Designing a cost aware gradient based protocol for Wireless sensor networks, employing data aggregation and clustering

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Abstract— **Many routing protocols have been designed and evaluated for Wireless Sensor Networks using simulation tools. Only a few of these proposed works have been tested in real world scenarios. This paper presents a Wireless Sensor Network (WSN) data aggregation & clustering protocol that used cost aware gradient based routing. The proposed mechanism combines a gradient based routing scheme GRACE with the hierarchical scheme of the LEACH protocol. By combining these two protocols and taking the important factor of node energy into consideration when selecting the cluster heads, a robust strategy for data aggregation and routing is developed. This protocol was compared with flooding routing scheme, energy-Efficient Protocol with static clustering (EEPSC) protocol and LEACH protocol using simulation approach (OMNET++). Simulation results show that the proposed protocol improves the wireless sensor network performance in two ways. First, the data aggregation feature reduces 75% data load on the network and second, energy aware clustering and cost aware multi-hop communication increases the lifetime of network as compared to LEACH and EEPSC routing protocols.**

1. Introduction

The emerging field of wireless sensor networks combines sensing, computation, and communication into a single tiny device based on the recent advances in micro electromechanical systems (MEMS) technology [5]. Developing a wireless platform is less expensive and has several uses in environment monitoring, home/building security, bio-habitat monitoring, disaster management etc. WSN is a new emerging technology and to make this technology attain its expected ubiquity, more effort is vital to identify and satisfy real-world needs. Large deployment of sensor nodes is one of the fundamental concepts of sensor network applications. This is considered to be the case in most applications in order to achieve better coverage of the sensor field and to cover for failure of sensor nodes and communication channels. Deployment of such large number of sensor nodes is mostly assumed to be performed in a random manner such as throwing away from an ariel vehicle or through cluster bombs. One of the fundamental objectives of research in the field of wireless sensor networks is to prolong the network's operational lifetime. In a random deployment scenario, such prolongation can be achieved by employing self organizing mechanisms.

Routing in Wireless Sensor Networks (WSNs) is an open research field. Many protocols have been proposed for large area deployment and evaluated using simulation tools [12],[6],[8]. Self organization and energy efficiency are two of the most important characteristics of a largely deployed sensor network. These characteristic control the operation and lifetime of the network. Although, the number of proposed routing protocols for wireless sensor networks is considerably large, not many of those are suited to largely deployed sensor networks. Energy consumption also remains a bottleneck of performance in most of the proposed protocols.

In this paper we propose a new energy and cost aware, multi-hop routing protocol. Proposed protocol combines an energy efficient clustering mechanism with gradient based data routing technique. Moreover, contrary to how many routing protocols assume, the cluster heads are not considered to be privileged nodes and they cannot send their data directly to the sink. In the proposed scheme, the cluster heads have to rely on multi-hop communication for data routing towards the sink. The proposed technique is compared with Flooding, Energy-Efficient Protocol with Static Clustering (EEPSC) [1], and LEACH [11] protocol using simulations in OMNeT++ [7]. The initial network setup uses the GRACE [8] protocol to establish a "cost field" i.e. each node is aware of its link cost with sink. Among the sensor nodes, cluster heads are selected in different rounds for a particular time frame. Cluster heads form local neighborhoods of sensor nodes for aggregation of data. Sensor nodes send their sensed data to a single cluster head of which it is a member.

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The rest of the paper is organized as follows. In section II we present some related work followed by the details of our proposed technique in section III. Section IV presents the simulation results and comparison with other related techniques. Conclusion and possible future work is presented in section V.

2. Related Work

Traditional routing protocols cannot be used directly in wireless sensor networks because of the limitations imposed by sensor nodes such as processing capabilities, communication and power. Many algorithms have been proposed in order to solve routing problems in wireless sensor networks. Among the proposed protocols, LEACH [11] is one of the most significant routing protocols for wireless sensor networks.

The main idea of LEACH protocol is to form clusters of the sensor nodes with one cluster head for each cluster. This cluster head performs the necessary data aggregation tasks. The role of cluster head is changed randomly over time, defined as rounds. This helps in balancing the energy dissipation of the nodes. Since LEACH uses single-hop routing between cluster heads and the sink, it assumes that each node can communicate directly with the sink. As shown in Fig. 1.

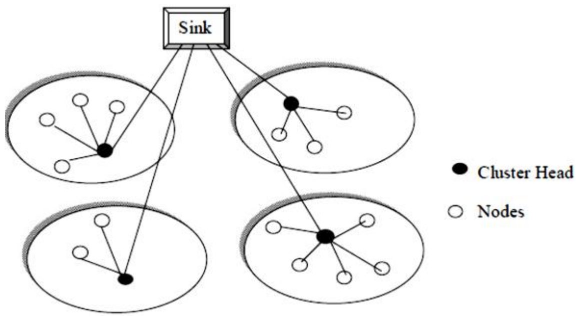

Fig. 1 LEACH Cluster Heads communication.

This supposition makes LEACH protocol unsuitable for sensor networks deployed over a large geographical area. This approach minimizes energy consumption of network since the transmissions is only done by cluster heads instead of every sensor node trying to communicate with the sink. Simulation results have shown that an optimal number of cluster heads is around 5% of the total number of nodes.

Gradient based routing was first proposed by Schurgers et al. in GBR [3]. Their proposed protocol is a modified version of Directed Diffusion [2].The key idea of their proposed protocol is to keep the number of hops minimum towards the sink. GRACE [7] forms a natural gradient towards the sink where a gradient is the link cost between a node and its neighbors. The data packets could use the path having the minimum cost to reach the sink. The gradient based routing is based on the fact that the direction of the communication in wireless sensor networks is always known, that is, from the sensor nodes towards the sink. Fig. 2 shows minimum cost path forwarding.

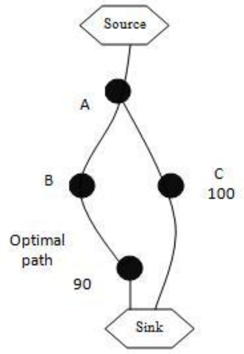

Fig. 2 Minimum cost path forwarding

Routing protocols that uses the advantage of aggregating data in a local neighborhood before forwarding it to the sink reduce the total in-network traffic. Moreover, aggregation of data in a local neighborhood also presents an advantage of reliable report on the state of the environment under consideration which cannot be determined from the reports of individual sensor nodes.

3. Proposed technique

We consider a network of homogeneous sensor nodes. Each Node has to perform the basic task of sensing the field parameters, form data packets, and communicate them with the cluster head. Cluster head is then responsible to forward this data towards the sink.

A. Model Assumptions

1. Initially the energy level of all nodes is the same and nodes are homogeneously, randomly deployed.
2. The sink is able to communicate only with members that are at a distance of one hop from it
3. Network lifetime is defined as the no of nodes that die out with the passage of time
4. Radio range of all nodes is assumed to be equal and is not effected by change in energy of the node
5. All sensor nodes are assumed to be homogeneous; therefore the energy consumption for sensing is the same for every sensor node

An initial gradient of network is formed from the sink towards the outer nodes so that every node is aware of its link cost from the sink. Once the initial gradient of the network is established, the next step is to elect cluster heads and form clusters which would serve the data aggregation purpose. The cluster heads are selected with a certain probability. Unlike the traditional cluster head selection mechanisms, we employ energy aware clustering strategy which considers the remaining battery power of each node before declaring it as a cluster head. Once the clusters are formed the cluster members send their sensed data to a specific cluster head which performs the necessary data aggregation function. The cluster heads then generate a report based upon the received data and forward this to a neighbor node that has minimum cost towards the sink. We define cost of node by considering its energy level and its link cost towards the sink. In this way the report reaches the sink through the most optimal path.

B. Cost Field Establishment

The cost-field setup is initialized by the sink and is expanded further by its neighbors. During the cost-field setup each node gets several packets from its neighbors containing different communication cost with the sink along different paths. Every node chooses the least costly path to the sink and only stores that least cost value. Cost of each node is computed by considering the following two parameters;

- Energy of each node
- Link cost between two nodes

Energy of node: Life time maximization of a network can be achieved by using high energy nodes for routing. Energy of a particular node is calculated by considering its initial battery power and remaining battery power. Each node stores the following attribute $\boldsymbol{E_i}$ as the energy constraint parameter.

$$E_i = \frac{P_o}{P_i} \qquad \text{(Equ. 1)}$$

where
E_i = Energy of node
P_o = Initial battery power
P_i = Remaining batter power

Link cost between two nodes: Link cost between two nodes 's' and 'v' can be defined using Equ. 2.

$$L_{s,v} = \frac{P_{t,s}}{P_{r,s}} \qquad \text{(Equ. 2)}$$

where
$L_{s,v}$ = link cost between s and v
$P_{t,s}$ = transmission power of *s*
$P_{r,v}$ = receiving power of *v*

Cost field: Cost field is defined with following parameters. Initially each node sets its cost to ∞

$$Cost_{\text{init}} = \infty$$

And

$$Cost_{\text{sink}} = 0$$

The sink broadcasts an advertisement message 'ADV' containing its own cost (0 initially). Upon receiving this ADV message from sink, node A sets its path cost as

$$C_A = C_{\text{sink}} + E_A + L_{\text{sink,A}}$$

Once node A sets its path cost, it further creates a new ADV packet containing its own cost value and sends it to its neighbors. Upon receiving the ADV from node A, node C set its link cost as:

$$C_c = C_A + E_C + L_{A,C}$$

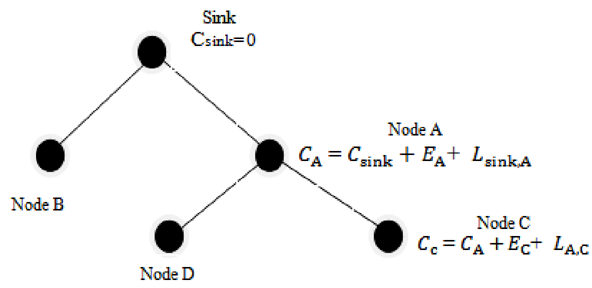

Fig. 3 Cost Calculation for Different Node

When a node receives multiple ADV packets from its neighbors as shown in fig. 4, then it adds minimum received cost to its energy and link cost. For example if node C receives ADV from node A and node B then to calculate its own cost it selects

$$C_{\min}\ (C_A, C_B)$$

Node C selects its minimum cost path and further propagates it in its own ADV packets to other neighbors.

$$C_C = C_A + E_C + L_{A,C} \qquad \text{if } C_A < C_B$$
$$C_C = C_B + E_C + L_{B,C} \qquad \text{if } C_A > C_B$$

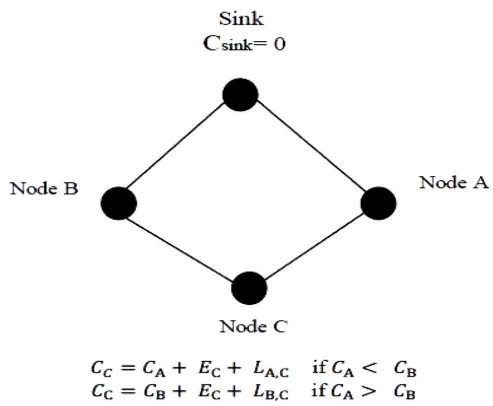

Fig. 4 Cost calculation with multiple neighbors

C. Cluster formation

Groups of nodes are organized into clusters where each group of nodes has an elected cluster head CH. Sensed data is sent to CH rather than the sink. The proposed technique has two main phases

1. Energy Aware Clustering phase

2. Routing Phase

Energy aware clustering phase: Many energy aware WSN routing protocols have been proposed [9],[10]. We perform energy aware clustering in rounds and each round results in election of different cluster heads. In LEACH protocol, nodes are periodically elected as cluster-heads with a certain probability. We propose a new cluster head election mechanism. Each node calculates T(*i*) in every round as shown in Equ. 3. T(*i*) gives threshold value of each node which considers remaining battery power of each node before selecting it as a cluster head. In Equ. 3, *p* is a predetermined cluster-head proportion, *r* is the current round of cluster-heads selection, *i* is node ID, and *G* is the set of nodes that have not been elected as cluster-heads in last 1/*p* rounds. E(*i*) represents the ratio of remaining energy and initial energy of node.

$$T(i) = \frac{p}{1-p\left(r \bmod \left(\frac{1}{p}\right)\right)} + \sqrt{E(i)} \qquad \text{(Equ. 3)}$$

Where $i \in G$ and

$$E(i) = K * \frac{E_{avg} + E_{residual}}{E_{avg}} \qquad \text{(Equ. 4)}$$

where
K= random number between (0.9,1)
E_{avg} = Average Energy of node
$E_{residual}$= residual energy of node

By using Equ. 4, nodes with higher energy have an increased probability of becoming cluster heads in each round.

Routing Phase: Each node decides to which cluster head it becomes a member of. If a node receives multiple cluster head advertisement, it becomes the member of the cluster head with the larger signal strength. The cluster head then assigns TDMA communication slots to all members. Once the clusters are created and TDMA schedule is fixed, data transmission can begin. All nodes send their sensed data to their respective cluster heads. Cluster head will choose the path with lowest cost and forward the aggregated report towards the sink.

In this work gradient based data routing mechanism is used following the basic principle of GRAB protocol that introduces multi-hop routing, instead of cluster heads communicating directly with the sink node. Cost field is established towards the sink from all the sensor nodes and the routing decisions are taken based upon the value of the gradient at a particular node. Moreover, the nodes need not maintain routing tables since local neighborhood information is sufficient for a source node to send its data towards the sink. Combining energy aware clustering and gradient based routing for data aggregation and life time optimization is the main theme of this work. Since many critical applications cannot rely on the report generated by an individual node, clustering is employed not only to organize the network into hierarchy but also to fuse the data generated so that minimal data is transferred across the network. The flow chart of proposed mechanism is shown in fig. 5.

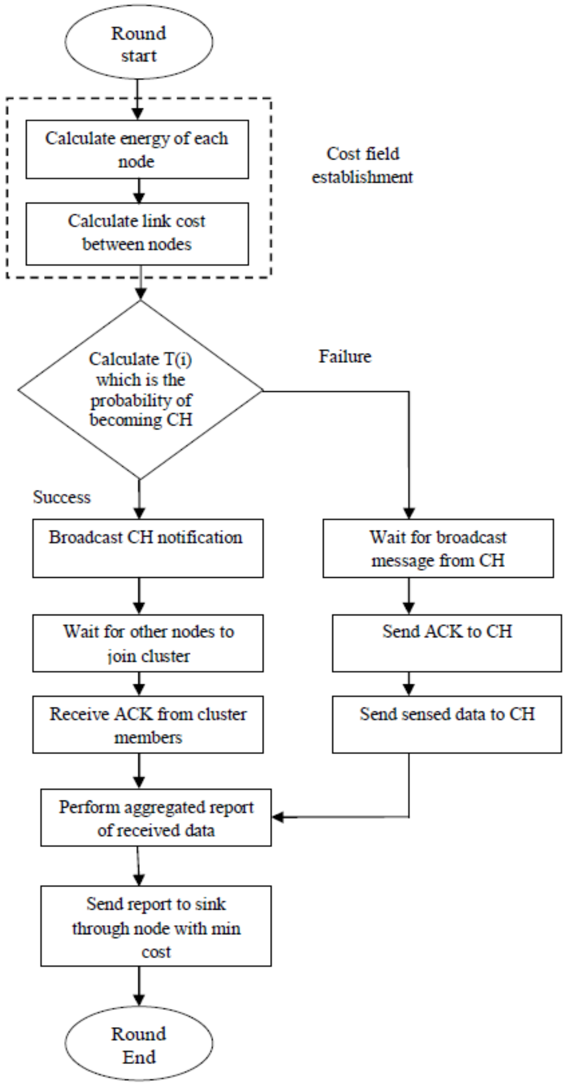

Fig. 5 Flow Chart of Proposed Protocol

4. Simulations and Results

In order to verify the claims made in this paper, thorough research simulations were carried out in OMNeT++ [4]. Different types of topologies varying in number of nodes, different in-network communication channels, and propagation delays were used. The number of nodes was varied from 10 to 200. The network conditions were dynamically changed by simulating changing channel characteristics. Different numerical parameters used for this simulation are given in table 1.

Table 1.

Parameter	**value**
Simulation time	550 s
Topology size	1300×2400 m
Communication range	50m
Number of nodes	10, 50, 100, 200
CH probability	0.1, 0.2, 0.5
Initial node power	100 j
Node Distribution	Nodes are randomly distributed
Sink position	Bottom left corner (218×2111)
Data rate	40kbps

Fig. 6 shows the uniform random distribution of 100 nodes in a field size of 1300×2400 m. We have considered a large area with a single sink, placed at one corner of the field. The position of sink is 218×2111. This graph shows that network topology on which most simulations were carried out

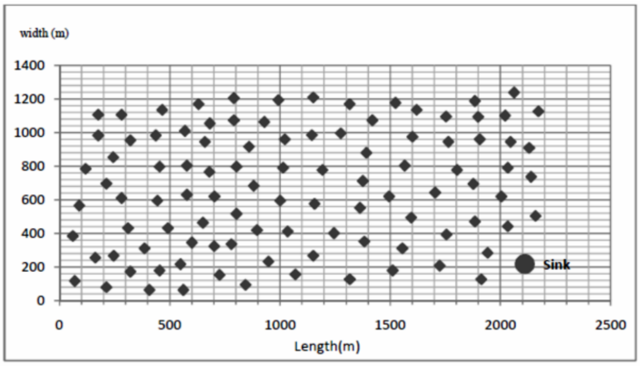

Fig. 6 Uniform random distributions of 100 nodes

Fig. 7 shows the graph of initial gradient setup time. Comparison of Cost field gradient used in our approach is done with hop count gradient setup in which the gradient consists of minimum distance of each node from the sink. The set up time of cost field Gradient is slightly higher than the hop-count gradient because of the required computations at each node. Moreover, the nodes use a small back-off time before making new ADV packets which contributes to the overall time of gradient setup

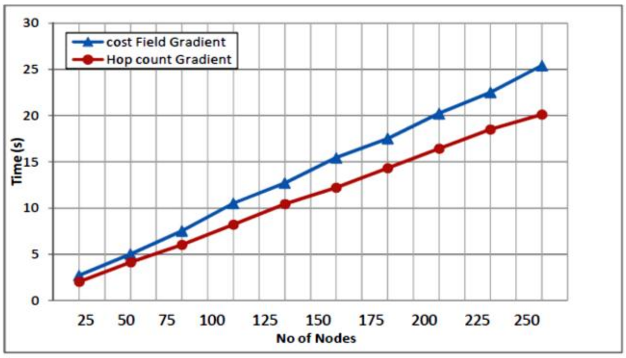

Fig.7 Gradient Setup time of WSN

Fig. 8 represents the number of ADV packets received by nodes and the number of broadcasts made in result to these advertisements. The implemented Cost field gradient gives only one broadcast per node throughout the network. This is the case even if nodes receive varying number of ADV packets. In hop count gradient setup a node can broadcast more than 1 ADV packets to its neighbors resulting in energy loss and network overhead

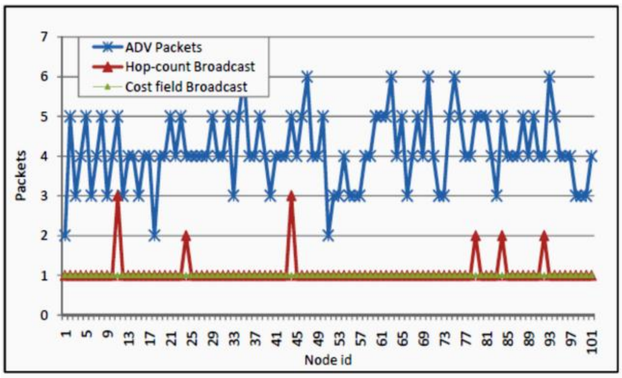

Fig.8 Number of ADV packets vs. Number of Broadcasts made

Fig. 9 shows the battery level of each node in different rounds of cluster head selection. In each round, the number and distribution of cluster heads is different across the field. The important thing to consider here is how much energy is consumed by a particular node during one cluster round. As shown in figure the nodes are consuming battery power at almost constant rate. This pattern continues for each cluster head selection round and hence the number of nodes which die out with the passage of time will not occur uniformly at the end of network operation

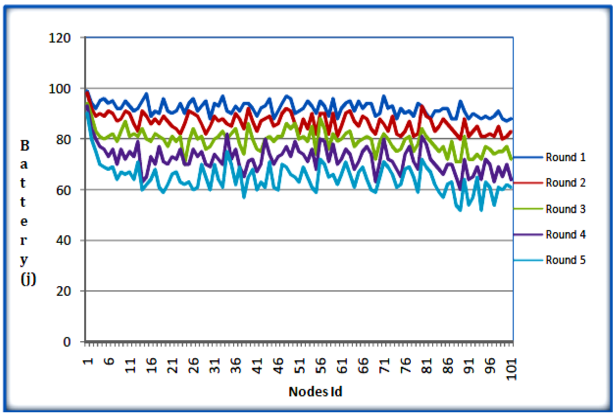

Fig. 9 Battery level of each node in different rounds

Fig. 10 shows the amount of data sensed by the node and the aggregated reports that were actually sent to the sink. All nodes send their sensed data to their particular cluster heads. The cluster head aggregates all the received data from its members and then generates a report based on this aggregated data. This aggregation of data results in reducing the network wide traffic. There is a 75% decrease in the data load over the network resulting in achieving lifetime optimization of network.

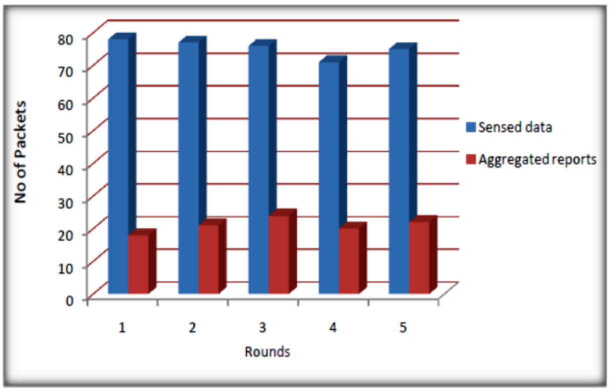

Fig.10 Data sensed vs. aggregated reports

Fig. 11 compares latency of LEACH, EEPSC and flooding routing schemes with proposed approach. In Energy-Efficient Protocol with Static Clustering (EEPSC), the network is partitioned into static clusters. The latency of this scheme is highest as data packets have to move all around the network before reaching the sink. LEACH has lowest latency as the cluster heads directly communicate with the sink but this direct communication reduces the battery power considerably resulting in appearance of dead nodes earlier. Proposed approach keeps a moderate latency but does not consume excessive battery power.

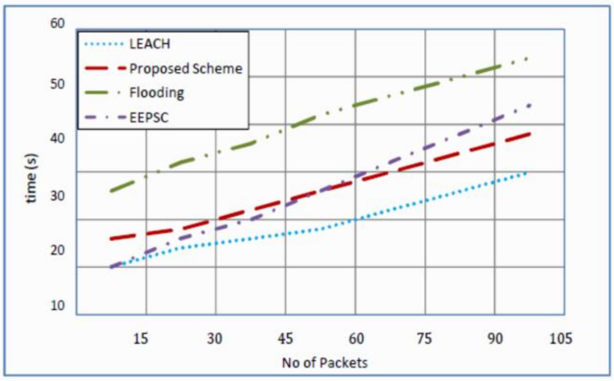

Fig. 11 Latency Comparison

Fig. 12 shows the comparison of proposed scheme with LEACH, flooding and Energy-Efficient Protocol with Static Clustering (EEPSC). LEACH protocol uses direct communication of Cluster heads with the sink, due to this reason a large amount of energy is consumed, resulting in early dead nodes in the network.. In the proposed scheme cluster head do not communicate directly with the sink, instead Gradient based routing is implied which selects the shortest path from each cluster head to the sink. The graph in figure 12 shows that in LEACH protocol the nodes starts to die out after 240s, in EEPSC after 320sec and in proposed scheme no node die out in first 400s. Hence the objective of networks lifetime maximization is achieved. The simulation results show that improved protocol has the better performance than LEACH and EEPSC

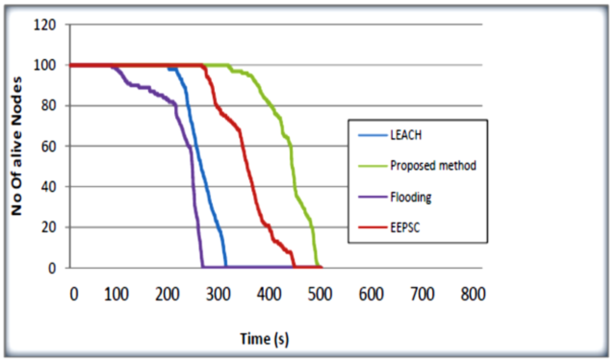

Fig.12 Comparison of proposed approach with LEACH, flooding and EEPSC

5. Conclusion and future work

This paper proposed a mechanism for lifetime optimization of sensor networks. The technique performs data aggregation to reduce the load on network and uses multi-hop communication instead of long range direct communication with the sink. Not only does the periodic clustering takes place for uniform usage of energy and data transmission but also the periodic refreshing of the gradient ensures that correct information about the state of the network is available. In future, this work can be extended to include the impact of having multiple sinks in the wireless sensor networks. A model with heterogeneous sensor nodes may be investigated and the approach may also be tested for mobile sinks. The immediate point to consider is the establishment and maintenance of the gradient in a multiple sink sensor network scenario.

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