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Optimization of sink sojourn time for enhancing the lifetime of wireless sensor network

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***Abstract*---**Reducing the energy holes by using multiple mobile sinks and reducing the one hop sensor energy consumption is one of the important research issues in wireless sensor network. The proposed work focus on deploying multiple mobile sinks to move across a predetermined trajectory for data collection. The network area is divided into triangular partitions and the mobile sinks are allowed to move along triangular partitions. The work proposes a clustering protocol to form data collection trees. The contribution is extended further by formulation an optimization model for improvising the sensor network lifetime. The mobile sinks are allowed to travel along the predetermined trajectory and stop at each sojourn location for an optimal time location. The optimization model considers the one hop residual energy and energy consumption of the individual sensor. Simulation experiments showcase better performance of the proposed work in comparison with existing model.

***Keywords*---**WSN, cluster, network life time, energy holes.

Introduction

One of the primary area of research in wireless sensor network is the reduction of energy hole formation by minimizing the energy consumption among the one hop sensor nodes. Usually the sensor nodes are installed in huge numbers in hostile environments to monitor specific phenomenon. These tiny sensor nodes are energy constrained and it is not possible to recharge them due to various practical difficulties. Due to this the battery power of the sensor nodes has to be utilized in a very effective manner so as to increase the lifetime of the network. Various measures have been initiated for minimizing the energy consumption of the individual sensor nodes. One such measure is the reduction of hotspot formation in the network which will have a huge impact on the network lifetime. Hotspots are formed in clustered network when the nodes that are deployed around the cluster head is overloaded. The nodes that are far away from the cluster head cannot route their data packets directly to the cluster head as they are constrained in their communication range. So the data packets are forwarded to another sensor node available within its own communication radius which is then forwarded to another sensor node. This multi hopping of messages is continued until the data packet reaches the base station.[1] This kind of scenario increases the overhead of sensors which are deployed near to the cluster head. Sensor nodes that are deployed around the cluster head is technically called as one hop sensors. Thousands of data packets are accumulated among the one hop sensor nodes from the nodes that are farther away. It becomes imperative for the one hop sensors to forward all the data packets to the cluster head. A one hop sensor node consumes energy to receive and transfer the data packets. As the packets are very high in number the amount of energy spent is also very high. Due to this all the one hop sensor nodes lose their energy very soon thus leading to their death. Such a condition is termed as “Energy hole”. Formation of energy hole around the cluster head will make it impossible for the rest of the sensor nodes to communicate with the cluster head. This results in failure of the network and though the majority of sensors are alive in the network but it is impossible to use their sensed data for any decision making process. So minimizing the formation of hot spot and avoiding the energy hole is an important metric to be considered. The best possible solution to eradicate the formation of hotspot formation is to mobilize the cluster head rather than assuming it as static. The cluster head to different location will spread the one hop sensors across the network area thus minimizing the energy hole formation. Mobilizing the cluster head helps in minimizing the energy consumption among the one hop sensors thus increasing the lifetime of the network.

Researchers have experimented with various mobile entities like mobile sink, mobile cluster head, mobile base station and even mobile sensor nodes. [2] Even research works are carried out on placing multiple mobile entities in the network rather than relying on single entity. Researchers focused on finding the appropriate location for the placement of mobile entity, amount of sojourn time, trajectory path and optimal number of mobile entities to be deployed etc. Many algorithms and protocol models were researched in large numbers. Mathematical formulations and theorems were also framed as an effort to maximize the lifetime of the network. Single mobile cluster heads, multiple cluster heads, single/multiple mobile base stations and even mobile nodes are utilized in the network to extend the network lifetime. also helps in One of the become deployed may be working various recent research works. Mobile entities like mobile sinks, mobile cluster heads, mobile base stations and even mobile sensor nodes are deployed with the intention of reducing the hotspot formation among the one hop sensors which will have a direct impact on the network lifetime [3]. Changing the one hop sensors frequently will reduce the early demise of sensor nodes which will increase the network lifetime to a great extent. This paper aims to enhance the lifetime of wireless senor network by using multiple mobile sinks in a virtual triangle based geographical partition. Each network partition is assigned a mobile sink where the mobile sink moves on a predetermined trajectory to collect the sensed data. Moving the sinks along the predetermined trajectory will reduce the hotspot formation by distribution the load fait among all the sensor nodes. [4]

The trajectory is designed in such a way that almost all the sensor nodes are involved in data communication. Fair load distribution is one of the important parameter to be enhanced in any kind of protocol designed for increasing the network lifetime. Overloading of sensor nodes is the primary reason for the minimization of network lifetime. This paper focuses on maximizing the network lifetime by minimizing the one hop energy consumption. [5] The network is partitioned in to various virtual triangles where each triangle is assigned a mobile sink. The mobile sinks travel along a predetermined trajectory to collect data from the sensor nodes in their respective triangle. It is taken into consideration that the mobile sinks are able to coordinate among themselves to pass their sensed data messages for aggregation which is then routed to the base station. The purpose of partitioning the network into triangle layers is to avoid any sort of overlapping in the partitions. [6]

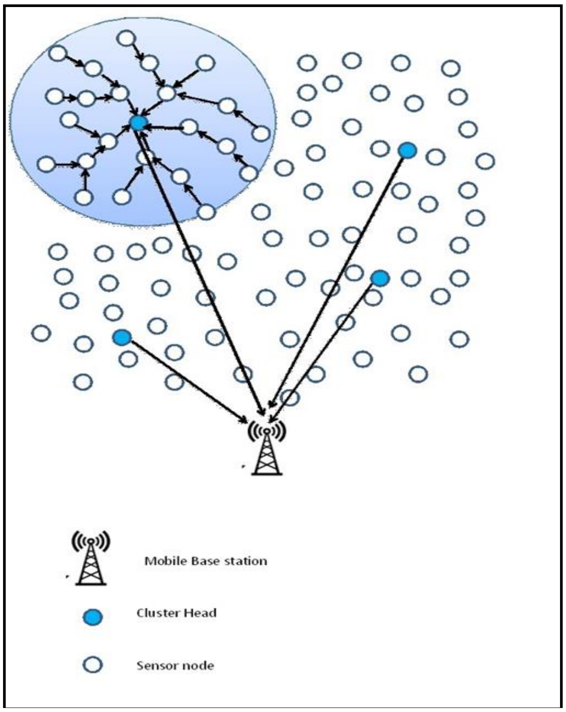


Fig. 1. Architecture of Sensor Network

Related Work

The work proposed in [7] speaks about the formation of energy holes around the cluster heads/sink nodes and the authors propose changing the position of sinks across the network to reduce this issue thereby increasing the network lifetime to a huge extent. A clustering algorithm is proposed for this and the sinks are repositioned to new locations at frequent intervals. The proposed algorithms show significant improvement in various parameters like lifetime of network, throughput, balance residual energy, energy consumption and so on. Similarly, in another work proposed in [8] the authors have proposed an energy- efficient routing algorithm by exploiting an approach termed as Density-based Fuzzy C-Means clustering (DFCM). The proposed work tries to achieve load balancing among all the sensor nodes.

Another work is proposed by [9] argues that the finest method for minimizing the energy consumption among the sensors is to minimize the transmission between each individual nodes. The work means that minimizing the distance of transmission in sensor nodes is a NP-Hard problem. So it is suggested to deploy the concept of SGO optimization for resolving this issue which in turns helps in minimizing the energy consumption of sensor nodes for transmission. The performance of the proposed algorithm is compared with the performance of SGO with Particle Swarm Optimization and Generic algorithm. It is observed that the proposed algorithm outperforms the other two algorithms.

In [10] , the authors proposes an approach with the aim of accessing the factor of reliability and data that are senses in a WSN . The data sensing starts with the nodes of the sensor and the data that are collected is sent to the head of the cluster. IN paper[11], detailed discussion is made on the clustering patterns called HQCA. In [12], the aggregation concept is explored base don the ELM technique. The method proved to be effective. The work proposed in [13] exploits the concept of clusters to maximize the lifespan of wireless sensor network. The proposed work partitions the entire network area in to clusters by means of a three tier clustering algorithm. The work argues that the clustering algorithm developed is efficient increasing the lifetime of the network. The proposed method outperformed the existing methods.

The authors in [14] proposes load balanced cluster algorithm. The proposed work tries to balance the load equally among all the cluster heads and improvises the performance parameter of the network. The authors have utilized ACO procedure to choose the optimized routing pathway for the sensors to route the sensed data packets to the cluster head. Experimental results are conducted to evaluate the performance of the optimization algorithm. The proposed algorithm reduces the overall number of control messages and the amount of energy consumed in each sensor node during data transmission that helps in maximization of network lifetime.Paper [15] By creating a novel clustering algorithm in which clusters are produced dynamically, the problem of lifetime maximisation in WSNs is addressed. The authors investigate the subject of network lifespan optimization by balancing energy consumption across cluster heads. The authors claim that the suggested approach significantly reduces message overheads and calculations. In comparison to existing clustering protocols, simulation results demonstrate that the proposed algorithm improves the balance residual energy by 18% and increases the network's life span by a factor of 19%.

The three factors considered[16] for optimization are the number of clusters, compactness, and separation. In comparison to algorithms like ERP, IHCR, and SEP, simulation trials reveal that the suggested method performs significantly better. For selecting the cluster head, The authors in [17], consider a clustering method that employs a fuzzy logic. The authors contend that the suggested method provides a better quality of service than existing algorithms, which while improving network lifetime and other parameters, do not provide a good quality of service. The paper [18] proposes a method SPDAC (Shortest Path Discovery for Area Coverage).The proposed method uses the concept of strategic node deployment to reduce the routing trajectory of mobile relay nodes.Aside from that, the authors have developed a prediction-based clustering strategy for energy usage as an addition (PCP-EC). The proposed algorithms, according to the authors, extend the node’s life. Simulations are carried out using NS2, which reveals that the suggested algorithm performs well when compared to other algorithms.

Contributions of the Paper

The proposed work focus on improvising the lifetime of wireless sensor network by using multiple mobile sinks. The entire network area is divided into partitions which are triangular shape. Each partition is allocated with one mobile sink and the sinks are allowed to move in each partition. The sinks stop at each sojourn point for a specific time period. The amount of time the sinks stops at each sojourn point is optimized using an optimization model. At each sojourn location the optimization model or the linear programming formulation is run to find the optimal time the sink would stop at that particular point. The optimization of time is considering the residual energy of the one hop sensor nodes which in turn will enhance the network lifetime. The contributions of the proposed research work are categorized as follows.

- The paper proposes a linear programming formulation to optimize the sojourn time of the sink by considering the residual energy of the one hop sensor nodes.
- Optimizing the stopping time of the sink will enhance the network lifetime to a greater extent thus making it optimal.
- A clustering protocol is proposed for creating data collection trees at the sojourn points for the sinks to collect data from the sensor.

Network Architecture and Problem Definition

The network model is assumed to be heterogeneous model where a collection of static nodes and mobile entities are deployed in the network area which needs to be monitored. Network area is a collection of thousands of sensor nodes deployed and the nodes are grouped into groups termed as clusters and each cluster is assigned a head termed as sink. The sensed data packets are routed to the sink by the sensor nodes and aggregated by the sinks which are then forwarded to the base station for decision making process. The sensors in this model are presumed to be static nodes and they are deployed at fixed locations to sense the required information. Data sensed by the sensor nodes are communicated to the sink nodes which are assumed to be mobile. Sensor nodes tend to produce data packets at a fixed rate ri and communicate the packets to sink nodes through multi hop communication. The aggregated data packets with the sink nodes are communicated to the base station for further processing of data. The following are the assumptions about the network architecture of the proposed work,

- The type of network assumed is heterogonous and the sensor nodes are considered to be fixed and deployed in an area which needs to be monitored for a specific cause.
- The communication between the sensor nodes is considered to be bidirectional link and it is assumed to be collision and error free for analytical simplicity.
- The network area is divided into triangular partitions and each partition is assigned with a mobile sink node for the purpose of data collection.
- The mobile sink nodes travel along a predetermined trajectory in their respective partition and stops at various sojourn locations for a time period “t” for data collection.’
- Clustered tree are formed by the sink nodes at various rendezvous points and the data is collected through the clustered tree structure.
- The aggregated data is communicated to the base station by the sink nodes through multihop communication.
- Each node has got only limited battery power and the buffer size is unbounded.

Problem Statement

The problem statement can be defined as follows:

“The sensing area is partitioned into triangle shaped partitions deployed with static sensor nodes and each partition is assigned a mobile sink node. Formulate a model to move the mobile sink node along a predetermined trajectory and stops at various rendezvous point for a time period “t” for the purpose of data collection. And also frame a clustering procedure which can be used by the mobile sink during the data collection phase at rendezvouspoint for forming clustering tree structure”.

The predetermined is designed in a manner that the trajectory considers majority of the sensor nodes in the partition to acts as one hop sensors. Distributing the one hop sensors across the partition helps in reducing the formation of hotspot. The energy consumption of the sensor nodes is equalized by having various rendezvous points. The mobile sinks stops at each rendezvous point for fixed time duration for data collection. At the expiry of the time period the mobile sink moves to the next rendezvous point. The fixed stopping time of the mobile sink can be decided based on the one hop residual energy of the cluster. The time can be the sum of time taken for the cluster formation and the time taken by the sink for receiving and aggregation the sensed data from all the clustered sensor nodes. At the end of the time period the mobile sinks would have collected the sensed data from all the nodes and aggregated them. Then the sink moves to the next rendezvous point and forms a clustering tree structure using the cluster formation algorithm. The clustering algorithm proposed is able to form non overlapping clusters. After a specific number of data collection rounds the aggregated data packets are sent to the base station by using multihop communication. A particular sink can send the aggregated data to another sink which can be routed to the base station.

Proposed Predetermined Trajectory

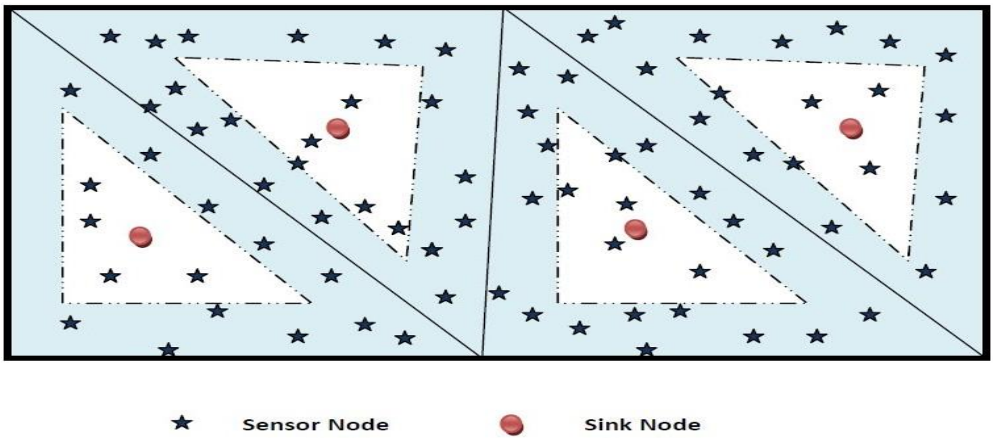
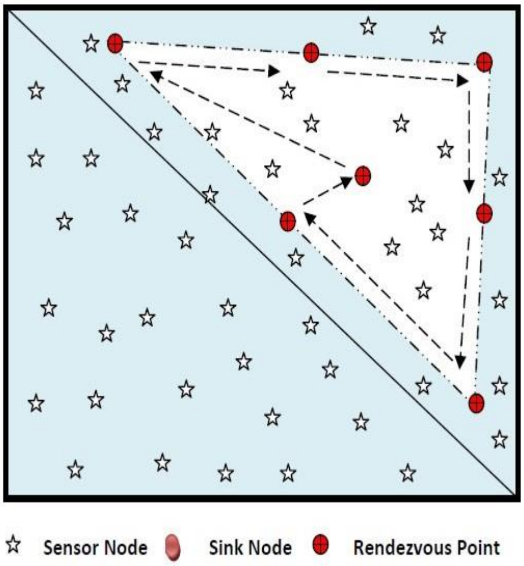


Figure 2 Network Model

The entire network area is partitioned into triangular partitions. Partitioning the network is to triangles offers benefits like non overlapping structure and reduced complexities which exist in case of hexagonal tiling partition. Each triangular partition is assigned one mobile sink. The mobile sink travels along a predetermined trajectory and stops at various rendezvous points along the trajectory for fixed time duration. The rendezvous points are fixed at appropriate location such that at each rounds, a different set of sensor nodes forms the first three corona levels around the mobile sink. This helps in reducing the formation of hotspot and the energy consumption is evenly spread across all the sensor nodes in a particular partition. Spreading the energy evenly among all the sensor nodes is one of the important parameter to be considered to improvise the lifetime of wireless sensor network. This will huge impacton network longevity and also enhances various other performance parameters of the network.The proposed predetermined is depicted in Figure3.

The rendezvous points and the order in which they are visited are shown as directions. The mobile sink starts from a particular rendezvous point, creates a cluster tree structure for data collection and performs data collection for a time period "t".At the expiry of time period "t" moves to the next rendezvous point. The same set of procedures is then repeated for all the rendezvous points. At the end of the all rendezvous points, the same pattern of visiting is repeated. A threshold energy value is initialized and the value has to be met by the rendezvous points for the mobile sink to stop at the point. When the one hop residual energy of a rendezvous point gets dropped below the required threshold then the mobile sink will not stop at that particular rendezvous point. The rendezvous point where the one hop residual energy has dropped below the threshold is ignored. This is done to minimize the death of one hop sensors at the particular rendezvous point. Doing so will minimize the early demise of the network lifetime.



Clustering Procedure

The mobile sinks stop at each rendezvous point in the predetermined trajectory for a fixed time duration “t”. In order to instigate the data collection round, the mobile sinks call the cluster formation procedure which will form clusters where the nodes are connected for form clustered tree structure. This clustered tree structure is used by the mobile sink to collect data from all the sensor nodes in the partition. The clustering procedure is efficient to produce clusters where the sensor nodes are connected exactly to one mobile sink. The procedure is also efficient in dealing with the scalability parameter where any sensor node can be added or removed from the cluster without any time delay. The clustering procedure starts with the sensor nodes initializing two parameters SinkID and HopCount. Initially SinkID is set to NULL as the node is not attached to any Sink node. HopCount is the parameter which represents number of hops required for the sensor node to reach the Sink. Followed by this, each mobile sink in the network broadcast a message incorporating their ID and Hop_Count which is set to 1 initially. Sensors which receive the message directly from the sink node are assumed to be within the communication radius of the sink. These sensors are termed as one hop sensors and they can pass the messages directly to the sink node. Each node compares the received hop count with their own hop count. Of the received hop count is found lesser then the sensor node attaches themselves to the sink node with Minimum hop count. A particular sensor node may receive multiple broadcast messages from multiple sinks. But they attach themselves with the sink with minimum hop count. A broadcast with higher hop count is automatically ignored by the sensor node. At the end of cluster formation procedure each sensor node in the network will exactly be a member of one cluster group.

The proposed protocol starts by allocating one mobile sink to each network partition. The sink starts from a particular rendezvous point as proposed in the predetermined trajectory model. One hop residual energy of the rendezvous pointis compared with the threshold energy required. If the energy requirement is met the mobile sink stops at the particular rendezvous point for a time period “t”. The sink initiates the cluster formation procedure which will form clustered data collection trees. The clustered trees are utilized for collection of data from the sensor nodes process. If the required energy is not greater than threshold energy level, then the particular rendezvous point is ignored and the sink moves to the next point. The proposed clustering procedure is able to efficiently deal with carious implementation issues in clustering like overlapping clusters, optimal cluster size, cluster formation time and scalability.

Linear Programming Formulation

The time span of the wireless sensor network in our proposed work is defined as the amount of halt period of the mobile sink at each stopping position of the triangular partitions. In order to enhance the lifespan of the network and to make the halting time as optimal we propose an integer linear programming formulation by considering the following parameters.

The general assumption about the energy model of a wireless sensor network defines that the overall energy expended by an sensor node is equalized to the overall energy required for a receiving data and the energy for transmission. Thus the power requirements for sensing , transmitting and receiving n bits of data are assumed as follows.

$e_t = (\beta_1 + \beta_2 r^n)$ b.
$e_r = \delta_1$ b.
$e_{sense} = \alpha_1$ b.

Where the values for the various parameters are assumed as follows

$\alpha_1 = 60 \text{ X } 10^{-9}$ J/bit
$\beta_1 = 45\text{X } 10^{-9}$ J/bit
$\beta_2 = 0.001\text{X } 10^{-12}$ J/bit/m^4
$\delta_1 = 135 \text{ X } 10^{-9}$ J/bit

The proposed integer linear programming model enhances the lifespan of the wireless sensor network by optimizing the sojourn time of the mobile sink at various halting points of the triangular partition. The ILP formulation takes into consideration the parameters like energy consumption for receiving , transmitting and sensing are equalized. Also the formulation checks whether the energy expended is always less than the minimum energy requirement

Parameters

ST	Sojourn time of the mobile sink
nos	Number of sojourn points
Z	Network Lifetime (in seconds)
$\mathbf{E_{Tr}}$	Sensor node's transmission energy
$\mathbf{E_R}$	Sensor node's receiving energy
Ei	Residual energy
$\mathbf{g_i}$	Rate of data generation
N	Count of sensor nodes
M	Count of mobile sinks
T	Count of locations
$\mathbf{g_{ij}}$	Rate of data flow of sojourn
N(i)	Sensor nodes that are adjacent
$\mathbf{E_{min}}$	Min residual energy

LPP Formulation

The proposed model enhances the lifespan of the wireless sensor network by optimizing the sojourn time of the mobile sink at various halting points of the triangular partition. The ILP formulation takes into consideration the parameters like energy consumption for receiving, transmitting and sensing are equalized. Also the formulation checks whether the energy expended is always less than the minimum energy requirement. Constraint (1) requires that the energy spent a sensor node for sensing and receiving packets from its neighbor should be equalized to the total number of outgoing packets.

$$\sum_{k \epsilon N(i)} g_{ki} + g_i = \sum_{j \epsilon N(i)} g_{ij} \; 0 \leq i \leq N \qquad (1)$$

Constraint (2) says the power expended by a sensor node for transmitting its own packets and the packets received from its neighbors and the energy sepnt for receiving the packets should be less than a minimal threshold value.

$$E_i - \left(E_{Tr} \sum_{j \epsilon N(i)} g_{ij} + E_R \sum_{k \epsilon N(i)} g_{ki}\right) \geq E_{min} \, , 0 \leq i \leq N \quad (2)$$

Constraint (3) says that the halting period of the mobile sink at a halting point in the triangular partition should be greater than 0.

$$\mathbf{t_i} \geq \mathbf{0} \qquad (3)$$

Max Z= $\sum_{i \in nos} ST$ Subject to

$$\sum_{k\epsilon N(i)} \mathbf{g_{ki}} + \mathbf{g_i} = \sum_{j\epsilon N(i)} \mathbf{g_{ij}} \quad \mathbf{0 \le i \le N} \tag{1}$$

$$E_i - (E_{Tr} \sum_{j\epsilon N(i)} g_{ij} + E_R \sum_{k\epsilon N(i)} g_{ki}) \ \ge\ E_{min}, \tag{2}$$

$$0 \le i \le N$$

$$\mathbf{t_i} \ge \mathbf{0} \tag{3}$$

Simulation setup

We have used first order radio model as the energy consumption model. According to themodel, the energy spent to receive and transmit k bit data packet for a distance of d yields the following values.

ETr(d, k)= k × (eelec + eamp× dα) ERc(k)= k ×eelec

Parameters	Description and Setup Value
Eamp	Energy consumption constant for tr,eamp is set to 0.1 nJ/bit/m^2.
A	Path-loss exponent
D	Distance for sending a packet (The value of d is set to 10m in our experiment)
Eelec	Represents the transmission and receiver electronics energy consumption constant. eelec is set to 50 nJ/bit in our simulation setup,
K	Number of bits in a single data packet. The value of K= 512 bits
ETr(d, k)	Total energy consumption during the transmission of k bit packet
ERc(k)	Total energy consumption during the receiving of k bit packet

The initial energy is set as 0.1 Joules for each sensor node. Sensor nodes are randomly deployed in four network quadrant. Number of mobile data collectors employed is four and the network size is varies with 100 and 200 nodes. The following schemes are considered by us for our simulation. The performance of the algorithm is compared with the following four classifications of existing models.

First Case: The sink is considered to be static and placed at the geographical centre for data collection. No mobile data collector deployed.
Second Case: Multiple Mobile sinks are utilized and deployed at random locations on the network for data collection.
Third Case: One Mobile sink is utilized and allowed to move on the network periphery for data collection.
Fourth Case: Multiple mobile sinks are deployed according to the proposed network model and allowed to move on the proposed predetermined trajectory.

The experiment is initiated with 100 sensor nodes randomly deployed in the network area. All the above mentioned four cases are tested and network lifetime is calculated in terms of number of rounds. The number of data collection rounds until the expiry of one sensor node is noted for all the four categories. Similarly the total amount of lifetime is noted before the expiration of 10 percentages of sensor nodes. These two variations is considered as the expiry of single node will not have a huge impact in terms of network performance. So we have considered 10% of sensor nodes as the threshold for lifetime calculation.

The results are shown in Figure 4 and Figure 5. The proposed model shows a significant improvement in both the categories. Similarly, the same set of experimented is repeated for a network size of 200 nodes. The results for network lifetime with 200 nodes is shown in Figure 6 and Figure 7.

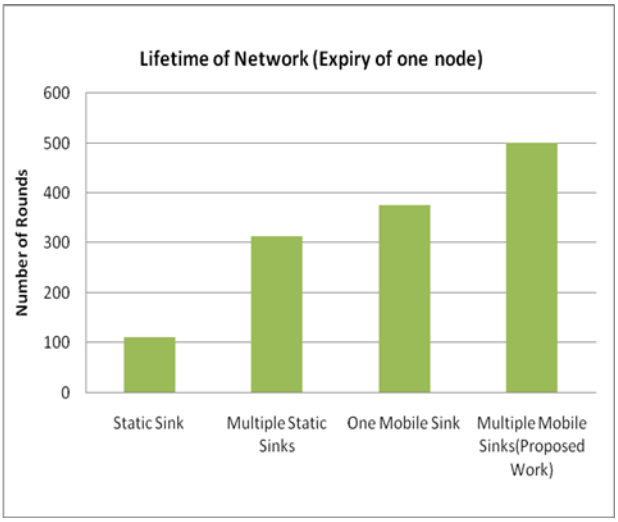


Figure 4 Lifetime of network with 100 nodes (Expiry of one node)

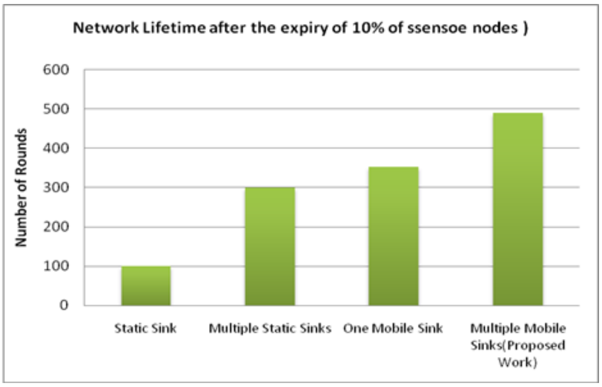


Figure 5 Lifetime of network with 100 nodes (Expiry of 10% of nodes)

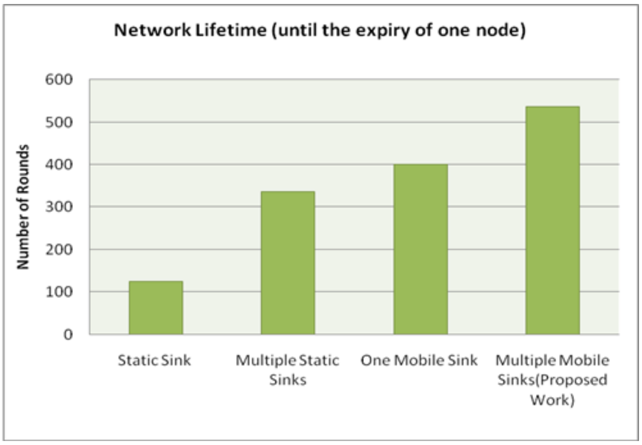


Figure 6 Lifetime of network with 200 nodes (Expiry of one node)

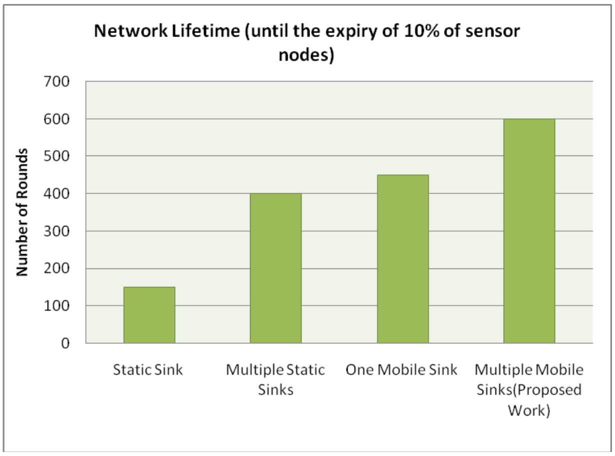


Figure 7 Lifetime of network with 100 nodes (Expiry of 10% of nodes)

Likewise the average energy consumption sensor node at the first corona is noted. Energy consumption of the first corona plays a crucial role in improvising the lifetime of sensor network. A good algorithm or mobility model should minimize the energy consumption in first corona thereby enhancing the network lifetime. The proposed algorithm shows a very good minimization of energy in comparison with the other schemes. The graph is depicted in Figure 8.

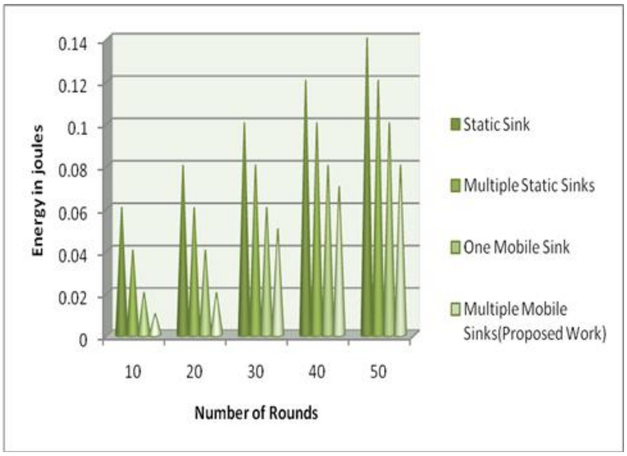


Figure 8 Average energy consumption of first corona sensors

Similarly, total number of alive nodes and dead nodes are significant metrics to be measured for showcasing the performance of the network. Total number of live nodes in the network implies that the lifetime of the network will be longer. The proposed algorithm increases the number of live nodes in the network in comparison with all the existing schemes. The results are depicted in Figure 9.

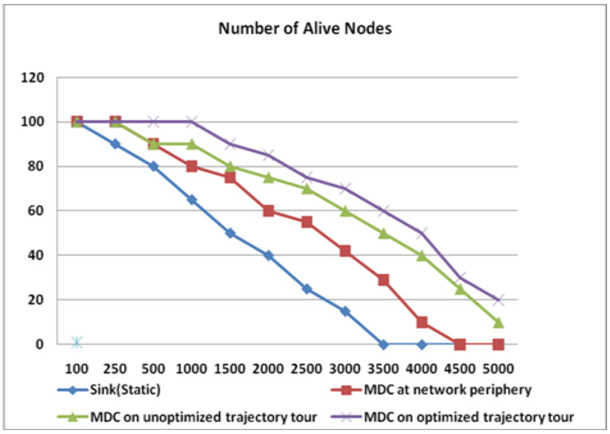


Figure 9 Number of live nodes after a specific number of rounds

Likewise, number of dead nodes is yet another important parameter to measure. More number of dead nodes after a set of rounds indicates the expiry of network lifetime. An efficient algorithm which aims to improvise the network lifetime should minimize the number of dead nodes in the network. The proposed scheme minimizes the number of dead nodes to a great extent in comparison with the other existing scheme. Theresults are showcased in Figure 10.

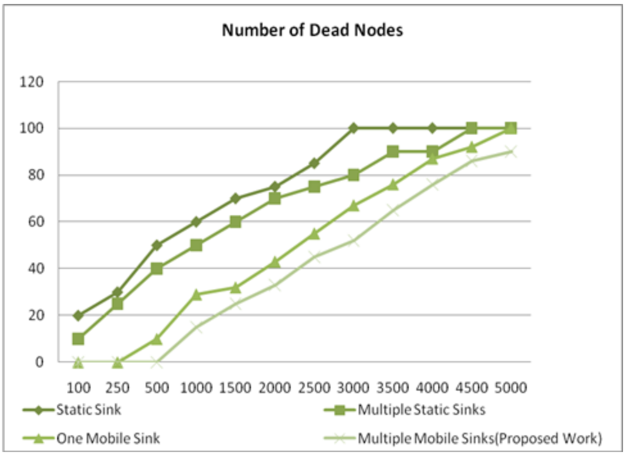


Figure 10 Number of dead nodes after a specific number of rounds

Conclusions

The work proposes a clustering protocol to form data collection trees. The contribution is extended further by formulation an optimization model for improvising the sensor network lifetime. The mobile sinks are allowed to travel along the predetermined trajectory and stop at each sojourn location for an optimal time location. The optimization model considers the one hop residual energy and energy consumption of the individual sensor. Simulation experiments showcase better performance of the proposed work in comparison with existing model.

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