Mobile Sink Based Reliable and Energy Efficient Data Gathering Technique for WSN

P. Madhumathy, D. Sivakumar
Easwari Engineering College, Chennai, Tamil Nadu, India
Department of CSE, Easwari Engineering College, Chennai, Tamil Nadu, India.

ABSTRACT

In wireless sensor network (WSN), data gathering causes more energy consumption. Also most of the existing literature work on data gathering process considers only distance and node density and skips reliability criteria. Hence in order to offer both reliability and energy efficiency, in this paper, we propose to design a Mobile Sink Based Reliable and Energy Efficient Data Gathering technique for WSN. In this process, a biased random walk method is used to determine the next position of the sink. Then, a rendezvous point selection with splitting tree technique is used to find the optimal data transmission path. When the data is sensed and ready for transmission, the sensor node encodes the data and communicates it to the sink. On receiving the encoded data from the sensors, the mobile sink decodes the messages and stores the resulting block in its local buffer. Once all blocks have been correctly decoded, the mobile sink reconstructs the original bundle. The increased packet losses in a specific region of the network can be prevented by increasing the pause time of the sink. By simulation results, we show that the proposed technique increases the reliability and energy efficiency.

Keywords:
Mobile sink, Data gathering, Rendezvous point, Splitting tree technique, Energy efficiency, biased random walk

Nomenclature

T_R	*overall in-network communication cost*
$DR(i)$	*data generation rate*
$E(i)$	*expected transmission count (ETX) of the link of any node and its neighbor*
η	*parameter related to energy consumption*
CN_i	*be the counter for every vertex i*
∂_i	*be the degree of vertex i*
$\Pr_j$	*the probability of visiting neighbor vertex j*
$\mathrm{Re}P_{mr}$	*rendezvous point with mobile sink nodes*
K	*Median*
P_{0g}	*the global optimal path*
P_0	*optimal path is estimated using the rendezvous point with mobile sink nodes RePmr*
Σ	*stretch factor*
S	*sink*
N_i	*static node*
EM	*error message*
h	*time required for the sink to visit all the nodes*
n	*number of sensors in the network*
T_{ts}	*maximum time that the sink is stationary*
M_{tx}	*total message transmitted*
E_{tx}	*maximum amount of energy utilized for data transmission*
ψ	*average data generation rate*
E_{ia}	*idle energy*
T_{exp}	*total time taken for the experiment*
w_e	*appropriately received encoded messages*
e_{ia}	*energy spent by the sensors during idle time*
T_{ts}	*maximum time the sink remains static in each round h*

1. INTRODUCTION

1.1 Wireless sensor networks (WSNs)

Wireless sensor networks (WSNs) consist of several sensor enable nodes, where each node is connected to one or several sensors. These nodes generate data and operate in a multi-hop fashion to relay data from other nodes. They consist of sensing, data processing, and communicating components, result in the idea of sensor networks based on collaborative effort of a large number of nodes. Such types of sensor nodes could be deployed in home, military, science, and industry applications [1,2]. In wireless sensor network, each individual sensor node is able to sense in various modalities but has limited signal processing and communication capability [11]. The nodes are battery powered and have a limited resource [14,15].

Typically, the nodes of the sensor network are pre-programmed to form a connected network such that essential network functionality is enabled, like query sending, query replying and other information propagation. After deployment, the network's main responsibility is to extract sensing data from the field and to communicate those to the end user. Due to the energy limitations and the potentially large geographical coverage of the WSN, collecting the data produced can be a challenging process [3,5]. In wireless sensor network some data are duplicate or unnecessary which can be received by sensor nodes multiple times. Therefore, such redundant messages will increase the average energy consumption of network. So non-rechargeable battery power which is expected to run

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for a long time are the issues which are considered to be in data gathering [1,4,6,14].

1.2 Mobile sink based data gathering in wireless sensor networks

Mobility of sink for energy efficient data collection in WSNs is mainly proposed to solve the problem in data collection. Mobile sink prevents tracking or detecting on it by adversaries during its data collection phase around the sensor field. This strategy aims to select a trajectory for mobile sink node, which in turn minimizes the total number of message communication from all static sensor nodes to the mobile sink node (including multi-hop relaying) and thereby reducing the possibility of being detected by the adversaries. The sink moves probabilistically, favoring to the less visited areas in order to cover the network area faster, while adaptively stopping more time in network regions that tend to produce more data.

A mobile agent that moves closer to the nodes can help conserve energy since data is transmitted over fewer hops, thus reducing the number of transmitted packets. The extra energy spent for the operation and movement of the sink does not affect overall sensor network lifetime since the mobile sink is considered an external to the network factor. The two challenging issues in using mobile sinks are: seamless data collection and energy conservation. Since the location of the sink keeps changing, data reports from the sensor nodes can be lost because an existing path can become invalid when the sink moves. As sink location changes constantly, routing algorithms designed for static sink are no longer suitable [7-10].

1.3 Our contribution

In paper [6], it reduces the possibility of detection on the sensor network and protects the mobile sink against tracking. But there is a problem of energy consumption. On the other hand, paper [9] use biased, adaptive sink mobility scheme for data collection and adjusting the local network conditions which minimizes the energy consumption. But it selects the visiting schedule of the sink based on only the distance and node density. Moreover, it does not ensure reliability. In order to solve the above issues, we propose to design a Mobile Sink Based Reliable and Energy Efficient Data Gathering technique for WSN.

2. RELATED WORK

Truong et al. [2] have proposed a scheme for opportunistically using an uncontrolled mobile sink to achieve reliable and robust data delivery in wireless sensor networks during building emergencies. This process shows that with the reservation technique, the use of a mobile sink yields increased message delivery rate by up to 50%. However, this is not suitable for a hazardous environment.

Du et al. [4] have proposed the rendezvous data collection problem for the mobile element (ME) in heterogeneous sensor networks where data generation rates of sensors are distinct. Here they have introduced to optimize the energy consumption on gathering the global data. Then they have given two algorithms for dealing with different rendezvous data collection scenarios. However, the link quality is instable in this network model and the sensory data cannot be aggregated when transmitting.

Sha et al. [7] have proposed an anti-detection moving strategy called transverse forward through (TFT) moving strategy for mobile sink node while achieving the data collection task. Different from other works on node mobility in WSNs, the goal is to reduce the possibility of detection on the sensor network and to protect the mobile sink against tracking. The mobile sink node uses greedy algorithm to choose an optimal direction during each sojourn time between two motions. It also provides the best adaptability than the other three moving strategies. However, the consumption of energy is high in this proposed scheme.

Cheng et al. [8] have presented a network model to address the problem of efficient data collection in wireless sensor networks and propose an efficient Query-Based Data Collection Scheme (QBDCS). Empirical study has demonstrated that QBDCS can complete a query-based data collection cycle with minimum energy consumption and delivery latency. However, for a WSN that consists thousands of sensors, gathering data by querying each sensor node individually will incur significant delay, thus is not feasible for many applications.

Kinalis et al. [9] have proposed and evaluated a mobility scheme via simulation in diverse network settings. Compared to known blind random, non-adaptive schemes, this method achieves significantly reduced latency, especially in networks with non-uniform sensor distribution, without compromising the energy efficiency and delivery. However, the protocols assume only knowledge of the initial energy reserves of the sensor nodes and operate using only local knowledge; they do not acquire any global knowledge about the network conditions, this may cause problem in the networks.

Ani et al. [12] have discussed about data gathering with tour length-constrained mobile elements in wireless sensor networks. The authors have proposed a novel cluster-based algorithm for finding efficient tours for mobile elements used for data collection in WSN. In this algorithm average number of iterations is mainly influenced by the number of clusters so if the number of cluster is very large then number of iteration also large which may cause increasing in complexity of system.

Arshad et al. [13] have discussed about routing protocol for data collector in WSN. The authors proposed mobile data collector (MDC) based LEACH routing protocol for environmental application. MDC based LEACH routing protocol employs self-organized sensor nodes through distributed cluster formation technique. The energy consumption of sensor nodes is reduced and network lifetime is enhanced by this protocol. The delay of this system is high because this system take multi-hops to reach the base station which is nearly same as channel access delay.

3. THE PROPOSED MODEL

3.1 Overview

In this paper, we propose to design a Mobile Sink Based Reliable and Energy Efficient Data Gathering (MSREEDG) technique for WSN. This technique considers tree based network topology.

3.2 Estimation of in-network communication cost

The overall in-network communication cost is estimated using the following equation (1)

$$T_R = \sum DR(i) \cdot E(i) \cdot \eta \qquad (1)$$

where DR(i) is the data generation rate, E(i) is the expected transmission count (ETX) of the link of any node and its neighbor and η is the parameter related to energy consumption.

3.3 Determination of next position and optimal path for the sink

In general, the movement of sink can be hold back by some obstacles and this causes the sink to move in random manner. Also there is a possibility that sink may be unaware of the network topology which changes dynamically. Hence in our approach, we use biased random walk model [9] to estimate the next position of the sink. This technique utilizes probabilistic transitions among the cells. The subsequent position of the sink is estimated by choosing one the neighbors of the current cell, as shown in Fig. 1.

Let CN_i be the counter for every vertex i

Let ∂_i be the degree of vertex i

Initially $CN_i = 0 \forall\, i \in J$

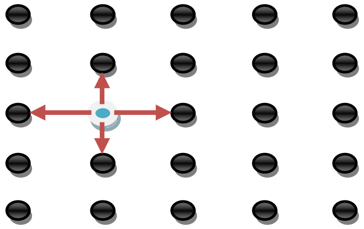

Fig. 1. The overlay graph Go and probabilistic sink movement.

The steps involved in the sink's position estimation are as follows.

(1) When a mobile sink S enters the area related to i, it increments the counter CNi by 1. This reveals that the recurrent visits of each area is estimated and stored in the sink.

(2) The sink selects the next area to visit based on biased random manner using the following equation (2)

(3) If S is on vertex i with ∂_i, Then

$$CN_{\text{nei}}(i) = \sum_j CN_j, \quad \forall j : (i, j) \qquad (2)$$

End if

(4) The probability of visiting neighbor vertex j is estimated using the following equation (3)

$$\Pr_j = \frac{1 - CN_j / CN_{\text{nei}}(i)}{\partial_i - 1}, \quad \text{for } CN_{\text{nei}} \neq 0. \qquad (3)$$

When $CN_{\text{nei}} = 0$, $\Pr_j = 1/\partial_i$.

This reveals that, when the sink is located at closer region, very less frequently visited areas are preferred. Further, the path that needs to be traversed by the sink is determined by applying the rendezvous point selection with splitting tree technique. The steps involved in the path estimation are as follows.

(1) Initialize the tree-shaped network topology.

(2) S computes the T_R for each node. The node with minimum T_R is chosen as Median (K).

(3) The tree-shaped node topology is directed via K.

(4) K is inserted into a queue Q.

(5) Then the optimal path (P_0) is estimated using the rendezvous point with mobile sink nodes (ReP_{mr}).

P_0 = ReP_{mr} (A, B, C), where $C = Q$. Pop() $\forall Q \neq \text{NULL}$

A is the adjacent matrix of the tree-shaped topology and B is the maximum length of mobile elements path.

(6) The P_0 value is inserted into candidate set CS

(7) The children of C is inserted into Q

(8) The global optimal path (P_{0g}) with minimum T_R is shown in Eq. (1) is estimated from CS.

For example, consider a tree shaped network topology as shown in Fig. 2. The node with minimum T_R is chosen as Median (K) as shown in Fig. 3.

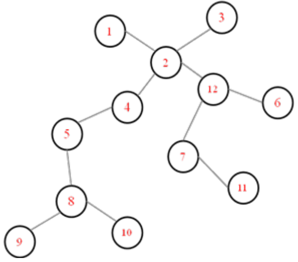

Fig. 2. Tree-shaped network topology.

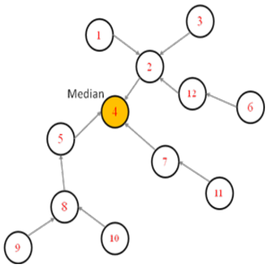

Fig. 3. Orienting the network into directed tree rooted at K.

Fig. 4 and 5 illustrate the first iteration of finding the optimal path passing through K. The resultant optimal path is P_0 (1): $N_5 \rightarrow N_4 \rightarrow N_{12}$.

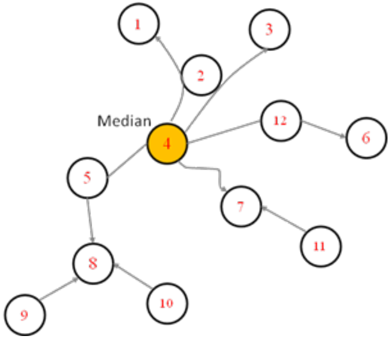

Fig. 4. First iteration of optimal path

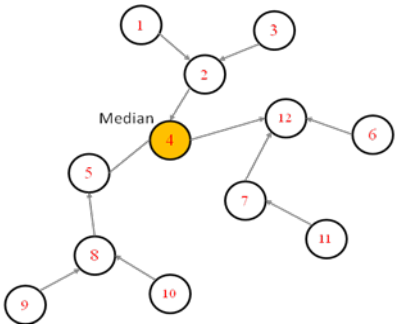

Fig. 5. First iteration of optimal path passing through K

Fig. 6 shows that tree has been split into three sub-trees and Fig. 7 shows the optimal path P_0 (2): $N_1 \rightarrow N_2 \rightarrow N_3$, P_0 (3): $N_5 \rightarrow N_8 \rightarrow N_{10}$, P_0 (4): $N_7 \rightarrow N_{12} \rightarrow N_6$

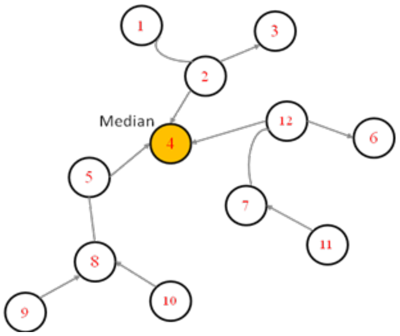

Fig. 6. Splitting of tree into sub trees

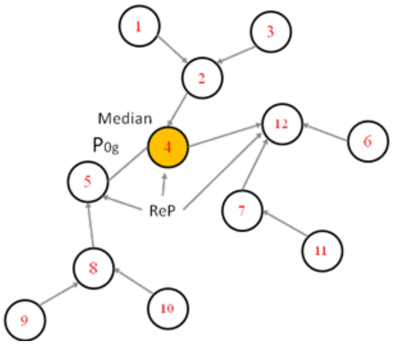

Fig. 7. Optimal path (P0g).

3.4. Data transmission technique

Following the estimation of the optimal path, the reliable data transmission technique is proposed. It involves three phases: data encoding, communication and data decoding.

3.4.1. Phase I: data encoding

Each static Ni encodes the data packets by adding redundancy to the source bundle. This is performed utilizing the conventional codes, such as the Reed–Solomon (RS) codes. This technique makes use of systematic codes such that the coded data include a verbatim copy of the source elements. Thus, if there are w elements, y out of w need not be encoded which in turn reduces the memory utility. The encoding process is as follows

(1) To maintain y value as minimum and independent from the source bundle, the source data are split into Z blocks (i.e. $z_0, z_1, z_2, \ldots, z_{Z\text{-}1}$).

(2) Each Z block includes y data units.

(3) Each block is encoded individually to generate w data units.

(4) The ratio among number of redundant and original messages is termed as stretch factor σ

$$\sigma \overset{\Delta}{=} \frac{w}{y}$$

(5) When a source data is ready, encoding is performed by sensor node.

(6) The sensor node now initiates the communication when it detects multiple *S* in its transmission distance (described in Phase II).

3.4.2. Phase II: communication

Let S and Ni be aware of the w and Z within the bundle and encoding function.

This phase takes Hybrid Adaptive Interleaved Communication Protocol into consideration for performing reliable communication.

(1) Ni schedules encoded data units selected from different blocks.

(2) Ni then encapsulates one encoded data unit into a message of size zmes bytes and transmits zmes to Ss.

(3) S stores the encoded data unit from zmes into its local cache.

(4) S uses block ID and sequence number from z block from the encoded message header to derive if atleast w distinct message for each block has been received to decode the original bundle.

(5) S feedbacks acknowledgement message (ACK) at every time interval t to the respective Ni. ACK includes the details about the appropriately received encoded (we) messages.

(6) If there is no ACK message within t, then it is assumed that S is outside contact limit.

(7) Ni gathers ACK message from all S in the contact region.

(8) From the ACK message, Ni stores the lowest value of messages for each block.

(9) Now, Ni is able to derive whether additional data transmissions are required or not.

(10) Ni transmits additional encoded messages for all blocks for which less than w messages have been received.

(11) Ni performs the data transmission always initiating from the latest sent messages to transmit new and useful encoded messages.

(12) The above step is repeated till the minimum set of encoded messages has been received by all the Ss.

(13) Once w different encoded message have been received for each block at S, decoding is performed (shown in Phase III).

3.4.3. Phase III: data decoding

(1) *S* after receiving the *w* different encoded message decodes the message and stores the resulting block in its local buffer.

(2) Once all *Z* blocks have been appropriately decoded, *S* obtains a copy of the original bundle.

(3) If all the necessary encoded messages are not received by the *S*,
Then
The decoding is failed
Error message (EM) is transmitted to respective sensor nodes
End if

3.5 Data gathering linked with pause time

An adaptive pause time technique is used which involves the computation of pause time with respect to the local density of the network and reliability of the nodes. The estimation of pause time is described below.

Let h be the time required for the sink to visit all the nodes. n be the number of sensors in the network, Tts is the maximum time that the sink is stationary, Mtx is the total message transmitted, Etx is the maximum amount of energy utilized for data transmission, ψ is the average data generation rate, Eia is idle energy, Texp is the total time taken for the experiment and we is the appropriately received encoded messages.

The initial energy of all Ni in the network,

$$E_i = M_{tx} \cdot E_{tx} = n \cdot \psi \cdot T_{ts} \cdot E_{tx} + E_{ia}$$

The maximum pause time which can be used by S till the entire energy gets depleted is as follows

$$E_t = n \cdot e_i = D \cdot G \cdot e_i$$

where G is the network size, D is the density of sensor deployment and ei is the initial energy of each Ni.

The idle energy,

$$E_{ia} = e_{ia} \cdot n \cdot T_{ex} - e_{ia} \cdot n \cdot T_{ts}$$

where eia is the energy spent by the sensors during idle time. Then,

$$T_{ts} = \frac{E_t - e_{ia} \cdot n \cdot T_{\exp}}{n \cdot \psi \cdot E_{tx} - e_{ia} \cdot n} = \frac{W_e \cdot D \cdot G \cdot e_i - e_{ia} \cdot n \cdot T_{\exp}}{n \cdot \psi \cdot E_{tx} - e_{ia} \cdot n}$$

The total pause time for each round, Ttsr = Tts/h

Ttsr is the maximum time the sink remains static in each round h. When there are more packet losses in a specific region of the network (which can be determined in the decoding phase of data), then the pause time can be increased.

4. SIMULATION RESULTS

The proposed Mobile Sink Based Reliable and Energy Efficient Data Gathering (MSREEDG) is evaluated through NS2 [16] simulation. We consider a random network of sensor nodes deployed in an area of 500 m×500 m. The number of nodes is varied as 20, 40, 60, 80 and 100. The sink nodes are assumed to be situated 100 m away from the above specified area. The simulated traffic is CBR with UDP. The transmission rate is varied from 50 to 250 kb (Table 1).

Table 1. Summarization of the simulation parameters.

No. of nodes	20, 40, 60, 80 and 100
Area size	500×500
Mac	802.11
Routing protocol	MSREEDG
Traffic source	CBR
Packet size	512 bytes
Rate	50, 100, 150, 200 and 250 kb
Transmission range	250m
Transmit power	0.395 W
Receiving power	0.660 W
Idle power	0.035 W
Initial energy	15.1 J

4.1 Performance metrics

The performance of MSREEDG is compared with the Biased sink mobility with adaptive stop times for low latency data collection BSMASD [9] scheme. The performance is evaluated mainly, according to the following metrics.

- *Packet drop*: The number of packets dropped during the data transmission.
- *Energy*: It is the average energy consumed for the data transmission.
- *Delay*: It is the average time taken by the packets to reach the destination.
- *Average packet delivery ratio*: It is the ratio of the number of packets received successfully and the total number of packets transmitted.

4.2. Results

4.2.1. Based on nodes

In our first experiment, we vary the number of nodes as 20, 40, 60, 80 and 100 .

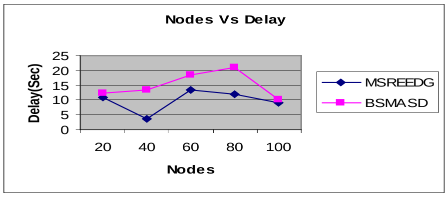

Fig. 8. Nodes vs. delay.

Fig. 8 shows the delay of MSREEDG and BSMASD techniques for different number of nodes scenario. We can conclude that the delay of our proposed MSREEDG approach has 34% of less than BSMASD approach.

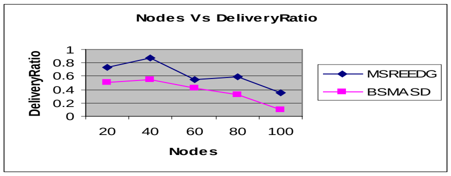

Fig. 9. Nodes vs. delivery ratio.

Fig. 9 shows the delivery ratio of MSREEDG and BSMASD techniques for different number of nodes scenario. We can conclude that the delivery ratio of our proposed MSREEDG approach has 42% of higher than BSMASD approach.

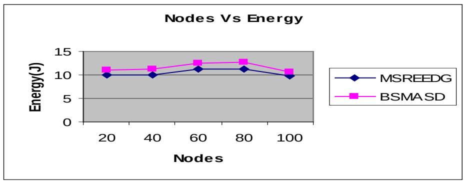

Fig. 10. Nodes vs. energy

Fig. 10 shows the energy consumption of MSREEDG and BSMASD techniques for different number of nodes scenario. We can conclude that the energy consumption of our proposed MSREEDG approach has 10% of less than BSMASD approach.

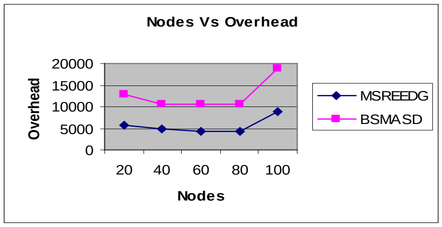

Fig. 11. Nodes vs. overhead.

Fig. 11 shows the overhead of MSREEDG and BSMASD techniques for different number of nodes scenario. We can conclude that the overhead of our proposed MSREEDG approach has 56% of less than BSMASD approach.

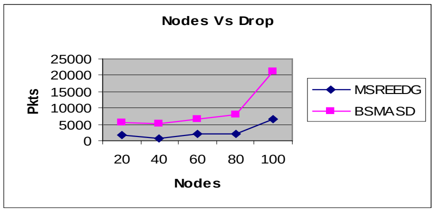

Fig. 12. Nodes vs drop.

Fig. 12 shows the drop of MSREEDG and BSMASD techniques for different number of nodes scenario. We can conclude that the drop of our proposed MSREEDG approach has 74% of less than BSMASD approach.

4.2.2. Based on rate

In our second experiment we vary the rate as 50, 100, 150, 200 and 250 kb .

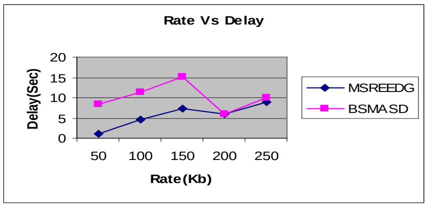

Fig. 13. Rate vs delay.

Fig. 13 shows the delay of MSREEDG and BSMASD techniques for different rate scenario. We can conclude that the delay of our proposed MSREEDG approach has 42% of less than BSMASD approach.

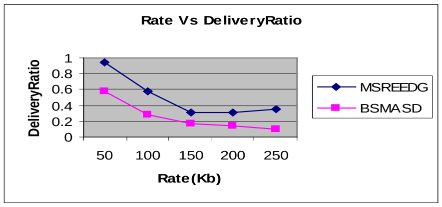

Fig. 14. Rate vs. delivery ratio.

Fig. 14 shows the delivery ratio of MSREEDG and BSMASD techniques for different rate scenario. We can conclude that the delivery ratio of our proposed MSREEDG approach has 53% of higher than BSMASD approach.

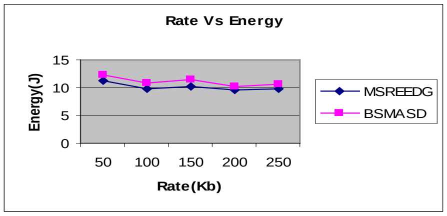

Fig. 15. Rate vs energy.

Fig. 15 shows the energy consumption of MSREEDG and BSMASD techniques for different rate scenario. We can conclude that the energy consumption of our proposed MSREEDG approach has 9% of less than BSMASD approach.

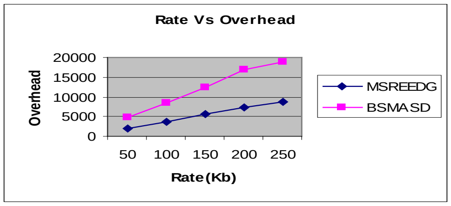

Fig. 16. Rate vs. overhead.

Fig. 16 shows the overhead of MSREEDG and BSMASD techniques for different rate scenario. We can conclude that the overhead of our proposed MSREEDG approach has 56% of less than BSMASD approach.

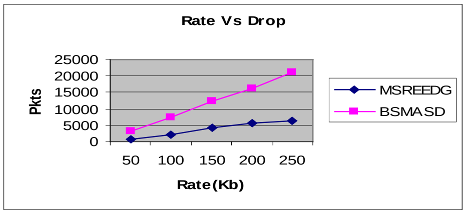

Fig. 17. Rate vs. drop.

Fig. 17 shows the drop of MSREEDG and BSMASD techniques for different rate scenario. We can conclude that the drop of our proposed MSREEDG approach has 69% of less than BSMASD approach.

5. CONCLUSION

In this paper, we design a Mobile Sink Based Reliable and Energy Efficient Data Gathering technique for WSN. Initially biased random walk and rendezvous point selection method is used to determine the next position of the sink and the optimal data transmission path. In addition to it the sensor encodes the data by using RS coding and transmit to the mobile sink, then the mobile sink decodes the messages and reconstructs the original bundle. In our method, pause time depends on node density and received encoded data. Thus improves the performance of the nodes. The performance of MSREEDG is compared with the BSMASD and by simulation results we have shown that the proposed technique increases both the reliability and energy efficiency. We plan to continue this work by coordinating the motion strategies for multiple mobile sinks.

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P. Madhumathy obtained her Bachelor’s degree in Electronics and Communication from Anna University, Chennai in 2006. Then she obtained her Master’s degree in Applied Electronics from VMU in 2009 and MBA from Madras University, Chennai. Currently, she is a full time Research Scholar at Easwari Engineering College, Affiliated to Anna University, Chennai. She has published papers in many international and national conferences. Her research interests are Wireless Sensor Networks, Network Security, Mobility Management for WSN and Heterogeneous Wireless Networks.

D. Sivakumar received the Bachelor's degree in ECE from Madras University, Post graduation in Instrumentation from Annamalai University and Ph.D. degree from Anna University, Chennai. He has 17 years of teaching and research experiences in various reputed engineering colleges. He is currently a Professor in the Department of CSE at Easwari Engineering College, Chennai. He has published more than 11 research papers in leading international and national journals and more than 24 research papers in leading international and national conferences. His research interests include Mobile Computing, MANET, Wireless Sensor Networks, Parallel and Distributed Computing.