

Extended Comb Needle Model for Energy Efficient Data Aggregation in Random Wireless Sensor Networks

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Abstract

Background/Objectives: Energy conservation in Wireless Sensor Network is essential to enhance its life. A sensor node consumes more energy for communication than performing data gathering or data processing. Data aggregation minimizes the data size for communication. **Methods/Statistical Analysis:** The Comb Needle model is available in literature to perform data aggregation for grid networks (regular deployment). Extended the Basic Comb Needle Model in randomly deployed sensor networks. The simple random network with Comb Needle Model is compared with simple random network without Comb Needle Model. The theoretical analysis and simulation study shows that Extended Comb Needle Model performs better data aggregation. **Findings:** When we apply the Proposed Model in random network, the communication cost, overhead, and energy consumption are significantly reduced. The simulation results for the proposed Extended Comb Needle Model prove that the energy consumption and overall communication costs are substantially minimized. The simulation comparison is done for simple random network with and without Comb Needle Model in terms of communication cost, energy consumption, delay, packet loss, packet delivery ratio, and throughput. We found that the communication cost is decreased from 82% to 58%. the average energy consumption is decreased from 80% to 40%. Delay is decreased from 76% to 20%. Packet loss is decreased from 67% to 12%. Packet Delivery Ratio is increased from 82% to 87%. And throughput is increased from 70% to 90%. **Application/Improvements:** Proposed Model optimizes WSN performance in terms of better packet delivery ratio, improved throughput, minimized energy consumption and reduced delay. Simulation results as well as theoretical analysis affirm the same.

Keywords: Comb Needle Model, Energy Consumption and Communication Cost, Random Network, Wireless Sensor Network

1. Introduction

Wireless Sensor Networks (WSNs) are been utilized for applications such as health care, monitoring, domestic, surveillance systems, ocean pollution detection and disaster management¹. Generally, Wireless Sensor Networks have a huge number of sensor nodes with the higher capacity to transmit the data within them and to external base station or sink node². The basic wireless sensor network³ is shown in (Figure 1). Most of the applications needs sensor to sporadically sense and forward

sensitive information to the base station for transmitting frequently through multi hop path. Collecting the data in the energy efficient way is very crucial process in the wireless sensor networks, because sensor nodes, once it is deployed that requires no maintenance at all and hence we cannot recharge or replenish the battery. It is essential to maintain the less energy consumption. Sensor node energy consumes to perform the following operations such as data processing, data transmission and sensing the data. Typically, data processing and sensing requires less energy when compared to the data transmis-

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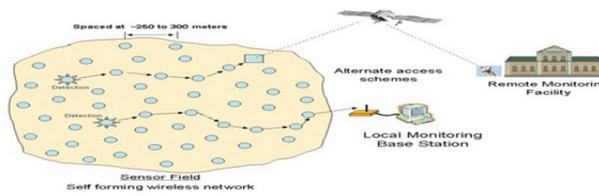


Figure 1. Wireless Sensor Networks Architecture (Taken from (3))

sion. If the transmission cost is reduced in the wireless sensor network then the life span of the network will be improved.

Therefore decreasing the total energy consumption in the network is considered as major challenge to the researchers in the wireless sensor network design. Many researchers have different idea and different perspective about the energy conservation², The main objective of this study is to provide a proper deployment of the sensor nodes for the routing and data aggregation in the wireless sensor nodes and to improve the energy efficiency by deploying the comb needle model and that obviously improve the network life span.

The data gathering mechanisms is being applied to store and gather the data. The major issues are found in the recent past years were the higher energy consumption in the battery⁴, however numerous effective data aggregation schemes were proposed but still they have various drawbacks in their mechanisms⁵. To overcome such drawbacks, the effective and efficient technique is proposed.

Wireless sensor networks are developed utilizing infrastructure less and infrastructure networks. Infrastructure networks provides the attributes such as connectivity and position of the sensor nodes, Wireless sensor networks are restricted in the memory and energy resources. Data aggregation is also important role to design energy efficient protocol. Data aggregation technique is depend on linear programming⁶ improves the network life span by utilizing multiple sink nodes. Heuristic-based data aggregation protocols employed in changing network traffic conditions for increasing the performance of wireless sensor network.

The wireless sensors in the networks would be distributed in uncongenial surroundings to collect the information without the risk of human emergencies. Even though the network life time critical or execution time

nature of these applications requires the efficient data distribution and significant information retrieval techniques in the network performance. For the complete effort of the network capacity in terms of data distribution and data collection, which are evaluated for scalable and reliable service in information discovery as well as in data storage in the random networks.

Generally, mechanism for the information discovery in the wireless sensor nodes can be either reactive or proactive. The particular sensor that collects the data can identify an event which can push the information to the all the sensor that is available in the network or it would wait still the sensor which would pull this information through querying. Hence, the pull or push based techniques are potential, based on the demand of the information. If the huge number of sensors are requesting for the same information that time push based mechanism would be more significant than the pull based mechanism. However, while the requisition of the information is lower, pull based mechanism would be more significant.

As a key communication rule, data aggregation plays a vital role in the field of wireless networks. Several performance aspects associated to data aggregation have been widely discussed in this literature. For example, significant construction of data aggregation routing protocol was analyzed⁷, energy-efficient algorithms in data aggregation were studied⁸ effective scheduling algorithm for reducing the delay in the data aggregation were discussed in⁹, etc.

Apart from the energy efficiency, data exactness or quality and delay are also very essential elements in the data aggregation process. The trade-off between the energy efficiency and data aggregation was initially found by the author Pham et al¹⁰. Further, this study was analyzed by the Zhu et al¹¹ for estimating the quality of service in the data aggregation to obtain the energy efficiency in the wireless sensor networks. It is provided dissemination based on the data precision for the specific task. Later on, author Tang and Xu¹² had demonstrated about the data precision in different manner for gathering the data from the various sensor to maintain the minimum energy consumption, which had improved the network life span. Hence, there were various related study associated with improving the energy efficiency, data aggregation and network life span. Particularly, author¹³ had concentrated on reducing the total error bound with improved network life span; they had proposed a new technique to

meet the arbitrary data precision requirement of different data aggregation applications in terms of obtaining the energy- efficiency based data aggregation

Liu et al¹⁴ had introduced the comb needle model, which utilized push and pull based query strategy in order to obtain the information discovery and data dissemination. The source nodes forward its query to the sensor nodes in the network, which is considered for the grid networks. This query response is obtained from the tank nodes; it is presented in the (Figure 2). Therefore, sensor nodes identify the events in the network. These responses are noted as the needles. The process of information collection is looks like the combing for the needle in the sand.

Luo et al¹⁵ had evaluated about the advantages of using compressive sensing to data aggregation tree construction in order of improving the network through put. This hybrid method had eliminated the overflowing of traffic conditions at leaf nodes; it also utilized the benefits of compressive sensing. It minimized the traffic load conditions near the sink nodes and then hybrid compressive sensing can obtain the effective improvement in the throughput.

Ratnasamy et al.¹⁶ had demonstrated about the data centric process, which utilized the Geographic Hash Table (GHT). While the sensor nodes produce an event or data that related information is stacked away by their location along with original name inside the wireless sensor network. The nodes available in the networks are selected with the geographic position at the storage point. If the query is generated for the particular event was published and they were guided towards the geographical position by utilizing the routing protocol The major limi-

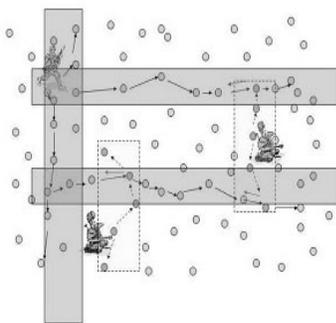


Figure 2. Comb Needle Model for Random Networks (Taken from (15))

tation of this system was they have not considered about the energy levels and their storage. However, this method was not applicable for the sparse networks and as well as due to proximity that leads to the imbalanced networks and decreases the network entire life time.

Rachuri et al.¹⁷ had introduced an energy efficient query based resolution methodology in wireless sensor networks for improving the ray search technique, where the instigator does not capable of identifying the exact target information. The main goal of their research was to reduce the transmission costs among the nodes. The proposed method is a subset of the entire sensor nodes and forward the search data packets to the complete circular area is extended by these transmissions and moreover the target node would also obtain the search packet. However, sequential ray growth leads higher delay rate to the process of query based resolution.

Saranya V, et al.¹⁸ have proposed a framework for tracking named *Energy Efficient Tracking (EET)*, which defines the sensor nodes of the spatial region around the target. Clustering concept is used in EET to reduce energy consumption.

Vijayan K, et al.¹⁹ have proposed *Cluster Arrangement Energy Efficient Routing Protocol (CAERP)*. Which uses efficient way of forming clusters and distributed multi hop routing. They differentiated the clusters based on distance from base station to perform inter cluster data communication.

Mary Livinsa Z, et al.²⁰ proposed an energy saving localization algorithm in WSN. It identifies the moving target location and improves the energy of nodes.

Munusamy K, et al.²¹ applied the *Least Power Adaptive Hierarchy Cluster (LPAHC)* framework obtained the CSI using the Frequency Division Multiplexing (FDM). It will reduce the average energy cost. They used adaptive Hierarchy cluster to improve network lifespan.

In our earlier work ²², we had demonstrated about the cluster-based Comb- needle model for regular network (grid network) for data aggregation. It improved the energy efficiency, minimized the communication cost and wastage of resources in wireless sensor networks. In our another work, the survey of the data aggregation techniques, energy consumption and their drawbacks are given in²³, proposed method would be efficient than all these method and overcome these drawbacks.

This paper makes an important contribution to the wireless sensor network, by estimating the best suited network for the lower energy consumption, efficient

data aggregation in the random networks. It uses the Extended Comb Needle Model for the random network. The experimental results demonstrated that if we deploy comb needle model in random network, that obtains the lesser energy consumption and communication cost in the networks.

2. Proposed (Extended) Comb-Needle Model

The basic comb needle model is proposed by X. Liu et al¹⁵ for grid network (regular deployment). We extend that model for supporting random networks. We extend the basic comb needle model by redefining the comb and needle that supports random networks which also uses push and pull strategies for information discovery. The push-pull based comb needle model performs the process of combing for needles (events in WSN) in a pool of sand or a haystack (WSN region). The basic comb needle for random network is represented in the (Figure 2).

2.1 Model Assumptions

In our proposed research work, we make certain assumptions:

1. All the sensor nodes are aware of their location
 2. All sensor nodes deployed randomly in sensor region
 3. We are applying comb-needle model on random network, As the nodes are randomly deployed so it is difficult to form a comb with perfectly shaped spikes as in basic comb needle model, so we redefine the terms - comb (and spikes), and needle in terms of range as shown in (Figure 4).
 4. Base station is in top left corner of the sensor region.
- Note:** Multiple Base stations are likely to be present in the WSN region as the nodes with soldiers generate queries. In our work we are considering only one sink node for simplicity
5. When a query (e.g., Where is the tank?) is generated, the comb is formed and routes are established.
 6. Once the tank is found (i.e. needle found = event detected) the event detection information is passed vertically towards the spikes of the comb. The route which was already constructed is used for notifying the base station about the event detection. As the route is repeatedly used for query propagation and event notification.

The proposed comb-needle model is based on two important mechanisms - push and pull. When the base station pushes the query the path for query dissemination is established as a comb (with spikes). The node detecting the event occurrence communicates this to certain neighbouring nodes vertically towards spikes (both upward and downward). It resembles a needle.

Our proposed scheme gives the optimal number of the soldier nodes (aggregation points) which is depend on the trade-off balance between the tank nodes (number of hops) and receives information discovery to the soldier nodes (aggregation points) through push-pull based query mechanism. (Figure 3), it presented graphically and estimate the number of soldier's nodes (aggregation points) and tank nodes (number of hops) in the random network.

2.2 Extending the Comb Needle Model for Random Networks

We consider the random network with n nodes located in plane at (x, y) , where sensor node range is specified as $0 \leq x, y < n$. The deployment area starts at (x, y) and the boundary is given as (x_n, y_m) As shown in (Figure 4). Here, it is assumed that sensor nodes are uniformly distributed in the network.

When a query is generated then the comb structure is formed in the network. Let's assume that query node is located at (x, y) . If the query is send through the vertical direction from (x, y) to (x, y_m) and $(x, 0)$. Then the query is distributed at the horizontal lines from nodes $(x, y+s), (x, y+2s)$ to $(x_n, y+s), (x_n, y+2s)$. In this mechanism, s is used as combing degree or inter spike spacing. The resulting routing structure looks like a comb.

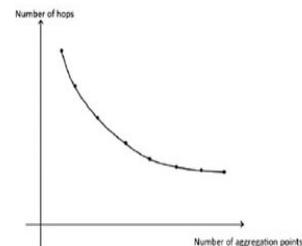


Figure 3. Expected Number of Hops Versus Number of aggregation Points

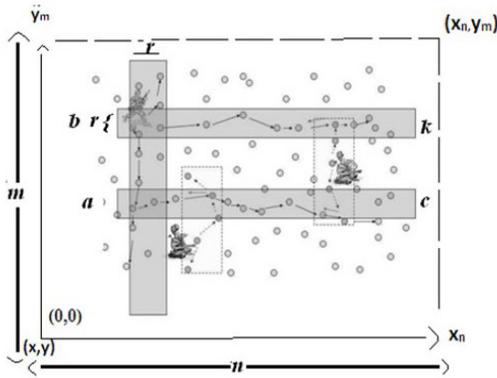


Figure 4. Definition of Comb Base and Spike for Extended Comb Needle Model

Let us assume that theoretical analysis of the random networks is given below:

$$(x, y+s) = a \tag{1}$$

$$(x, y+2s) = b \tag{2}$$

$$(x_n, y+s) = c \tag{3}$$

$$(x_n, y+2s) = k \tag{4}$$

From the equation (1) to (3) and (2) to (4) where the horizontal lines are formed, (x, y) to $(x, 0)$ and (x, y) to (x, y_m) vertical lines are formed. While estimating the distance from the plane s .

$$s = (y_m - y_0)/3 \tag{5}$$

For illustrating the query response in horizontal direction $(x, y+s)$ and $(x, y+2s)$ are points generated for the horizontal response. Thus the push based query performance is operated while it is performing in the horizontal direction in the (Figure 4). The comb structure has been developed. Then we need to specify the range of the comb needle model in the random network by using the following criteria, where r represents the range of the comb base and spike.

When the range is established for the random networks, it is demonstrated in the following equations

Vertical range: $(x+r, y)$ to $(x+r, y_m)$

Based on equation (1) and (3) Horizontal range for spike a to c is

$$\left(a + \frac{r}{2}, a - \frac{r}{2}\right) \text{ to } \left(c + \frac{r}{2}, c - \frac{r}{2}\right)$$

Based on equation (2) and (4) Horizontal range for spike b to k is

$$\left(b + \frac{r}{2}, b - \frac{r}{2}\right) \text{ to } \left(d + \frac{r}{2}, d - \frac{r}{2}\right)$$

The sensor nodes would pass the query depending on the Euclidean distance, which is used to consider the shortest path. The Euclidean distance is represented in the following equation:

$$\xi_{dist} = ((p, q)(u, v) = \sqrt{(p-u)^2 + (q-v)^2} \tag{6}$$

For example, consider the scenario as shown in (Figure 5). e, f, and g are neighboring nodes on the spike. As per Euclidian Distance link is established in between e and f.

2.3 Analysis of the Comb Needle Model

It is considered that any event can be produced by any nodes in the random networks.

The following important performance metrics are determined as:

$$f_q = \text{Query frequency}$$

$$f_e = \text{Event frequency}$$

$$f_d = \frac{f_e}{n^2} \text{ events occurs frequency in the sensor node}$$

However, in our proposed mechanism, overall communication cost may be based on the broadcast or unicast, which utilized in the random networks. Here, we assume unicast for the analysis in the Extended Comb Needle Model. The cost of the developing the single comb needle for the length l is $l-1$.

We consider that frequency of Query f_q , The frequency of data event f_e is termed as $\frac{f_e}{f_q}$, which

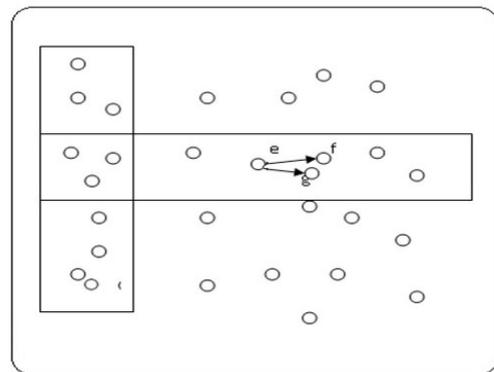


Figure 5. Establishing the Communication Link in between Neighbors

means that number of events produced for per query in a comb needle is $l-1(f_e/f_q)$. As $C_l = l-1$, then it would be modified and given as event produced for needle:

$$= C_l(f_e/f_q) \tag{7}$$

Analysis of the Complete Comb Needle Model can be referred in our previous work ²¹.

2.3.1 Analysis of Communication Cost

For analyzing the communication cost in both Grid (Regular) and random networks, the following scenario is considered:

Comb is assumed to be at the extreme left and needle at the extreme right (Figure 6).

Case 1: Grid Network:

Number of hops for event notification = n hops as shown in (Figure 7).

Case 2: Random Network:

Communication overhead depends on the way the nodes take their position at the time of random deployment as shown in (Figure 2).

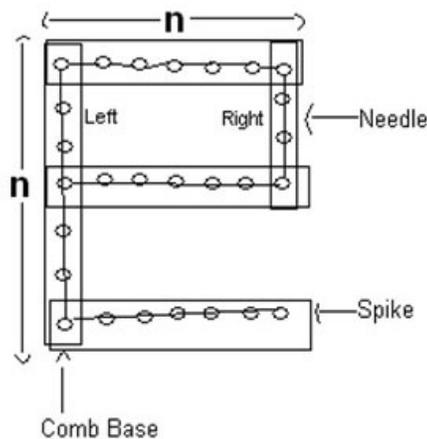


Figure 6. Comb and Needle in Grid Network

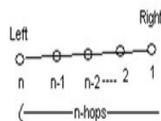


Figure 7. Communication Using n Hops in Grid Case

Best Case:

Nodes between two ends, Left and Right, take position as shown in (Figure 7).

Number of hops required for event notification = n;

Increase in hops compared to Case1 (Grid network) = 0.

Worst Case:

In the worst case nodes take their position as shown in Figure 8.

Number of hops required for Event Notification = n+(n-1);

Increase in hops compared to Regular deployment = (n-1);

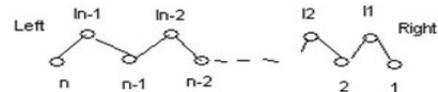


Figure 8. Communication in Random Network

To calculate the Number of hops required for Event Notification in the average case, We consider the results of both the best and worst cases.

Therefore Increase in Number of hops for Event Notification in average case = $0+(n-1)/2$

$$= (n-1)/2$$

This means that the communication overhead increases by 50% in case of random deployment. When compared to regular deployment (Grid networks).

3 Simulation

We evaluated the performance of the Extended Comb Needle Model for the random network by using the NS2 network simulator version 2.33 (NS2.33) and compared it with the existing methods.

3.1 Simulation Parameters

Simulation of the wireless sensor network with 50 nodes (excluding Sink node) deployed randomly in the area of 20 x10 square units is carried out using NS2. It is assumed that the sensor nodes are distributed independently and uniformly.

The simulation parameters for the Extended Comb Needle Model in the random network are identified as follows in (Table 1).

3.2 Performance Metrics

The following metrics are used for evaluating the performance of proposed work:

a) **Packet Delivery Ratio (PDR):** It is determined as the ratio of overall packets received to the overall packets sent.

b) **Throughput:** It is determined as rate of successful message delivered over a communication channel in the random networks.

c) **Average Delay:** It means time difference between packets sent and packets received.

d) **Energy consumption:** It is determined as the average energy consumed on idle sleep, data processing, sensing, and data transmission.

e) **Communication cost:** It is determined as the number of packets transmitted and received for query and event notification.

3.4 Simulation Results

We utilized the performance metrics to validate the proposed Extended Comb Needle Model in random networks. The obtained results are demonstrated in (Figures 9-16). From simulation results, it is clear that Extended Comb Needle Model in random network is significantly better than simple random network.

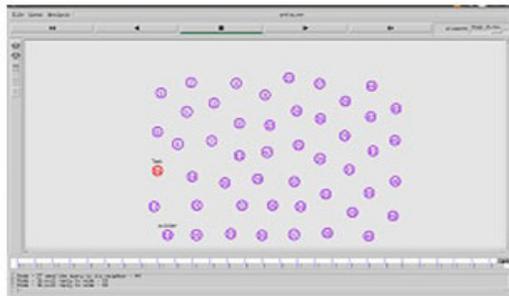


Figure 9. Simple Random Network

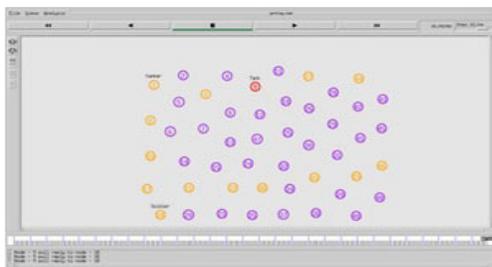
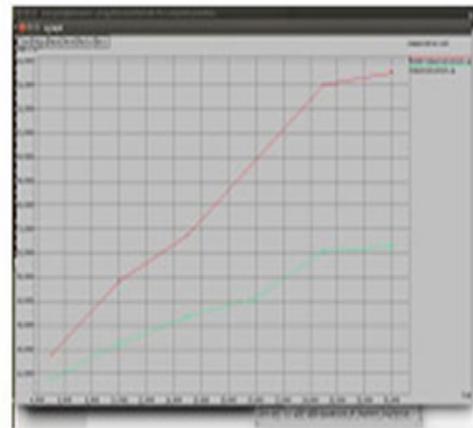
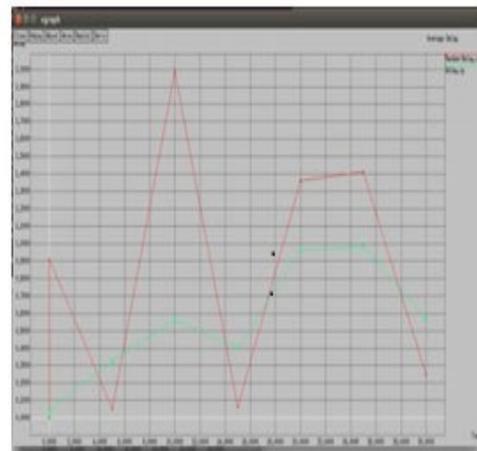


Figure 10. Extended Comb Needle Model for Random Network



*Red line indicates Simple random network
*Green line indicates Extended Comb Needle Model

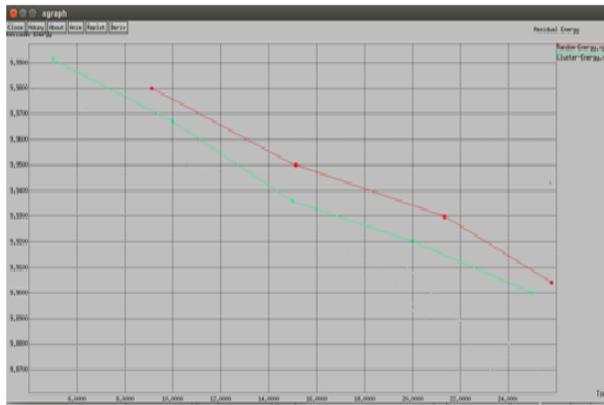
Figure 11. Communication Cost



*Red line indicates Simple random network
*Green line indicates Extended Comb Needle Model

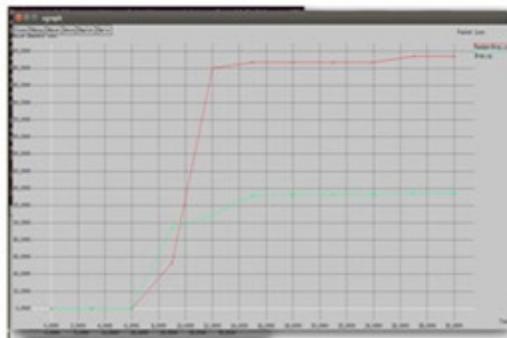
Figure 12. Energy Consumption

Figure 9 represents the network topology of the simple random network, that the base station (soldier node) push the query into the network in order to know the occurrence of events. Figure 10 demonstrates the network topology of the Extended Comb Needle Model in the random network in which base station sends the query in vertical comb base and horizontal spikes in order to process information efficiently with minimum energy consumption.



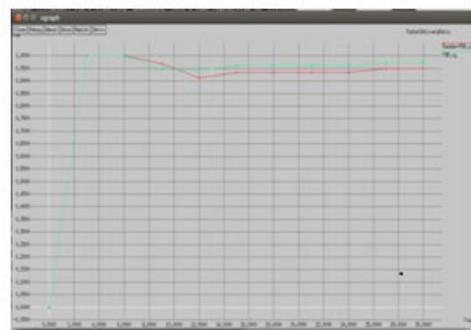
*Red line indicates Simple random network
 *Green line indicates Extended Comb Needle Model

Figure 13. Delay



*Red line indicates Simple random network
 *Green line indicates Extended Comb Needle Model

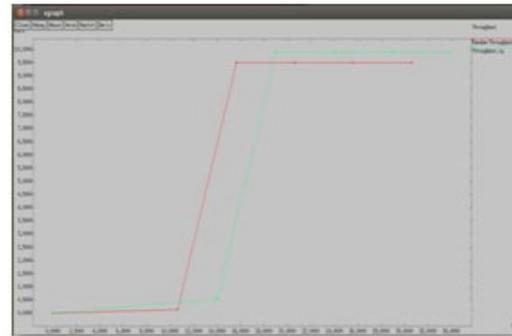
Figure 14. Packet Loss



*Red line indicates Simple random network
 *Green line indicates Extended Comb Needle Model

Figure 15. Packet Delivery Ratio

Figure 16. Throughput



*Red line indicates Simple random network
 *Green line indicates Extended Comb Needle Model

Figure 16. Throughput

Hence, the simulation results are compared between the simple random network and Extended Comb Needle Model in the random network. It is well understood from the obtained results graph that Extended Comb Needle Model got higher performance than simple random network.

The performance analyzed in terms of communication costs, energy consumption, packet delivery ratio, packet loss, delay and throughput. They are represented in (Figures 9-16).

The following graphs (Figures 17-19) shows that efficiency of Extended Comb Needle Model in random networks and Simple random networks.

- Communication cost in Extended Comb Needle Model for Random Networks is 58 % and in Simple random Network is 82%. So 24% Communication Cost is decreased in our proposed model.
- Average Energy Consumption in Extended Comb Needle Model for Random Network is 41 % and in Simple random Network is 80%. So 39 % energy is saved in our proposed model.
- Delay in Extended Comb Needle Model for Random Network is 20 % and in Simple random Network is 76%. So 56% delay is reduced in our proposed model
- Packet Loss is 12 % in Extended Comb Needle Model for Random Network where as 79% in Simple random Network. So 67% is reduced in our proposed model

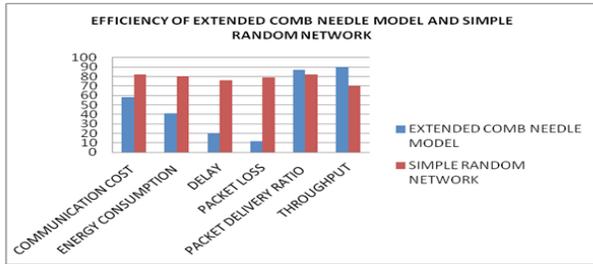


Figure 17. Efficiency of Extended Comb Needle Model and Simple Random Network

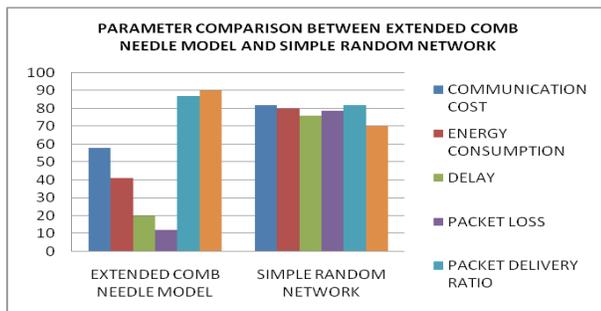


Figure 18. Parameter Comparison between Extended Comb Needle Model and Simple Random Network



Figure 19. Efficiency of Two Models

- Packet Delivery Ratio is 87% in Extended Comb Needle Model and 82% in Simple Random Network. 5% is improved in our proposed model.
- Throughput is 90% in Extended Comb Needle Model and 70% in Simple random network. 20% is improved in our proposed model.

4. Conclusion

In this paper, we extended the basic Comb Needle Model to support data aggregation mechanism in randomly

deployed wireless sensor networks. With the proposed model, the problems, namely, higher energy consumption, and higher communication cost have been resolved in random network. We have applied Extended Comb Needle Model in the random network to design best data aggregation technique with energy efficiency, and thereby increase the life span of the WSN. The experimental results also comply with theoretical analysis in terms of packet delivery ratio, throughput, communication cost, energy consumption, and delay.

The Extended Comb Needle model for random networks will be improved by Clustering concept for better performance. Further compression techniques will be applied on aggregated data for achieving ultimate energy consumption. And security mechanisms can also be added to make data aggregation more secured.

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