MULTIPLE MOBILE SYNCHRONISED SINKS (MMSS) FOR ENERGY EFFICIENCY AND LIFETIME MAXIMIZATION IN WIRELESS SENSOR NETWORKS

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Abstract: Wireless Sensor Networks(WSNs) consist of battery operated sensor nodes. Improving the lifetime of sensor network is a critical issue. Nodes closer to the sink node drains energy faster due to large data transmission towards a sink node. This problem is resolved through mobility of the sink node. The Mobile sink moves to particular positions in predetermined order to collect data from the sensor nodes. There is considerable delay in the case of single mobile sink. In this paper we have used the concept of multiple mobile sinks to collect data in different zones which in turn coordinate to consolidate the data and complete the processing of data received from all the sensor nodes. A distributed algorithm synchronizing all the mobile sinks are used to reduce the delay in consolidation of data and reducing the overall energy consumption. The twin gain increases the lifetime of the Wireless Sensor Network. Simulation results using Multiple Mobile Synchronized Sinks clearly shows that there is an increase of 28% and 56% in the lifetime of the Wireless Sensor Networks in comparison with Single Mobile Sink and Static Sink respectively.

1 INTRODUCTION

Wireless Sensor Network (WSNs) uses battery operated wireless micro-sensor nodes to collect the information from a geographical field and transmits in multihops to the sink. Hundreds or thousands of this micro-sensors are deployed to watch the environment and collects the data about it. These sensor batteries are impractical to replace or recharge and hence energy of the sensor nodes are to be saved to increase the lifetime of the Network. The operational lifetime of a sensor node is in terms of weeks or months. Sensor node spends energy for each process like sensing, transmitting and receiving data. Hence, energy is an important criteria in Wireless Sensor Networks.

WSNs have considerable technical challenges in data processing and communication to deal with dynamically changing Energy, Bandwidth, Delay, Sensing and Processing power. The vital issue in WSNs is to maximize the network operational life. In order to achieve this, it is necessary to minimize the energy utilization of every sensor node. Energy can be conserved by efficient routing and data aggregation. Another important issue in WSNs is security when it operates in a hostile environment and needs to be protected against intruders.

For the small networks, source sensors can directly transmits the data to the sink node. For a larger network, multihop communication is needed to reach the static sink. For real time applications, the sensitive data should reach the sink node without any delay. There are many methods to reduce the distance between the source and the sink. First method is to move the sink node over the entire network to collect the data, the second method is to have multiple static sinks at different locations and third method is to increase the number of mobile sinks. Thus the distance between the source and sink is reduced.

When an event occurs, immediately the sensor node communicates the information to the sink node. Neighbor nodes of the sink node depletes energy faster due to the large and continuous data forwarding towards the sink. Thus, lifetime of the sensor network is reduced even though non-neighbor nodes

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have enough energy for communication. To overcome this problem Gatzianas et al., (Gatzianas and Georgiadis, 2008) have considered the use of single mobile sink. The mobile sink collects the information from the sensor nodes during its round trip time *i.e.*, time during which mobile sink visits entire network in predetermined positions.

Motivation. In static sink sensor network, nodes closer to the sink depletes their energy fast, though other nodes in a network have enough amount of energy for communication. The single mobile sink keeps moving to predetermined positions and stays for a specific period of time to collect the data. The sensitive data moving from the source sensors may loose their importance due to the nonavailability of the single mobile sink. This is due to the delay in the arrival of the single mobile sink to that position. This problem is addressed in this paper by implementing distributed algorithm with multiple mobile sinks and thus sensitive information reaches the sink without delay.

Contribution. The main contribution of this paper is the development of an efficient distributed algorithm using Multiple Mobile Synchronized Sinks offering an alternative to the single mobile sink. A distributed algorithm for computing the maximum lifetime of a wireless sensor network, which routes data to the nearest mobile sink by imposing flow conservation to all positions with respect to sinks. An interference-free sensor network with a multiple mobile synchronized sinks reduces delay, uses less Bandwidth, consumes lower energy and increases the lifetime of the WSNs.

Organization. The rest of the paper is organized as follows: Related work and Background work are discussed in Section 2 and Section 3 respectively. System Model and Network Architecture are explained in Section 4. Problem Definition and Mathematical Model is formulated in Section 5. Algorithm is developed in Section 6. Simulation and Performance parameters are analyzed in section 7. Conclusions are presented in Section 8.

2 RELATED WORK

Gatzians et al.,(Gatzianas and Georgiadis, 2008) addressed the maximization of lifetime of a mobile sink WSNs in-terms of energy constraint. A distributed Synchronous ε -relaxation algorithm based on the subgradient method is presented to minimize the required time to route data from other nodes of the network to a mobile sink. The system is restricted to semi-deterministic settings resulting in considerable delay.

Michail et al.,(Michail and Ephremides, 2003) discussed the routing connection-oriented traffic in wireless sensor networks with energy efficiency. Minimization of data transmission cost with limited bandwidth resources have been considered. Real-time constraints in the system and the restriction of nodes to the boundary of location leads to long routing paths between end to end nodes.

Xiao et al.,(Xiao et al., 2004) focused on link based optimal routing in wireless data networks. They have exploited a Simultaneous Routing Resource Allocation (SRRA) problem and capacitated multicommodity flow model to describe the data flows in the WSN. Joint link scheduling, routing and power allocation are not emphasized in this work.

Chang et al.,(Chang and Tassiulas, 2000) considered flow augmentation, flow redirection algorithm to balance the energy among the nodes in proportion to their reserve energy. The robustness of Shortest path routing to maximize the lifetime of a network is not discussed in this work.

Madan et al.,(Madan and Lall, 2006) formulated a distributed algorithm to compute an optimal routing scheme. The algorithm derived the concept of convex quadratic optimization & time constraint to maximize the lifetime of network. They have not considered asynchronous sub-gradient algorithm.

Ritesh et al.,(Madan et al., 2005) discussed the mixed integer convex program to maximize the lifetime of network. Non linear class of interference free Time Division Multiple Access for load balancing, Multihop routing frequency reuse & interference mitigation are utilized to increase lifetime of network. The work is restricted for non-distributed low topologised model with lower bound. Shashidhar et al.,(Gandham et al., 2003) proposed a flow based routing protocol to minimize the energy consumption in the sensors of WSNs.

Weiwang et al., (Weiwang and Chua, 2005) have used mobile relays to prolong the lifetime of Wireless Sensor Networks. The lifetime of the dense sensor network with mobile sink and mobile relays are almost same as that of mobile sink.

Branislav et al.,(Kusy et al., 2009) have developed an algorithm for data delivery in mobile sensor networks. Mobility patterns in the network, enables the algorithm to maintain an uninterrupted data stream. Scalability and communication cost are not considered.

Huang Zhi et al., (Zhi et al., 2010) have developed routing strategies for Dynamic WSN with single sink and multiple sinks. DWSN with single static sink is more reliable than the multiple static sinks. Frequent changes of routing table consumes more energy and the lifetime of Dynamic WSN is reduced with long latency and weak reliability.

Getsy et al.,(Getsy et al., 2010) proposed cluster based routing protocol for Mobile WSN (MWSN). Bayes rule is used in selection of cluster head with highest energy, least mobility and best transmission range. It is not fault tolerant.

3 BACKGROUND

Nodes in a Wireless Sensor Network produces information at a deterministic rate. Sensor Nodes nearer to the static sink, drains energy soon because of large data transmission to the sink node. To increase the lifetime of the sensor network Luo et al.,(Luo et al., 2005) considered a single mobile sink. Each node drains energy as the mobile sink moves to close to a position of occurrence of an event, spends a specified amount of time to collect the data from the sensors around the location of occurrence of the event.

The following conditions are assumed to give feasible solutions to the outgoing links of node to maximize the lifetime. The total expended power should not exceed the initial reserve energy. A peak power transmission constraints are imposed in all the location of sink and time intervals. A mobile sink can reside in a particular location for nonzero sojourn time and when sojourn time becomes zero, it moves to the next location.

In a distributed algorithm each node must store the following information., (i) Sink is distinguished from other nodes by unique node tag identifier,(ii) The maximum rate of information, energy and instantaneous power for each node, (iii) group of variables representing the flow and flow conservation cost which are used in minimum cost flow algorithm. (iv) the outgoing and incoming edges are doubly linked list, (v) a maximum array length to store parent and children of the node, (vi) variables independent of Network size.

4 SYSTEM MODEL AND NETWORK ARCHITECTURE

4.1 Definitions

Mobile Sink. One mobile sink moves to the predetermined positions collecting data from all the neighboring nodes.

Synchronized Sinks. Synchronization of multiple mobile sink is achieved through the common notion of time.

Multiple Mobile Sinks. More than one mobile sink moves to the predetermined positions collecting data from all the neighboring nodes.

Sojourn Time. The duration of time during which active mobile sink resides in a particular position.

Network Alive. The Network is alive until the sensor can transfer all generated traffic to the nearest sink by satisfying the energy/power and flow conservation constraints.

Energy Consumption. The amount of energy spent by each node in a sensor network for sensing, sending, receiving and processing data.

Lifetime of a Network. The period of time until the first node runs out of energy.

Delay. Time taken by the data to reach the mobile sink node from the source sensor node.

4.2 Network Architecture

The Multiple Mobile Synchronized Sink WSNs consists of two types of nodes, (i) Static ordinary sensor nodes which can only capture and transmit data, (ii) Mobile sink nodes that move to predetermined positions to collect data from the static Sensor nodes. Multiple mobile sink nodes can coordinate to consolidate data collected from the static sensor nodes. The Wireless Sensor Network is divided into a number of zones as shown in Figure 1. The movement of the mobile sink is restricted to its zone. This technique increases the collection of data from ordinary sensor nodes reducing the consumption of energy and delay. Both these features helps in increasing the lifetime of WSNs. When one of the sink fails, the zones are merged. The network still continues to function though at a reduced efficiency, there is increase in delay and is called *graceful degradation*. The employment of multiple mobile sink increases reliability and does not allow the WSNs to collapse even with the failure of some Mobile sinks. The multiple mobile sinks are in continuous communication synchronously and thereby any failure in the sinks will be immediately detected and can be rectified.

4.3 Network Model

Consider a Wireless Sensor Network consisting of battery operated static nodes, which are randomly deployed over a given geographical area. The system model for the mobile sinks x_m, moves to fixed position

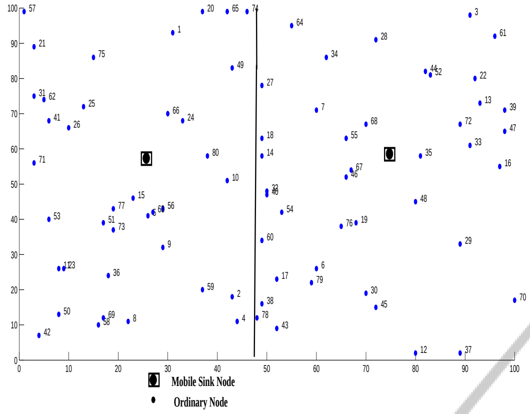

Figure 1: Basic Multiple Mobile Sink Wireless Sensor Network Architecture.

x_m^p to avoid early energy dissipation of neighbor nodes of the sink (*i.e.*, as in static sensor network)(Luo, 2006). Each node sensor $i = 1, \ldots\ldots, n \in V$ produces a fixed amount of information at rate of $I_i \geq 0$. It is assumed that all links between the nodes are bidirectional. The notations used in this paper are defined in Table 1.

The movement of the sinks to different positions creates a subgraph $G(V, L)$. All nodes $i \in V$ except for the sink are equipped with a non-renewable amount of energy $E_i > 0$. The energy of the sensor is gradually depleted as the nodes participate in routing. Once a node's energy is drained, the node can no longer transmit which leads to network failure.

5 PROBLEM DEFINITION AND MATHEMATICAL MODEL

5.1 Problem Definition

Given a set of Wireless Sensor Nodes $i \in V$, where $i = 1, \ldots\ldots, n$ and set of mobile sinks, $t_{x_m}^p$ the sojourn time of the m^{th} sink at position p, $t_{x_m}^{p,k}$ for a set of iterations where $k = 1, \ldots\ldots, K$. The objectives are

1. To decrease energy consumption and increase the lifetime of the Wireless Sensor Network.
2. To find optimal routing, maintain synchronization between the mobile sinks, to improve sojourn time and increase the survival time of the network (T). Where

$$max\ T = \sum_{1}^{p} \sum_{k=1}^{K} x_m^{p,k} \tag{1}$$

Table 1: Notations.

G	Undirected Graph.
V	Set of sensor nodes.
L	Edge set or link set.
S_i	Source node i, $i = 1, \ldots, n$.
x_m	m^{th} mobile sink.
i	Single sensor node, $i \in V$.
S_i^p	set of outgoing neighbors of node i at sink at position p.
I_i	Information generated at the node i.
x_m^p	p^{th} position of the mobile sink $x_m, p \in P$.
P	set of mobile sinks positions.
$R_{ij}^{p,k}$	Data transmission rate from node i to j while sink stays at position p for k^{th} iteration.
R_{ij}^p	Data transmission rate from node i to j while sink stays at position p.
$t_{x_m}^{p,k}$	Time for k^{th} iteration of m^{th} mobile sink at position p.
$e_{ij}^{p,k}$	Power needed for data transmission from node i to j while sink stays at position p for k^{th} iteration.
e_{ij}^p	Power needed for data transmission from node i to j while sink stays at position p.
$t_{x_m}^p$	Sojourn time of the m^{th} sink at position p.
E_i	Initial Energy of the node.
G'	Sub graph $G' \subset G$.
e_t	Power needed for transmitting one bit of data.
e_r	Power needed for receiving one bit of data.
k_r	k bits of data is received.
k_t	k bits of data is transmitted.
α	transmission factor.
β	reception factor.
ε_i	power constraint
d_{ij}	distance between node i and j

and can be further reduced to a equivalent form of

$$max\ T = \sum_{1}^{p} t_{x_m}^p \tag{2}$$

From Equation 2, we can calculate the maximum lifetime of each mobile sink at different positions.

Assumptions

1. Sensor nodes are stationary, but the sinks change their positions from time to time with negligible traveling time between two positions. The positions of the sinks can be chosen within a finite set of $x_m^p \in P$.

2. A mobile sink has long range of communication that facilitates to transmit data.
3. Each sensor $i \in V$ produces information at fixed deterministic rate $I_i \geq 0$, which is routed in multi-hops to one of the mobile sinks x_m.

5.2 Mathematical Model

For receiving k_r $bits/sec$, the power consumption at sensor node is $e_r = k_r\beta$. where, β is reception factor indicating the energy consumption per bit. The power needed for transmitting k_t $bits/sec$ is $e_t = k_t\alpha d_{ij}$. where, α is transmission factor indicating the energy consumption per bit and d_{ij} is the distance between transmitting and receiving node. Therefore, total energy consumption at a node per time unit is

$$e_r + e_t = k_r\beta + k_t\alpha d_{ij} \approx e(k_r + k_t) \tag{3}$$

where, $e = \beta \approx \alpha\, d_{ij}$, because energy consumed to transmit a bit is approximately equal to the energy consumed for receiving a bit.

From the above discussions, the energy consumption at a sensor node i when the sink sojourn at position p is computed as

$$e_{ij}^p = e(\sum_{j \in S_i^p} R_{ij}^p + \sum_{j:i \in S_j^p} R_{ji}^p) \tag{4}$$

where, e_{ij}^p represents the total power needed for data transmission from node i to j while sink stays at position p. The energy is calculated through data transmission rate from node i to j and j to i vice versa with respect to the sink's position.

$$\sum_{1}^{p} \sum_{j\, \in S_i^p} R_{ij}^p e_{ij}^p\, t_{x_m}^p \ \leq E_i \,\forall\, i \in N \tag{5}$$

$$\sum_{j\, \in\, S_i^p} R_{ij}^p\, e_{ij}^p \ \leq \varepsilon_i, \quad \forall\, i \in N,\, \forall\, p \in P \tag{6}$$

$$\sum_{j \in S_i^p} R_{ij}^p = \ I_i + \sum_{j:i \in S_i^p} R_{ji}^p \tag{7}$$

The sink is moving through robots. The entire geographical deployment area has divided into two zones. In each zone sinks moves to the predefined positions. The mobile sink moves to different positions to collect the data from the source node. When an event occurs, the sensor senses the data and it forwards the data to the nearest mobile sink positions. If sink is not available in that position then sensors forwards the data to the next available position of the sink. We reduce the Response Time (RT) by introducing the multiple mobile sinks. The Response Time is computed as,

$$RT = RT_{end} - RT_{start} \tag{8}$$

RT_{start} is the time during which the packet started.
RT_{end} is the time during which the packet reached the sink.

Equation 4 represents the total amount of energy spent at node i and j that depends on the traffic rate on node i and j. Equation 5 and 6 explains the energy constraints for communication *i.e.*, energy required for transmitting and receiving data, must not exceed the residual energy of a node. Equation 7 gives the data transmission rate on link i, j *i.e.*, the sum of actual sensed information and traffic rate in the link.

6 ALGORITHM

6.1 MMSS Distribution Algorithm

The Multiple Mobile Synchronized Sink algorithm comprises of two algorithms: MMSS Routing Algorithm and MMSS Iteration Algorithm. In Table 2 the MMSS Distribution Algorithm begins with the selection of multiple mobile sinks. Each sink moves to a predefined position for a specified period of time to collect data from each zone. The neighbors of a active sinks are identified by sending the hello packets from all the sensor nodes to the nearest active sink. MMSS algorithm runs for various iterations for different sinks and positions.

MMSS Routing Algorithm selects a minimum distance routing to reduce the energy consumption in the network. When a sensor node has data to forward, it checks for the active sink position and then forwards the data. If the data transmission time exceeds the sink's sojourn time then forwards the data to the next nearest active position of the mobile sink.

The data collection during the sojourn time of the mobile sink is referred as iterations (*i.e.*, number of successive transmission). Number of iterations for a particular sink is computed by summing the number of successive transmission during its round trip. The amount of energy dissipated by each node for transmission and reception of data is calculated. If residual energy is equal to zero then $network\ fails$. Otherwise, the algorithm runs until one of the node's energy drains to zero in the network. Failure in the sink is detected and repaired as the sinks are synchronized.

7 IMPLEMENTATION AND PERFORMANCE ANALYSIS

In the setup of MATLAB simulation, a 100m x 100m region was considered with three sets of network

Table 2: MMSS Distribution Algorithm.

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The subgraph $G' \in G$ for all $k$, vectors $V, E, P, I, \varepsilon$ initial iteration $k_0$ are taken as input to the algorithm
Initialize $k = k_0$
Select $x_m$ as the number of mobile sinks and predetermine positions as $x_m^p$.
Fix the routing path of each sink $x_m$;
set arbitrary time $t$;

while $termination\ criterion$ is $false$ do
  for $p = 0$ to $|P| - 1$ do

    Phase 1: MMSS Routing Algorithm
    for $i = 1$ to $n - 1$ do
      for $j = i + 1$ to $n$ do
        Calculate the distance between all the nodes with respect to the active position of the sink $x_m^p$ at time $t$.
        $total\_distance = total\_distance + distance$ ;
      endfor
    endfor
    compute minimum $total\_distance$
    solve the minimum cost flow for subgraph $G'$
    determine $t_{x_m}^p$ ;
    if $t_{x_m}^p \geq transmission\ time$ then
      Route the data to the nearest active position of the sink $x_m$
    else Route the data to the next nearest active position of the sink $x_m$
    endif

    Phase 2: MMSS Iterations Algorithm
    update $t_{x_m}^p \ \forall (i, j) \in L$
    update from $k$ to $k + 1$ for all nodes
  endfor
  Calculate Energy dissipation as
  $Energy\ dissipation = Transmission\ Power + Flow\ Rate$;
  Calculate Residual energy of the node $E_i = Residual\ Energy - Energy\ dissipation$;
  if $E_i = 0$ then
    return;
  else
    $k = k + 1$;
  endif

  if sink $x_m$ is failed then $x_{m+1}$ is made active for that zone.
  endif
endw
```

topology with 20, 40 and 80 nodes respectively. The sink was allowed to move over 2, 4 and 8 locations, which were the same for all zones. In all cases, each node had an exogenous rate of $I_i = 1$. The flow cost of edge $L(i, j)$ is assumed proportional to d_{ij} the physical distance between the two nodes. Two scenarios were studied: in the first one, only a power constraint of $E_i = 100nJ$ is applied while in the second one, a power constraint of $\varepsilon_i = 10nJ$ is also imposed. The simulation parameters are shown in Table 3.

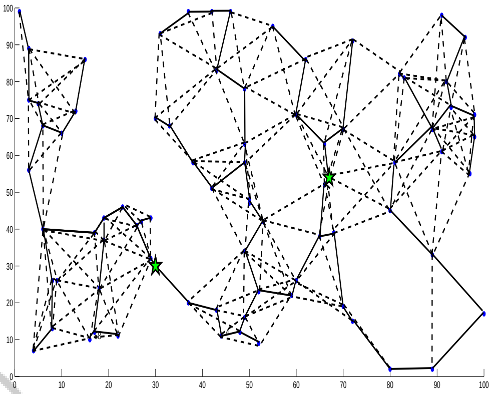

Figure 2: Complete Route tree for Multiple mobile sink in 100X100 area with 80 nodes.

We consider, as nodes increase in a sensor networks, the number of mobile sinks also increases. The Simulation environment deployed with 8x10 i.e., 80 nodes. Each node is identified through node identifier as node 1, node 2, node 3 etc... The simulation setup is varied for 20, 40, 80 nodes with multiple mobile sinks. Mobile sink moves in 2, 4, 8 locations and stays for a sojourn time. We observe that, there is a considerable increase in the lifetime of a multiple mobile sink of Sensor Network in comparison with static and single mobile sink.

Table 3: Simulation Parameters.

Parameter Type	*Test values*
Number of nodes	100
sink node	mote 1
Radio model	lossy
Multi channel Radio Transceiver	433MHz
Sensor type	Light, Temperature, Pressure
Outdoor Range	500ft
Energy consumption per bit	60pJ

Table 4, Table 5 and Table 6 gives the amount of energy residues in each node of 8x10 simulation setup after 914, 1386 and 1646 iterations of Sensor Network with static sink, single mobile sink and multiple mobile sink respectively. Table 4 shows the residual energy of nodes for single static sink. In the table zeroth row and first column represents node 1, the zeroth node and second column represent node 2 and the first row and first column represent node 11 in this manner nodes 1 to node 80 are identified. The amount of energy residues in node 1 is 1.378nJ.

Table 4 gives the residual energy of the node for the network with the static sink. We observe that nodes 25, 36, 45 and 66 closer to the static sink have zero energy remaining and the network fails after 914

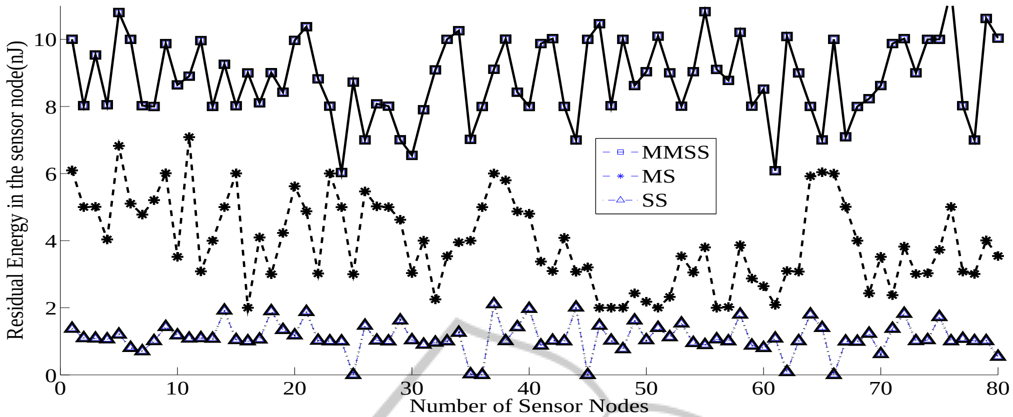

Figure 3: Comparison between the MMSS, SMS and SS Networks after 914 iterations.

Table 4: Residual Energy(nJ) in each node of 8x10 static sink WSNs after 914 iterations.

	1	2	3	4	5	6	7	8	9	10
0	1.378	1.096	1.085	1.062	1.204	0.805	0.706	1.009	1.430	1.180
1	1.085	1.096	1.08	1.92	1.04	1.001	1.056	1.900	1.340	1.185
2	1.876	1.021	1.002	1.000	**0.000**	1.467	1.024	1.000	1.623	1.035
3	0.902	0.963	1.001	1.258	0.020	**0.000**	2.109	1.008	1.424	1.970
4	0.876	1.021	1.002	2.009	**0.000**	1.467	1.024	0.767	1.623	1.035
5	1.402	1.125	1.535	0.952	0.890	1.060	1.003	1.800	0.873	0.803
6	1.085	0.086	1.007	1.802	1.401	**0.000**	0.996	0.989	1.230	0.623
7	1.376	1.823	1.009	1.037	1.726	1.004	1.078	1.009	1.009	0.543

iterations.

Table 5 gives the residual energy of the network with single mobile sink. Node 13, 16, 24, 25, 35, 36, 46, 47, 48 and 69 have zero energy after 1386 iterations where further communication is not possible.

Table 6 represents the residual energy of the network with multiple mobile sink. In this table node 8, 16, 23, 36, 39, 44, 45, 48, 52, 63, 66, 74 and 78 has zero energy after 1646 iterations. Table 7 explains the lifetime of the variable networks size. For 10 nodes with static sink network, the lifetime is only 143 iterations which is less than that network with single mobile sink and multiple mobile sink. As the number of nodes increase in a given area, the lifetime also increases.

Figure 2 shows the complete routing tree for multiple mobile sinks. This shows that energy at all nodes are used effectively through multiple mobile sinks, Thus it increases the lifetime of the network.

Figure 3 explains the amount of energy residues in each node for the same deployment of 8x10 after 914 iterations for Sensor Networks with static sink, single mobile sink and multiple mobile sink. It is observed that residual energy is higher in each node of that multiple mobile sink than with the static sink and single mobile sink.

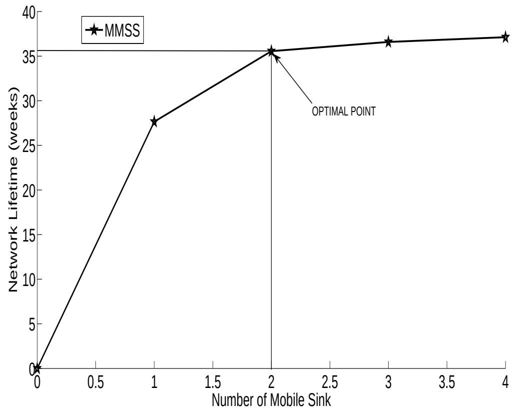

Figure 4: Optimal number of sinks for a 80 node network.

The variance of residue energy in WSN with static sink is 0.2578. The variance of residue energy in WSN with static sink is 0.2295. The variance of the residual energy in the network with multiple mobile sinks is 0.2235, which is lower than the network with the static and single mobile sink. It is observed that all nodes in MMSS network, drain their energy uni-

Table 5: Residual Energy(nJ) in each node of 8x10 Single Mobile Sink WSNs after 1386 iterations.

	1	2	3	4	5	6	7	8	9	10
0	0.096	0.003	0.009	0.036	0.826	1.104	0.778	0.209	0.009	0.518
1	0.085	0.086	**0.000**	0.002	1.004	**0.000**	0.096	0.020	0.230	0.623
2	0.876	1.021	1.002	**0.000**	**0.000**	1.467	0.024	1.000	0.623	1.035
3	0.002	0.25	0.535	0.952	**0.000**	**0.000**	0.003	0.800	0.873	0.803
4	1.378	0.096	0.085	1.072	0.204	**0.000**	**0.000**	**0.000**	0.430	0.180
5	1.002	1.325	1.535	0.052	0.800	1.00	0.023	0.867	1.873	0.643
6	1.085	0.096	0.08	0.92	1.04	1.001	1.009	**0.000**	1.430	0.518
7	0.376	1.823	0.009	0.03	0.726	0.004	0.078	0.009	1.009	0.543

Table 6: Residual Energy(nJ) in each node of 8x10 Multiple Mobile Sink WSNs after 1646 iterations.

	1	2	3	4	5	6	7	8	9	10
0	1.002	0.325	0.535	0.052	0.800	1.000	0.023	**0.000**	0.873	0.643
1	0.902	0.963	1.001	1.258	0.020	**0.000**	1.109	0.003	0.424	0.970
2	0.376	0.823	**0.000**	0.030	0.726	0.004	0.078	0.009	0.009	0.543
3	0.902	0.090	0.001	0.258	0.020	**0.000**	0.109	0.008	0.424	**0.000**
4	0.876	0.021	0.002	**0.000**	**0.000**	0.467	0.024	**0.000**	0.623	0.035
5	0.096	**0.000**	0.009	0.036	0.826	0.104	0.778	0.209	0.009	0.518
6	0.085	0.086	**0.000**	0.002	0.004	**0.000**	0.096	0.009	0.230	0.623
7	0.876	0.021	0.002	**0.000**	0.090	1.467	0.024	**0.000**	0.623	0.035

Table 7: Lifetime of the networks with Variable number of sensor nodes in a given area 100m x 100m.

Nodes	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
SS	143	298	452	547	667	713	760	778	804	824	856	889	904	910	914
SMS	276	438	618	734	868	964	1048	1099	1167	1201	1248	1298	1333	1346	1386
MMSS	354	556	739	866	996	1090	1179	1239	1296	1352	1398	1469	1528	1589	1646

formly and thus improves the lifetime of the network.

The selection of optimal number of mobile sinks depend on the size and density of the network. When the number of mobile sink increases to three, the network lifetime is approximately equals to lifetime of the network with two mobile sinks as shown in Figure 4. We can conclude that two mobile sinks are optimal for the network with 80 nodes.

Figure 5 and 6 presence the lifetime of the MMSS, SMS and SS. It is observed that the lifetime of MMSS approach is higher than SMS and SS approaches. While the lifetime of SS and SMS approach is 914 and 1386 time units, the lifetime of MMSS approach is 1646 units *i.e.*, 56% more than SS and 28% more than SMS.

Figure 7 depicts the number of sinks required for a variable number of sensors. It is observed that two sinks are sufficient for nearly 100 sensor nodes and there after there is a linear increase in the requirement of sinks to maintain the desired performance of lifetime and delay.

Figure 8 shows plot of the graph for the delay and number of sensor nodes with static sink, single mobile sink and multiple mobile sinks. The simulation starts with 10 sensor nodes to 80 nodes. Response Time (delay) is calculated as per Equation 8. We observe that there is a considerable reduction in delay for multiple mobile sink. This reduction of delay is due to less number of hops and reduced distance between the source and the sink. In SS approach, the average delay is 37 msec for 10 nodes while 30 msec

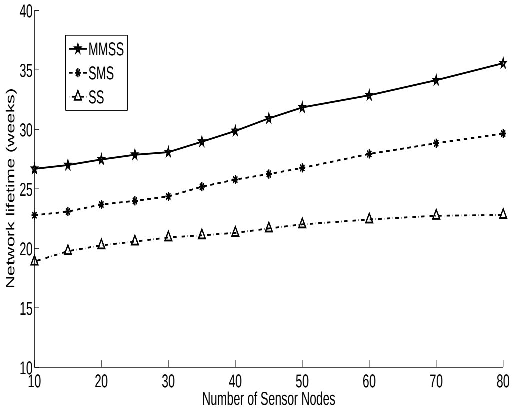

Figure 5: Comparison of lifetime between the MMSS, SMS and SS Networks.

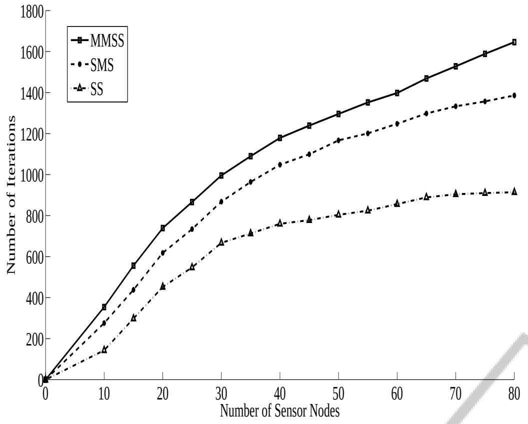

Figure 6: Comparison of number of iterations between the MMSS, SMS and SS Networks.

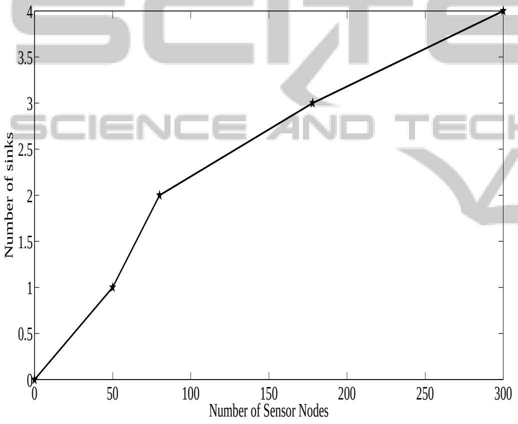

Figure 7: Number of nodes vs Number of sinks.

and 25msec respectively for SMS and MMSS approaches. Thus there is reduction in delay by 50% in MMSS in comparison to SS. As the network density increase, there is gradual reduction in average delay. Though, there is large reduction in delay between SS and SMS, but the reduction is much lower between SMS and MMSS.

8 CONCLUSIONS

In WSN with a static sink, all source node forwards data towards the sink. In a single mobile sink network, sink moves to pre-determined positions and stays for the sojourn time to collect the data. We propose a distributed algorithm with Multiple Mobile Synchronized Sink to improve the lifetime of the sensor network. A linear program model is proposed to increase the lifetime of the network and to reduce the delay in the transmission of data between the source node and the mobile sink nodes. For the proposed model, simulation is carried out for multiple mobile sink which increases the lifetime by 56% over single static sink and 28% over single mobile sink network. During the last iteration of MMSS WSN, the residual energy of all the sensor nodes is almost same which shows that energy drains uniformly and thus increases the lifetime of the network. The proposed MMSS algorithm minimizes the delay in the network at a very small increase in cost of multiple mobile sinks. In future, this can be developed for large scale WSNs including reliability and recovery.

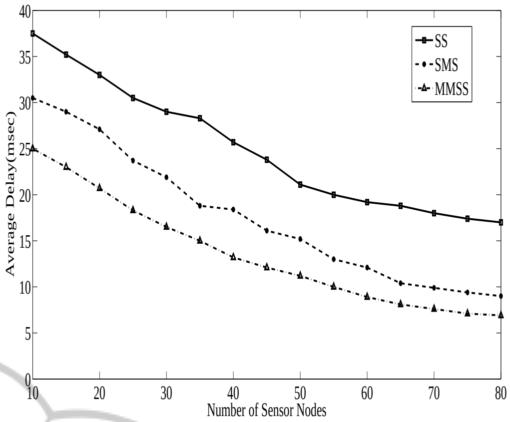

Figure 8: Number of nodes vs Response Time (Delay).

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