R < 1)$, node is selected as cluster head if it satisfies $R \leq Th_e(n_i)$ which is evaluated as:

$$Th_e(n_i) = \begin{cases} \frac{p_{ch}}{1 - p_{ch} * (r * mod(1/p_{ch}))}, & n \in V_{n_i} \\ 0, & otherwise \end{cases}$$

p_{ch} is the ratio of CH to number of nodes representing probability of sensor node electing as CH for round 0 (Zhang et al., 2018), r indicating current round for set of nodes $V_{n_i} \in [1, n]$ in a network that are not eligible to elect as CH in recent $1/p_{ch}$ round, when two nodes are communicating the $node\ X$ transmits $k\ bits$ of data to $node\ Y$ and distance between two nodes is equal to d the energy consumed can be evaluated as:

$$ET_x(k,d) = E_{T_{x_{elec}}}(k) + E_{T_{x_{amp}}}(k,d)$$

$$ET_x(k,d) = \begin{cases} E_{elec} * k + E_{fs} * k * d^2, & d \leq d_0 \\ E_{elec} * k + E_{amp} * k * d^4, & d > d_0 \end{cases}$$

Similarly, receiver sensor node's energy for receiving $k\ bits$ can be computed as:

$$E_{R_X}(k) = E_{R_{X_{elec}}}(k) + kE_{elec}$$

where transmitter and receiver energy consumed is given as E_{elec} and amplifier parameters E_{fs} and E_{amp} corresponds to free space and multipath fading model

LEACH does not consider density of nodes while selecting CH, not ensures uniform distribution of CHs (Miao et al., 2015), and not considers nodes residual energy and average energy to select CH. Therefore, the energy dissipation of proposed ESI-LEACH, considering the free space and multipath model, nodes closer to sink node through free space energy consumption of CH per round is given as:

$$E_{ch} = \left(\frac{n}{c} - 1\right) * k * E_{elec} + \frac{n}{c} * k * E_{DA} + k * E_{elec} + k * E_{fs} * d^2{}_{sink}$$

where c is cluster in WSN per round,$\frac{n}{c}$ is the average node in each cluster,$E_{DA}$is CH energy consumption upon receiving message k of 1 bit and $d^2{}_{sink}$ is the square distance between CH to sink. Considering the node coordinates $\rho(x_n, y_n)$ distributed in an area without loss of generality and sink located at(x_a, y_b), the distance between CH and sink is given as:

$$D^2{}_{sink} = \iint ((x_n - x_a)^2 + (y_n - y_b)^2)\rho(x_n, y_n)dxdy$$
$$\approx \iint \frac{(x_n - x_a)^2 + (y_n - y_b)^2}{A}\ dxdy$$

$A$is the deployed area and energy usage of CM per round is

$$E_{cm} = k * E_{elec} + k * E_{fs} * d^2{}_{ch}$$

$D^2{}_{ch}$is the square distance between CM to CH expressed as:

$$d^2{}_{ch} = \iint (x_n{}^2 + y_n{}^2)\ \rho(x_n, y_n)dxdy$$

Cluster energy consumption is given as in (Roy and Chandra 2018)

$$E_{clu} = E_{ch} + (\frac{n}{c} - 1)E_{cm}$$
$$\approx E_{ch} + \frac{n}{c}E_{cm}$$

ESI-LEACH energy consumption during each round is given as:

$$E_{round} = cE_{clu}$$
$$= k(2nE_{elec} + nE_{DA} + nE_{fs} * d^2{}_{ch} + E_{fs} * D^2{}_{sink})$$

Optimal cluster head selection using ESI-LEACH is given as:

$$O_{ch} = \frac{\sqrt{n}}{\sqrt{2\pi}}\frac{A}{d_{sink}}$$

Energy consumption and optimal cluster head selection using multipath fading model is given as:

$$E_{ch} = \left(\frac{n}{c} - 1\right) * k * E_{elec} + \frac{n}{c} * k * E_{DA} + k * E_{elec} + k * E_{amp} * d^4{}_{sink}$$

ESI-LEACH energy consumption during each round is given as:

$$E_{round} = cE_{clu}$$
$$= k(2nE_{elec} + nE_{DA} + nE_{amp}d^4{}_{sink} + nE_{fs}d^2{}_{ch})$$

Optimal cluster head selection using ESI-LEACH is given as

$$O_{ch} = \frac{\sqrt{n}}{\sqrt{2\pi}}\sqrt{\frac{E_{fs}}{E_{amp}}}\frac{A}{d^2{}_{sink}}$$

ESI-LEACH, the energy adjustment parameter of p_{ch} to regulate energy consumption and improve network lifetime is expressed as:

$$p_{ch} = \frac{p * V_{n_i} * E^n_{res} * E_{n_i}}{E_{tol} * E_{avg}}$$

$p$is probability of optimal CH selection, $E^n_{res}$is residual energy of node n ,initial energy of node represented as E_{n_i}, total energy of overall network is E_{tol} and average energy of all sensor node is E_{avg}. These parameters ensure the energy is distributed and balanced to extend network lifetime. If node having higher residual energy than E_{avg}, threshold value is evaluated $Th_e(n)$ to check the possibility of selecting node as CH after operating round, then average energy is obtained:

$$E_{avg} = \frac{E_{tol}(1 - \frac{r}{r_{max}})}{V_{n_i}}$$

ESI-LEACH Algorithm

1. n_i- sensor-nodes, E_{round} – number of rounds
2. Network is initialized by node deployment, assigning initial energy and sink node
3. Evaluate distanced_{sink}
4. for $i = 1$ to r
5. $E_{avg} = E_{tol}(1 - \frac{r}{r_{max}})/n_i$
6. $p_{ch} = p * n_i * E^n_{res} * E_{n_i}/(E_{tol} * E_{avg})$
7. $Th_e(n_i) = 1 - p_{ch} * (r * mod(1/p_{ch}))$
8. R= random number
9. if $R \leq (Th_e(n_i))$

10. $n_i \rightarrow CH$
11. estimate distance to CH d_{ch}
12. end if
13. if $d_{ch} < d_{sink}$
14. Select → CH
15. Transfer data to sink
16. $i = i + 1$
17. go to step 4
18. end

Tree Construction and Data Transmission

Sink initiates the tree construction for optimized routing after the cluster and cluster head formation. Tree is constructed mainly on CH position and current CH residual energy. Initially, sink broadcasts control message consisting of five fields- ID, energy level, parent, status and hop information indicating CH id, parent aggregation tree, residual energy at current time, its status of relay node or leaf node in the tree and the number of hops in path length to sink respectively. Sink node control message contains fields such as $(ID_{S_n}, -, \infty, status_{S_n}, l_0)$ assuming sink has infinite power and root for the aggregator nodes. Highest residual energy of CH records the parent node and optimal path to sink. After tree construction, compressive sensing data collection is carried at CH and compressed data is transmitted towards sink.

Let CH_n be cluster head and q_i represents readings of sensor at CH_n . Cluster head CH_n having N_i readings of data from set of nodes which can be given as:

$$q_i = [q_1, q_2, q_3, \dots \dots \dots q_{N_i}]$$

Without considering compressive sensing technique, network acquires N samples of q signal which can have large data traffic. If q data is k sparse we can obtain $L = [L_1, L_2, L_3, \dots \dots \dots L_M]$ where $M \ll N$ which include q information, by multiplying with compression matrix $\emptyset_i$. By solvingf_1 optimization problem q information can be recovered from L

Random matrix multiplication $\emptyset_i$ is used to multiply data at CH and the product L_i is sent to sink node. Upon receiving $L_i$from one cluster sink builds block diagonal matrix (BDM) as sensing matrix

$$\begin{bmatrix} L_1 \\ L_2 \\ L_3 \\ \vdots \\ L_M \end{bmatrix}_{M\times 1} = \begin{bmatrix} \emptyset_1 & 0 & 0 & 0 \\ 0 & \emptyset_2 & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & \emptyset_M \end{bmatrix}_{M\times N} \begin{bmatrix} q_1 \\ q_2 \\ q_3 \\ \vdots \\ q_{N_i} \end{bmatrix}_{N\times 1}$$

The sink receives compressed information $L = \bigcup_{i=1}^{C_i} L_i$the information is reconstructed from L using f_1 minimization

Tree Construction Algorithm

- Parent: parent node for each CH in aggregation tree
- power: CH’s residual energy at current time
- status: relay or leaf
- level: number of hops to sink node
- sink node S_n broadcast tree_const_msg containing

- $CH - ID, parent, power, status, level)$
- tree_const_msg for sink node $(ID_{S_n}, -, \infty, status_{S_n}, l_0)$
- assuming S_n has infinite power
- TDMA schedule for CH within the tree_const_msg also included
- if (no data transmission to sink from CH)
- switch off radio
- else
- forward the aggregated data to next level CH node rooted at sink node
- end if

6 Performance Evaluation

Simulation Environment and Parameters

Proposed ESI-LEACH is simulated using discrete event network simulation tool NS2 with Mannasim patch (NS 2009). The performance of ESI-LEACH is compared with ECDA scheme. The simulation parameters are listed in Table 1. The nodes are statically deployed and sink is placed at top hierarchy, clusters are formed based on distance to sink and CH is selected based on high residual energy using ESI-LEACH.

Table 1: Simulation Parameters

Parameters	Value
Nodes	100
Queue/cache size	50
Coverage range	250 mts
MAC-Layer	802.11 collision free
Deployed Area	1000x1000 mts
Packet-Type and size	CBR/512 bytes
Run Time	100 sec
Comparison Methods	ECDA and ESI-LEACH
Nodes energy	100 Joules
No of sink	1
Modulation	TDMA
Rounds	5-25

Performance Metrics

Network Stability

Energy is consumed upon data transmission and depends on the routing efficiency employed while routing data. Node is said to be dead, when nodes energy is completely drained. Network stability is defined as the period of node completed number of rounds, before first node goes into dead state.

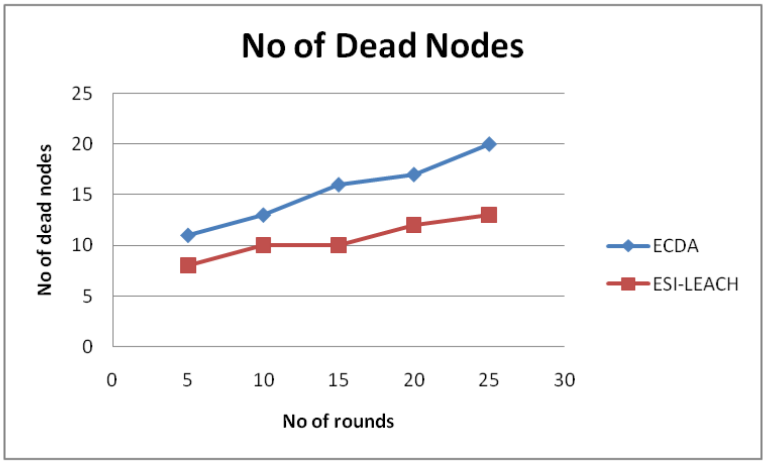

Figure 2: No of Dead Nodes vs No of Rounds

Figure 2, shows the comparison of dead nodes using ECDA and ESI-LEACH, It is observed from the graph during 5th round, number of dead node is higher in ECDA compared to ESI-LEACH. At round 5, number of dead node in ECDA is 11 compared to ESI—LEACH having 8 dead nodes. The reason for such stability is ESI-LEACH considers parameters such as node density, energy, residual energy, threshold energy and distance to sink to form optimal CH among sensor nodes. These parameters ensure to consume minimum energy by collecting *N* samples from CH using compressive sensing and tree-based routing which aims to determine the best path with the least hops, resulting in reduced transmissions and more stability. However, ECDA elects CH based on energy and distance considering only two parameters. Finally, at round 25, ECDA has 20 dead nodes while ESI-LEACH having 13 dead nodes.

Throughput

Throughput is defined as the number of bits obtained successfully at destination. It is expressed as kilobits per second (Kbps). Routing protocols efficiency is measured by successfully receiving data packets at destination. Routing packets reliably increases the QoS parameter, which is essential for network performance. Higher packets received at destination, increases the overall network throughput of various applications.

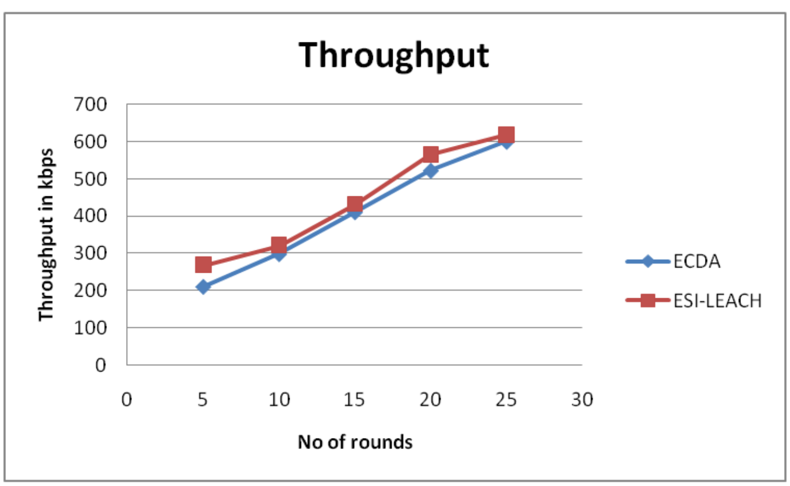

Figure3: Throughput with Respect to No of Rounds

Proposed ESI-LEACH achieves higher throughput than ECDA, Figure 3 shows the throughput graph. It is seen from the graph, data packets received at sink, at different rounds is higher in ESI-LEACH compared to ECDA, due to forwarding of compressed data through reliable path towards sink with minimum hop. It is observed that the throughput of ESI-LEACH at round 5 is 268 kbps compared to ECDA having throughput of 210 kbps. Reconstruction of data packets at sink promises to deliver data packets without any loss and helps to achieve higher throughput. Therefore, it is observed that at round 25, ESI-LEACH has throughput of 619 kbps compared to ECDA having 601kbps

Packet Delivery Ratio

PDR is defined as the ratio of transmitted packet from the source to the received packets at the receiver to destination. Higher the PDR ratio, better the routing protocol efficiency will be.

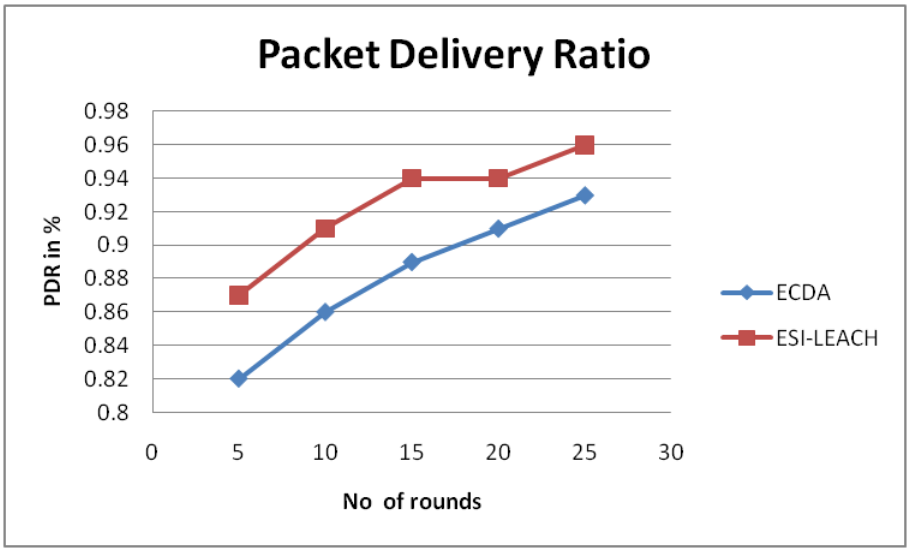

Figure 4: PDR with Respect to No of Rounds

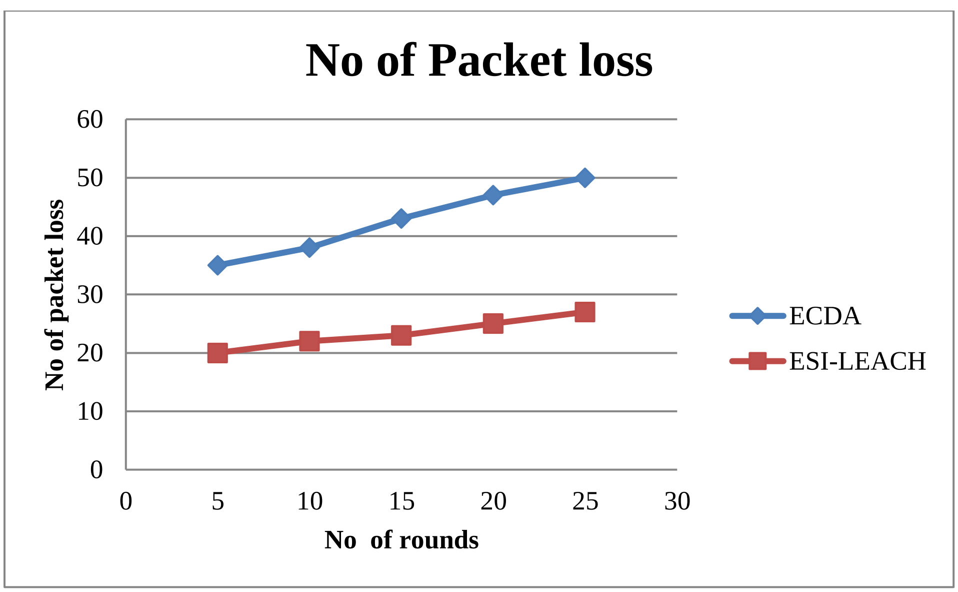

Figure 5: No of Packet Loss vs No of Rounds

Figure 4, shows the packet delivery ratio graph representing percentage of packets delivered. It is seen from the graph; packet delivery ratio is higher in ESI-LEACH due to scheduling of packet transmission through TDMA to ensure packet transmission without any channel congestion to avoid packet drop. The channel is utilized efficiently for forwarding packets towards sink. In figure 5, shows the number of packets drops at different rounds. ECDA has more packet loss compared to ESI-LEACH, due to lower channel fading. ESI-LEACH considers free space and multipath loss model such that packet loss is minimized.

Remaining Network Energy

Any protocol consumes energy at different rounds for data transmission, network energy decreases as the number of rounds increases.

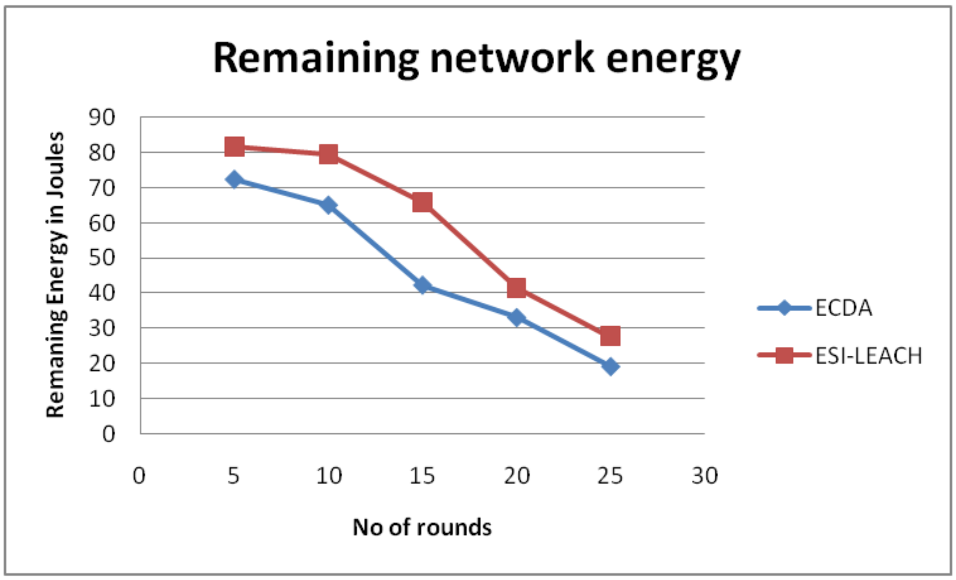

Figure 6: Remaining Network Energy with Respect to No of Rounds

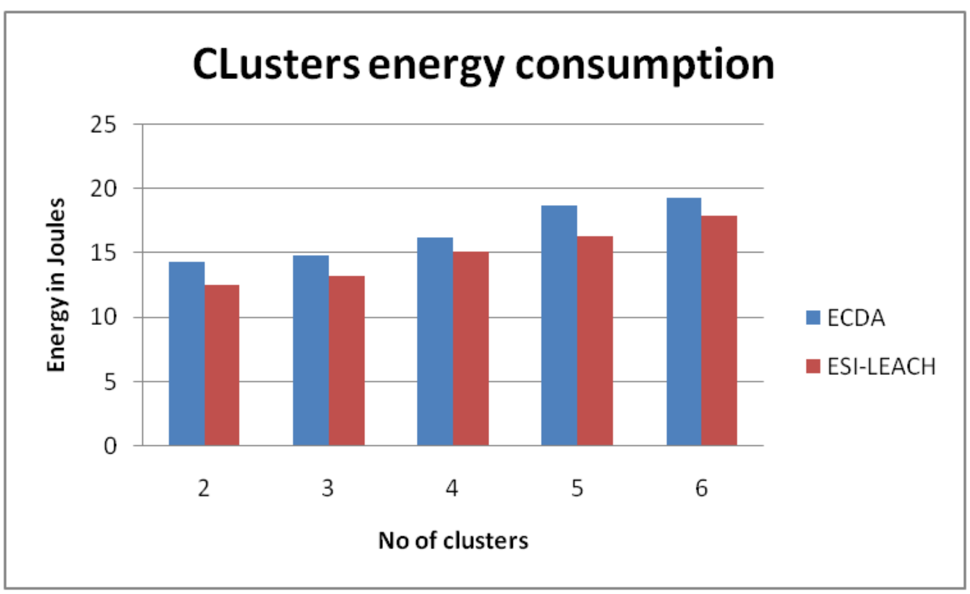

Figure 7: Energy Consumption with Respect to No of Clusters

It is comprehended from the figure 6, that ESI-LEACH has higher remaining energy compared to ECDA scheme after completing rounds. After round 5, ESI-LEACH has 81.7 Joules of remaining network energy compared to ECDA having 72.4 Joules and finally at round 25, ESI-LEACH has 27.6 Joules compared to ECDA scheme having 19.3 Joules. The reason for such performance is due to energy saving during cluster formation and routing of the gathered information from cluster members in a compressed format. Tree based optimal routing helps to reduce communication overhead in finding optimal routes to sink. Figure 7 shows the average energy consumption consumed by clusters for data transmissions.

7 Conclusion

To balance energy and to extend network lifetime several clustering protocols have been proposed. However, these protocols dissipate unnecessary energy and suffer from network isolation. LEACH clustering protocol uses high quality of energy during data transmission and damages nodes energy quicker. To save energy and improve network lifetime this paper presents energy saving scheme for cluster based compressed data gathering. Existing LEACH is modified to energy saving improved LEACH (ESI-LEACH), which considers important parameters for extending network lifetime such as initial energy, total energy, residual energy and average energy of all nodes. This scheme balances nodes energy and forms optimal clusters and selects CH based on threshold energy. Integration of compressive sensing reduces the number of data transmission, samples from cluster members are gathered and compressed using block diagonal matrix at CH and routed through tree based optimal routing. Tree construction helps CH to route the gathered information with minimum hops towards sink. Finally, at sink the reconstruction of compressed data is carried out. Extensive simulation is carried out and the performance analysis results are compared with ECDA scheme. Results shows proposed ESI-LEACH outperforms in terms of throughput, energy consumption and packet delivery ratio. In future, we can model a scheme to detect fault node such that back up cluster head comes to action without disturbing the network.

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