Energy Efficient Adaptive Cooperative Routing(EEACR) with Multiple Sinks in Wireless Sensor Networks

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***Abstract*—Wireless Sensor Networks(WSNs) consist of hundreds or thousands of battery operated, computable and low cost sensors. In WSNs energy conservation is an important design issue for routing, power management and data dissemination protocols. The existing cooperative routing is addressed to reduce the energy consumption. We propose an algorithm Energy Efficient Adaptive Cooperative Routing(EEACR), that maximizes the energy and Lifetime of the network. Mathematical model is developed to find the best location of the sink to reduce the distance between sources and the sink. A comparative study of EEACR with multiple static and mobile sinks is carried out. Simulation result shows that the EEACR algorithm produces better result than the existing Algorithms.**

***Index Terms*—Cooperative Routing, Energy Efficiency, Multiple Mobile Sinks, Static Sinks, Wireless Sensor Networks.**

I. INTRODUCTION

Wireless Sensor Networks(WSNs) consist of battery operated tiny sensors connected in a network for communication. They are limited in power, memory and computational capacities. These sensor nodes are deployed randomly to monitor the environment for one or more phenomena, process the data and forward the data to the sink. Once the battery of sensor node gets discharged completely, the network fails. It is essential to preserve the energy of the sensor nodes, since it is very difficult to recharge or replace the battery of the sensor nodes.

The effective deployment of nodes, efficient routing technique, memory management technique, better query processing technique, reduction of cost for transmission and reception of data etc.. are few techniques used to reduce energy consumption. Wireless medium operates in broadcast mode, i.e., the signal is transmitted from the source to the destination node and received by all the other nodes present within transmission range. This property is referred as Wireless Broadcast Advantage(WBA).

Nodes can cooperate with each other in transmitting the information to other nodes. It achieves energy conservation through cooperative routing using multiple antennas and the amount of energy conservation through the cooperative routing, is referred as Wireless Cooperation Advantage(WCA). Mobile sinks are classified into random, autonomous moving and planned movement and they move in the monitored region to collect the data. A Single mobile sink results in long delays and hence not suitable for real time applications. Optimal location of multiple static sinks and mobile sinks are considered for energy conservation.In WSNs, the source node transmits the data to the next node through direct transmission. The reliability of data reaching the destination is lower in direct transmission. The failure of data transmission is avoided through cooperative routing. In this work, nodes located nearer to the sink depletes their energy faster due to large and continuous data transmission to the sink. The main contribution of this paper is the development of an Energy Efficient Adaptive Cooperative Routing algorithm with static and mobile sinks. A mathematical model to find the best location of the sink to reduce the distance between the sources and the sink. The algorithm identifies the shortest path with more signal strength for the transmission of data. The route is either direct routing or cooperative routing for the successful transmission of data with minimal consumption of energy energy. The rest of the paper is organized as 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.

II. LITERATURE SURVEY

Shakkottai et al., [1], addressed the issue of crosslayer networking, where the physical and MAC layer knowledge of the wireless medium is shared with higher layers, in order to provide efficient methods of allocating network resources and applications over the internet. Gatzians et al., [2] addressed the maximization of lifetime of a WSNs. The sub-gradient method is presented to minimize the required time to route data from other nodes of the network to a mobile sinks. This system is restricted to semi-deterministic settings resulting in considerable delay. Madan et al., [3] formulated a distributed algorithm to compute an optimal routing scheme to maximize the lifetime of network. They have not considered asynchronous sub-gradient algorithm. Laura et al., [4] have experimented the measurement of an IEEE 802.11 wireless network interface to operate in an Ad Hoc Networks. Linear equations are used to calculate the energy consumption for sending, receiving and discarding packets of various sizes.

In the linear model the correlation coefficient is 0.99 in in every instance and uncertainty of the packets is 7% and energy conservation is about 150% in an Adhoc Networks. Energy consumption is calculated with respect to the following conditions distance, speed, cluster based routing protocols. Processing Quality is not considered for the energy consumption. Ahmed K. et al., [5] proposed distributed relay assignment protocol for cooperative communication in wireless Networks. The relay is selected from the nearest neighbor list. The simulation results showed that, significant increment in gain of the coverage area for the cooperative routing than the direct routing. Framework for mobile sink is considered in [6] and [7]. Since the sink is mobile in nature it reduces the distance between source and sink and delay for transmission. In our previous work [8] we developed a mathematical model for wireless sensor networks with a single static and mobile sink to maximize energy conservation.

III. BACKGROUND

The existing Shortest Non-Cooperative Path(SNCP) algorithm finds the shortest path using Bellman Ford Algorithm to route the data from source to destination without cooperative routing. While, Cooperative Along Shortest Non Cooperative Path(CASNCP) algorithm identifies the shortest path first then applies either cooperative routing or direct routing to route the data. In case of MPCR algorithm Ahmed et al., [9] have used cooperative routing while establishing the path itself. CASNCP approach does not exploit the complete benefit of Cooperative Routing. The Minimum Power Cooperative Routing(MPCR) algorithm guarantees throughput with minimum power single relay. They have formulated the model to reduce the power consumption as given below

$$min_{\omega\in\Omega}\sum_{w_i\in\omega}P_{w_i}\ show\ \ that\ \eta_w\geq\eta_0 \tag{1}$$

where P_{w_i} denotes the transmission power over the i^{th} hop. η_w is the end to end throughput and η_0 represents the desired throughput and w_i is the i^{th} hop of the route, represents all possible routes.

They have not considered Signal to Noise Ratio (SNR) in the channel; it is an important criteria for the successful transmission of data. If the amount of noise present in the channel is more than SNR threshold value , then the data cannot be transmitted over large distances. We consider mobile sinks to reduce the distance between the sources and sink. In our earlier work, we consider EEACR algorithm with single static and mobile sink to conserve energy and maximization of lifetime for the WSNs. In this work we propose a mathematical model to find minimum distance between the source sensor nodes with respect to multiple static and mobile sinks.

IV. SYSTEM MODEL AND NETWORK ARCHITECTURE

A. Network Architecture

In WSNs, sensor nodes are deployed randomly as shown in the Fig (1). Let s be the source node, it transmits the data through broadcast method. The data can be transmitted from source to next hop directly. If the distance between source node to the next hop is more than the limited range then the data cannot reach the next node directly. Through the broadcast advantage, data can be heard by all the sensor nodes which are present in the transmission range.

Routing data to the sink node is the multistage decision problem. Decision of the transmission, power consumption and power level are the parameters considered for the transmission of the data. As in Fig (1) a and b, the relay nodes for the source node s helps to transmit the data to the next hop via cooperative routing which is referred as Cooperative Routing Advantage (CRA). There are two relay nodes a and b for the source node s. Source s can select either a or b depending on the distance. The nearest node is selected to reduce the energy consumption.

When an event occurs, it is sensed through the nearest node named as source node s. Then, the source node s forwards the data to the nearest sink. First, source node applies the shortest path algorithm and finds the next hop to which data can be sent i.e., b. After sending data to node b, it calculates the strength of received signal r_s. If the received signal strength is less than the minimum fixed threshold value γ, node b sends re-request to the relay node by applying cooperative communication algorithm. If the relay node a has received the data correctly wihtout error, then it cooperatively forwards the data to node b. The procedure is repeated till the sink node is encountered. The nodes wait until next event occurs in the network.

The static neighbor nodes of static sink drains their energy fast due to the continuous transmission of data to the sink. To reduce the energy consumption we consider mobile sinks along with cooperative routing. All sinks are deployed randomly and movement of sinks in predetermined locations. When sensors have data for transmission it is aware of the position of the sink through the global information timer.The Energy Efficient Adaptive Cooperative Routing Sink Selection Algorithm selects the nearest sink based on the location of the sink to reduce delay and energy consumption.

B. Network Model

Wireless Sensor Network is modeled as an undirected graph $G = (V, E)$, where V is node set and E is an edge set

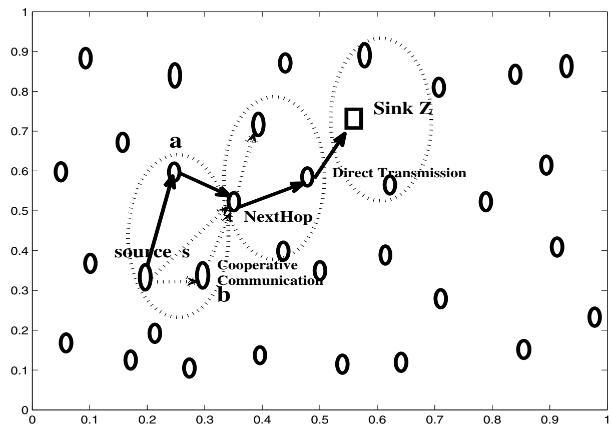

Fig. 1. Direct and Cooperative Transmission

representing the communication link between node pairs. We assume source node set $s \in V$ and the destination node set $Z \in V$. The system model for mobile sink Z_m moves to fixed location. The sensor nodes sense the data and produces the fixed amount of data and transmits the data at fixed rate r_i. All nodes are equipped with non renewable amount of initial energy $E_i > 0$. The movement of sinks at different location creates a sub-graph G^*, where $G^* \in G$. As the sensor node participates in communication it depletes their energy gradually, when sensor node drains their energy completely the network cannot survive further.

V. PROBLEM DEFINITION AND MATHEMATICAL MODEL

Given a set of Wireless Sensor Nodes $S_i \in V$ where $i = 1, 2, \ldots, n$. we consider different type of sinks for the simulation. The multiple Static Sinks (z^l) with the coordinates (x_z^l, y_z^l), where l indicates the location of the sink. The multiple Mobile Sinks (z_{mt}^k) with coordinates $(x_{z_{mt}}^k, y_{z_{mt}}^k)$, where k indicates the mobile sink number and z_{mt} indicates the location of mobile sink at time t. The objectives are

1) to reduce the energy consumption.
2) to maximize the lifetime of the network through the Adaptive cooperative routing algorithm.

A. Assumptions

1) All source sensor nodes are static.
2) Links in between the nodes are bidirectional.
3) Sink has higher communication range and energy than the source sensor nodes.
4) In the case of multiple mobile sinks, sink moves in the predetermined location with respect to global information timer.
5) Path loss exponent α = 1 to 4 and Threshold value for SNR_{min} is constant.

TABLE I
Notations

Symbols	*Description*
γ	Signal to Noise Ratio
d	Distance
$z_{x,y}^{(l)}$	Multiple Static Sink with coordinates x and y, where l is the location of static sinks,...
$z_{m_{xt,yt}}^{(k)}$	Multiple Mobile Sinks with Coordinates x and y at time t and $k = 1, 2, 3, \ldots$ which indicates the number of mobile sink
$\beta_{s,r}$	Channel Gain between Source Node s and Relay Node r
r_c	Received Power
ω	Noise Power
I	Interface Power
η	Additive Noise
h	Channel Coefficient
n	Number of Sensor Nodes
R	Transmission Rate
L	Number of Links
α	Path Loss Exponent
q	Laplace Transformation of Exponential Distribution
pc^C	Power Consumption for Cooperative Communication
pc^D	Power Consumption for Direct Communication
E	Energy Consumption Per Path
N	Noise Variance
s	Source Node
V	Node Set

B. Theorem

Identification of the sink location minimizes the distance between the source and the sink:

Proof:

Case 1:Multiple Static Sinks

In the case of Multiple Static Sinks, a graph G, node $i \in V$ with the coordinates of (x_i, y_i). Let z^l be the one among multiple static sinks with the coordinates (x_z^l, y_z^l) and $l = 1, 2, 3, \ldots$. The minimum distance $(d_i^{(l)})$ between source and the static sink z^l is

$$d_i^{(l)} = \sqrt{(x_i - x_z^{(l)})^2 + (y_i - y_z^{(l)})^2} \text{ for } l = 1, 2, 3, \ldots \quad (2)$$

Sink should be placed at location such that distance between sink with respect to all other sensor nodes should be minimum.

$$\sum_{i=1}^{n} d_i^{(l)} \to min \text{ for } l = 1, 2, 3, \ldots \quad (3)$$

Location of the sink is obtained by partially differentiating (2) with respect to x and y. That is,

$$\frac{\partial}{\partial x_z^{(l)}} \sum_{i=1}^{n} d_i^{(l)} = \frac{\partial}{\partial y_z^{(l)}} \sum_{i=1}^{n} d_i^{(l)} = 0$$

Partial differentiation of equation (2) with respect to x is

$$\begin{aligned} \frac{\partial}{\partial x_z^{(l)}} \sum_{i=1}^{n} d_i^{(l)} &= \sum_{i=1}^{n} \frac{\partial}{\partial x_z^{(l)}} d_i^{(l)} \\ &= \sum_{i=1}^{n} \frac{\partial}{\partial x_z^{(l)}} \sqrt{(x_i - x_z^{(l)})^2 + (y_i - y_z^{(l)})^2} \end{aligned}$$

$$= \sum_{i=1}^{n} \frac{2(x_i - x_z^{(l)}(-1) + 0}{2\sqrt{(x_i - x_z^{(l)})^2 + (y_i - y_z^{(l)})^2}}$$

$$= \sum_{i=1}^{n} \frac{(-1)(x_i - x_z^{(l)})}{d_i^{(l)}}$$

$$= \sum_{i=1}^{n} \frac{x_z^{(l)} - x_i}{d_i(l)}$$

Similarly Partial differentiation of equation (2) with respect to y is

$$\frac{\partial}{\partial y_z^{(l)}} \sum_{i=1}^{n} d_i^{(l)} = \sum_{i=1}^{n} \frac{y_z^{(l)} - y_i}{d_i(l)} \tag{4}$$

Case 2: Multiple Mobile Sinks

In the case of Multiple Mobile Sinks, a graph G, node $i \in V$ with the coordinates of (x_i, y_i). Let z_{mt}^k be the one among multiple mobile sink with the coordinates $(x_{z_{(mt)}}^k, y_{z_{(mt)}}^k)$ at time t and $k = 1, 2, 3, \ldots$. The minimum distance (d_{it}^k) between source and one of the mobile sink is

$$d_{it}^{(k)} = \sqrt{(x_i - x_{z_{(mt)}}^{(k)})^2 + (y_i - y_{z_{(mt)}}^{(k)})^2} \; for \; k = 1, 2, 3, \ldots \tag{5}$$

Sink should be placed at a location such that distance between sink with respect to all other sensor nodes should be minimum.

$$\sum_{i=1}^{n} d_{(it)}^{(k)} \rightarrow min$$

The location of the sink is obtained by partially differentiating (5) with respect to x and y. That is,

$$\frac{\partial}{\partial x_{z_{(mt)}}} \sum_{i=1}^{n} d_{it}^{(k)} = \frac{\partial}{\partial y_{z_{(mt)}}} \sum_{i=1}^{n} d_{it}^{(k)} = 0$$

Partial differentiation of equation (5) with respect to x is

$$\frac{\partial}{\partial x_{z_{(mt)}}} \sum_{i=1}^{n} d_{it}^{(k)} = \frac{x_{z_{(mt)}}^{(k)} - x_i}{d_{it}} \tag{6}$$

Partial differentiation of equation (5) with respect to y is

$$\frac{\partial}{\partial y_{z_{(mt)}}} \sum_{i=1}^{n} d_{it}^{(k)} = \frac{y_{z_{(mt)}}^{(k)} - y_i}{d_{it}} \tag{7}$$

C. Energy Model

Finally, Power Consumption for Direct Communication is obtained as

$$pc^D = \frac{(2^R - 1)N d_{s,d}^{\alpha}}{-log(pr(\varphi)^D)} \tag{8}$$

Power Consumption for Cooperative Communication is obtained as

$$pc^C = \frac{(2^R - 1)N(d_{s,r}^{\alpha} + d_{r,d}^{\alpha})}{-log(pr(\varphi)^C)} \tag{9}$$

TABLE II
Algorithm: Selection of Destination Sink (SDS)

Algorithm: SDS
Begin:
Using the global information of timer and location sensor nodes must decide the destined sink to which data need to be sent as
switch $(type\_of\_sink)$ **then**
. **case** $Multiple\_Static\_Sinks$:
. min = ∞;
. **for** $(i = 1;\ i \leq l;\ i++)$ **do**
. **if** $(dist(event, Z^{(i)} \leq min)$ **then**
. min = dist (event, $Z^{(i)}$);
. $u = i$;
. **endif**
. **endfor**
. $dest$ =$Z^{(u)}$;
. **break**;
. **case** $Multiple\_Mobile\_Sinks$:
. min = ∞;
. **for** $(i = 1;\ i \leq k;\ i++)$ **do**
. tm = get (timer of sink node) ;
. **if** $(dist(event, Z_{(tm)}^{(i)}) \leq min)$ **then**
. min = dist (event, $Z_{(mt)}^{(i)}$);
. $u = i$;
. $t = tm$;
. **endif**
. **endfor**
. $dest$ =$Z_t^{(i)}$;
. **break**;
endswitch
end

Total power consumption of the path becomes the additive power consumption at each link present in the path, where path comprises of many links.

$$E = \sum_{i=1}^{L} (pc^{C|D})(l_i) \tag{10}$$

where l_i is the total number of links present in the path.

VI. ENERGY EFFICIENT ADAPTIVE COOPERATIVE ROUTING ALGORITHM (EEACR)

Sensor nodes are deployed randomly in the given area. Sinks are located at the predefined locations. Energy Efficient Adaptive Cooperative Routing algorithm checks for the void node in the network. Sensor node selects the desired sink as the destination to forward data. We consider two different cases of sinks for the implementation in WSNs. In the case of multiple static sinks, all sensor nodes have the global information about the sinks location and hence source nodes can route the data to the destined sink.

EEACR algorithm consists of two phases. Selection of Destination Sink (SDS) and Routing Towards Sink (RTS) are the two phases of EEACR algorithm. In phase one SDS multiple static sinks source node selects the closest sink based on the minimum distance. In the case of multiple mobile sinks, source node selects the mobile sinks based on the distance and it decides the location of the sink with the help of global timer. In phase two RTS selects either direct or cooperative routing

TABLE III
Algorithm: Routing Towards Sink (RTS)

```
Algorithm RTS
Begin:
After selecting the destination sink dest source node
s forwards the data cooperatively using shortest path
algorithm
while (s! = dest) do
.   Find the neighbors of the source s node as
.   j = 0;
.     for (i = 1; i ≤ num; i++)  do
.       if (dist(s,i) ≤ range && i! = s) then
.         neighbor[j] = i;
.         j = j+1;
.       endif
.     endfor
.   select a node from neighbor vector of source to
.   forward the data. i.e
.   σ_any (next_hop ⊂ {neighbor})
.   Source s forwards the data to the next_hop node.
.   Calculate strength of the received signal
.   at next_hop as
.   r_s = α√d + η
.   if  r_s ≥ SNR_min then
.     Calculate pc^D;
.    Update Energy Consumed cost as E = E+pc^D;
.   else
.      Calculate pc^C;
.    Update Energy Consumed Cost as E = E+pc^C;
.   endif
.   s = next_hop;
endwhile
return Energy Conserved Cost E;
end
```

TABLE IV
Energy Efficient Adaptive Cooperative Routing Algorithm(EEACR)

```
Algorithm EEACR

The Subgraph G' ∈ G ∀n ⊂ N, initial iteration
C_t = 0 and type_of_sink are taken as the input to
the algorithm.
Initialize C_t = 0;
Initialize p = type_of_sink;
Set timer t = 0;
begin
. while void node is false do
.   while(!event) do nothing;
.    if(event) then
.       C_t = C_t + 1;
.         if(dist(event,i) ≤ min) then
.     Calculate d_i = dist(event,i) ∀ nodei
.         endif
.       Determine minimum d_i w.r.t i, choose nodei
as source node
.     endif
.   Phase 1 : Call Algorithm Selection of Destination
.             Sink (SDS)
.    Phase 2 : Call Algorithm Routing Towards Sink
.             (RTS)
.       for i = 0 to num do
.        if ∃ atleast i ∈ V such that E_(i) == 0
.        then Networkfails.
.        else
.         repeat the Algorithm;
.          return;
.         endfor
.   endwhile
. endwhile
end
```

depending on the minimum energy consumption on the path to route data to the sink.

VII. SIMULATION AND EVALUATION

In the setup of MATLAB simulation, a 100m X 100m region is considered with 100, 200 and 300 sensor nodes. All sensor nodes have equal amount of energy initially. EEACR is implemented for the effective transmission of data to the sink without any loss. All the links are bi-directional, it transmits a data at the fixed rate.

TABLE V
Simulation Parameters

$Parameter\ Type$	$Test\ values$
Number of nodes	300
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
Alpha	4
SNR γ	-10 dBm
Throughput	1.95
Initial energy of sensor nodes	50 J

A. Performance Analysis

Figure 2 shows the graph between the energy consumption versus the number of links for the WSNs with multiple Static Sinks. The proposed algorithm EEACR consumes less energy than the existing protocols SNCP, CASNCP and MPCR. It is observed in Figure 2 that our algorithm EEACR consumes much lower energy with Multiple Static Sinks when compared to the existing protocols SNCP, CASNCP and MPCR. The difference in consumption of energy is smaller in sparse networks and the difference increases with increase in the density of links in the network. The consumption of energy is further reduced with multiple mobile sinks. The percentage of reduction is 64.15% and is clearly observed in Figure 3.

Figure 4 and Figure 5 shows the lifetime maximization of WSNs using Multiple Static Sinks and Multiple Mobile Sinks. It is observed that the energy consumption reduces thereby lifetime increases rapidly when compared with other protocols SNCP, CASNCP and MPCR. Initially, when the number of nodes are around 20 the lifetime of network using Multiple Static Sink and Multiple Mobile Sinks is about 200 iterations compared with other protocols which last 100 iterations. But as the density of nodes increases there is a large rise in the lifetime of WSNs. In the case of Multiple Static Sinks, the lifetime is 1000 iterations when compared to other protocols which last an average iterations of 150 (See Figure 5), while in Multiple Mobile Sinks lifetime further increases to 1200 iterations and this is observed in Figure 5. This is an increase of 72.61% more than results obtained in other protocols.

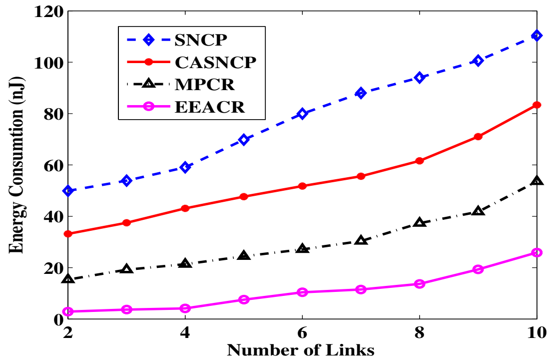

Fig. 2. Energy Consumption versus Number of Links for Multiple Static Sinks

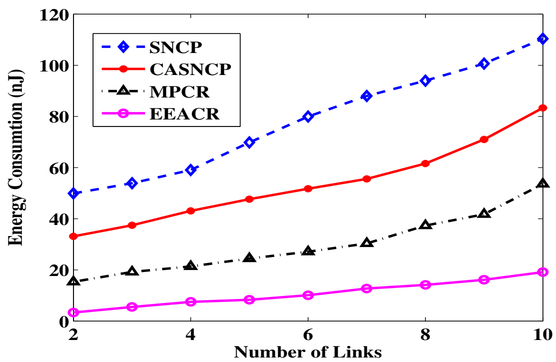

Fig. 3. Energy Consumption versus Number of Links for Multiple Mobile Sinks

VIII. CONCLUSIONS

Energy Conservation and lifetime maximization are important issues in WSNs. In this paper, we propose an EEACR to conserve energy and increase in lifetime of the WSNs. A mathematical model is developed to determine the best positions of sink to minimize energy conservation by considering noise variance and distances of the sources to the sink. Energy is conserved by using two important criteria i.e., by cooperative routing and positioning mobile sinks appropriately. Cooperative routing ensures that all nodes in WSNs participates uniformly without allowing the nodes nearer to the sink to drain out early. The multiple static and mobile sinks move in a fashion so as to reduce the distances of transmission of data from the sources to the sink thus ensuring reduction in consumption of energy. Multiple mobile sinks save maximum energy than multiple static sinks. These two factors i.e., adaptive cooperative routing and positioning of mobile sinks reduce energy consumption and maximizes the lifetime of the WSNs.

The EEACR algorithm is implemented for the random deployment of sensor networks with multiple static sinks and multiple mobile sinks. Results show that 64.15% and 72.61% improvement over the existing MPCR algorithm with respect to energy consumption and lifetime. This work can be extended in future with throughput and mobile sinks delay.

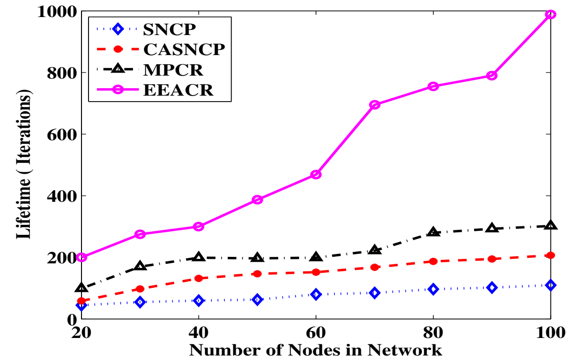

Fig. 4. Lifetime versus Number of Nodes for Multiple Static Sinks

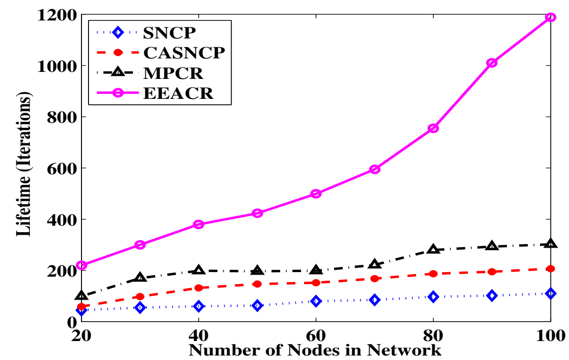

Fig. 5. Lifetime versus Number of Nodes for Multiple Mobile Sinks

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