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Simulation & Performance Evaluation of Routing Protocols in Wireless Sensor Network

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Abstract: Wireless Sensor Network (WSN) is consisting of independent sensors, communicating with each other to monitor the environment. Sensor nodes are usually attached to microcontroller and are powered by battery. The resource constrained nature of WSN implies various challenges in its design and operations, which degrades its performance. However, the major fact that sensor nodes run out of energy quickly, has been an issue. Many routing, power management, and data dissemination protocols have been specifically designed for WSNs, where energy consumption is an essential design issue, which preserves longevity of the network. Out of these, clustering algorithms have gained more importance, in increasing the life time of the WSN, because of their approach in cluster head selection and data aggregation.This paper elaborately compares essential routing protocols using NS2 tool for several chosen scenarios. The paper is concluded by mentioning valuable observations made from analysis of results about several imperative protocols.

Keywords: Wireless Sensor Network, Proactive Routing, Reactive Routing, Cluster Head, Energy Consumption, NS2.

I. INTRODUCTION

The evolution of wireless communication has enabled the development of an infrastructure consists of sensing, computation and communication units that makes administrator capable to observe and react to a phenomena in a particular environment. The building block of such an infrastructure is comprised of hundreds or thousands of small, low cost, multifunctional devices which have the ability to sense compute and communicate using short range transceivers known as sensor nodes. The interconnection of these nodes forming a network called Wireless Sensor Network (WSN) [1].The low cost, ease of deployment, adhoc and multifunctional nature has exposed WSNs an attractive choice for numerous applications. The application domain of WSNs varies from environmental monitoring, to health care applications, to military operation, to transportation, to security applications, to weather forecasting, to real time tracking, to fire detection [1] and so on. By considering its application areas WSN can be argue as a wireless network. But in reality, these networks are comprised of battery operated tiny nodes with limitations in their computation capabilities, memory, bandwidth and hardware resulting in resource constrained WSN. WSNs have severe resource constraints, asymmetric many to one data flow and unreliable network nodes. Also, there can be a link or node failure that leads to reconfiguration of the network and re-computation of the routing paths, route selection in each communication pattern results in either network delay by choosing long routes or degrade network lifetime by choosing short routes resulting in depleted batteries [2]. To this end, energy in these sensors is a scarce resource and must be managed in an efficient manner [3].To improve WSNs performance these challenges are subjected to be investigated. Therefore the solutions for such environments should have an efficient routing mechanism to provide low latency, minimum consumption of energy, high network lifetime, reliable, fault tolerant communication and quick reconfiguration. To maintain a reliable information delivery, data aggregation and data fusion is necessary for efficient and effective communication between these sensor nodes [4]. Routing protocols have a critical role in most of these activities. Routing in WSNs is a challenging task firstly because of the absence of global addressing schemes; secondly data source from multiple paths to single source, thirdly because of data redundancy and also because of energy and computation constraints of the WSN. Many routing protocols emerge continually with the developing of research on WSN as discussed in this paper.

The remainder of the paper is systematized as follows. In section II, we converse with the classification of routing protocol in details. In section III, we introduce network model and energy model whereas the simulation parameter and performance metrics are discussed in section IV. After discussing simulation results in section V we conclude with our inferences in section VI.

II. CLASSIFICATION OF ROUTING PROTOCOLS FOR WSN

With respect to WSN's application, single routing protocol cannot meet all the application requirements [2]. Thus, many routing protocols are proposed with the domestic and international research development of WSN. According to different classification standards, the various protocols can be classified as *flat*, *hierarchical* and *location-based* as shown in figure 1.

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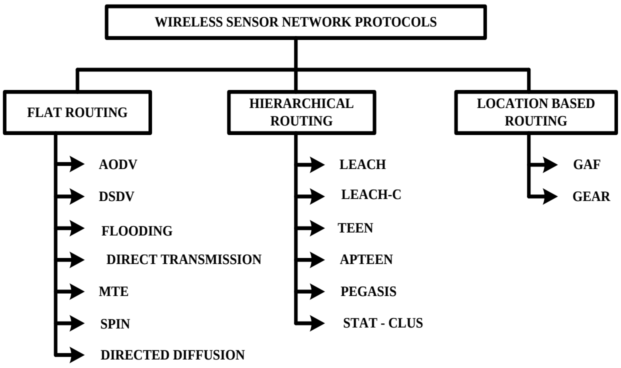

Fig. 1 Classification of Routing Protocols of WSN

In *flat* routing protocols, each node typically plays the same role and sensor nodes collaborate together to perform the sensing task. Flooding is *flat* type of routing protocol in which each sensor node receives data and then sends them to the neighbours by broadcasting, unless a maximum number of hops for the packet are reached or the destination of packet is achieved. Disadvantage of this routing technique is data redundancy and energy consumption [3]. To reduce this redundancy *Proactive* and *Reactive* routing protocols were developed. In *Proactive* routing, each node has one or more tables that contain the latest information of the routes to any node in the network. The *Proactive* protocols are not suitable for larger networks, as they need to maintain node entries for each and every node in the routing table of every node. This causes more overhead in the routing table leading to increases energy consumption. *Destination-Sequenced Distance-Vector* routing (DSDV) is one of the table-driven routing schemes for sensor networks based on the *Bellman-Ford* algorithm. To reduce this regular update, *Reactive* Routing protocols were developed. Reactive routing protocols *Dynamic Source Routing* (DSR) and *Adhoc On-demand Distance Vector* (AODV) discover route only when a source node wants to communicate with destination. The major drawback with *Reactive* routing technique is high routing overhead due to *Route Request* (RREQ), *Route Reply* (RREP) & *Route Error* (RERR) messages to maintain the network and produce higher energy consumption in network [5]. In *Minimum Transmission Energy* (MTE) routing, routes from each node to the Base Station (BS) were chosen such that cache node's next-hop neighbour is the closest node that is in the direction of the BS [5]. The drawback of this routing technique is energy consumption. All node pass own data to node closest to BS and that node will die sooner due to its higher energy consumption. Few amongst the serious disadvantages of the *flat* routing are identified as (a) absence of manage nodes in the network (b) lack of optimal management of the communication resources (c) complicated algorithms for self-organizing and cooperative work (d) slow response to the dynamic changes of the network etc.

Energy efficient routing is possible by means of cluster based routing or *hierarchical* schemes [6]. In *Static Clustering* protocol, the clusters are chosen a-priori and fixed. *Static Clustering* includes scheduled data transmissions from the cluster members to the cluster-head and data aggregation at this cluster-head [6]. However, the limitation of *Static Clustering* routing technique is energy consumption due to fixed cluster head node in every round. To overcome this issue, *Low Energy Adaptive Clustering Hierarchy* (LEACH) was proposed [7]. It is a protocol based on clustering hierarchy architecture. In the LEACH algorithm, the nodes are self-organized into different clusters, with electing *Cluster Header* (CH) nodes respectively.

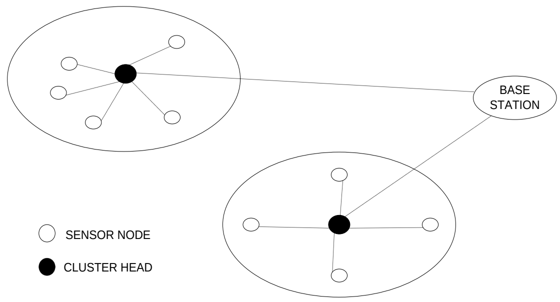

Fig. 2 LEACH Operation

Each cluster can only have one CH. All non-CH nodes send the data to the CH nodes of the clusters which they are in. Figure 2 shows a typical structure of WSN using the LEACH algorithm. In the LEACH algorithm, each node has to be the CH alternately for the sake of avoiding the energy of CH being consumed too fast. Thus the implementation of this algorithm is separated into several rounds. Each round also can be divided into a construction stage and a stable transmission stage.

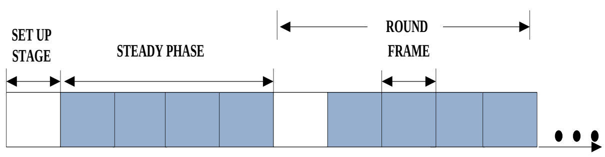

Fig. 3 Working Cycle of the LEACH Protocol

In the construction stage, it is random to choose a node as the CH node, of which the randomness ensures that the high cost of data transmission between the CH and the sink node is evenly allocated to all the sensor nodes. In the stable transmission stage, nodes continuously collect monitoring data and send them to the CH. Then the data will be sent to the sink node by CH after its necessary fusion processing. The working cycle of LEACH protocol and flow chart are shown in Figure 3 and 4 respectively. After the stable stage sustains for a period, the network moves forward into the next working round and reselect CH. For reducing the extra energy cost produced by dividing clusters, the stable stage is much longer than the construction stage [6][7]. Initially, the decision for selection of a CH is made by the node i choosing a random number between 0 and 1. If the number is less

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than a threshold T (i), the node becomes a cluster CH for the current round.

The threshold is set as:

i : If i ε G

: Otherwise

Where
P = the desired percentage of cluster heads (e.g., P = 0.05),
r = the current round, and
G is the set of nodes that have not been cluster-heads in the last 1/P rounds.

The nodes that are CHs in round 0 cannot be CHs for the next 1/P rounds. Thus the probability that the remaining nodes are CHs must be increased, since there are fewer nodes that are eligible to become CHs.

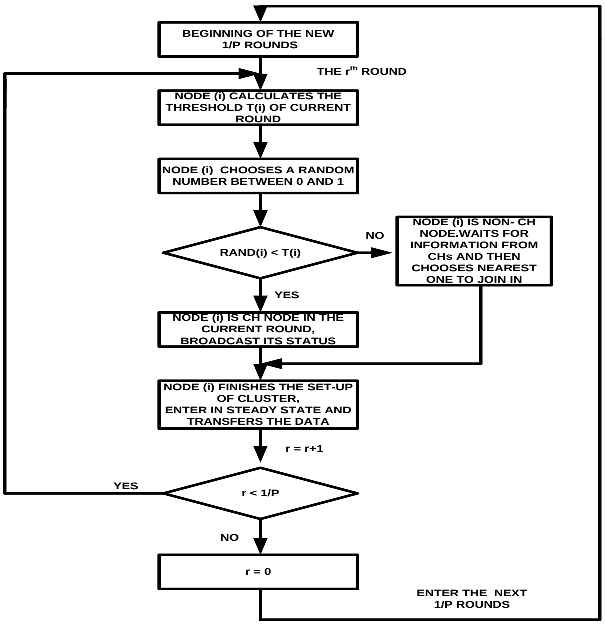

Fig. 4 The basic flow of LEACH algorithm

Comparing to the general other routing protocol, the LEACH protocol has a lot of advantages such as (a) it limits most of the communication inside the clusters and hence provides scalability in the network (b) single hop routing from node to CH hence saving energy (c) local data fusion processing (d) dynamic CH allocation and so on. It increases network lifetime in three ways. Firstly, distributing the role of CH (consumes more energy than normal nodes) to the other nodes. Secondly, aggregating the data by the CHs. Finally, TDMA, which assigned by the CH to its members, leaving most of the sensor in sleep mode, especially in event-based applications. Hence, it is able to increase the network lifetime, especially when dealing with the data having high correlations among them. A large amount of redundant data will be eliminated because of data fusion, which makes LEACH have a better performance on energy consumption [2][3][6]. However, Low energy nodes can also be selected as CH because of threshold condition and also additional overheads due to CH changes and calculations leading to energy inefficiency for dynamic clustering in large networks [7].

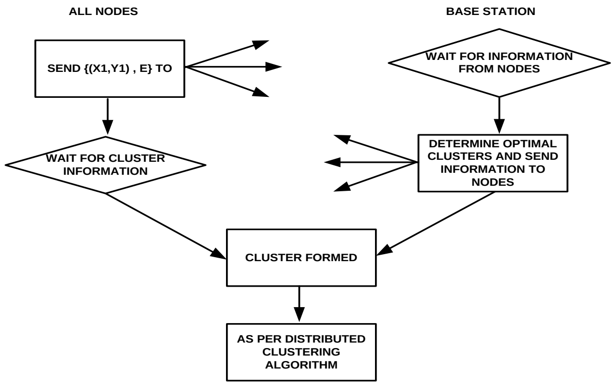

Fig. 5 The basic flow of centralized LEACH algorithm

LEACH has no knowledge about the CHs' places. However, centralized LEACH protocol can produce better performance by distributing the CHs throughout the network. The flow chart of centralized LEACH is shown in figure 5. During the set-up phase, each node sends to the sink its remaining energy and location. The sink then runs a centralized cluster formation algorithm to determine the clusters for that round. However, this protocol requires location information for all sensors in the network (normally provided by GPS)[8]. Disadvantage of centralized clustering routing technique is that cluster sizes are not uniform, which is resulting into formation of some very big clusters and very small clusters in the network. Since there is no limitation on the number of members in the cluster, this result in uneven distribution of traffic in the network, leading to higher percentage of deaths of CHs and child nodes.

III. NETWORK MODEL AND ENERGY MODEL

There are various network models for WSNs. In this work, a WSN model similar to that incorporated in [6], is assumed. Such model encompasses the following features:

- Sensor nodes are energy-constrained. All of them are stationary and BS is the node with high energy.
- Each sensor node periodically senses the monitored environment and has a perpetual desire to send the sensed data to the BS.
- Energy is dissipated during transmission and reception only and nodes failure is attributed to energy drainage only.

In this paper, we assume a simple radio energy model as shown in figure 6, where the radio dissipates E_{ELEC}=50 nJ/bit to run the transmitter or receiver circuitry and E_{AMP} = 100pJ/bit/m2 for the transmit amplifier to achieve an acceptable Eb/No. We also assume an r^2 energy loss due to channel transmission and d_0 = 87 m (crossover

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distance). Thus, to transmit a k-bit message a distance d using our radio model, the radio expends,

$$E_{TX}(k, d) = E_{ELEC}(k) + E_{FS} * k * d^2 \quad \text{for } d<d0,$$
$$E_{TX}(k, d) = E_{ELEC}(k) + E_{AMP} * k * d^4 \quad \text{for } d>d_0.$$

and to receive this message, the radio expends:

$$E_{RX}(k) = E_{ELEC} * k$$

Where,
ETX-elect - energy dissipated per bit at transmitter
ERX-elect - energy dissipated per bit at receiver
E_{AMP} - amplification factor
E_{ELEC} - cost of circuit energy to transmit/receive bit of data
K - Number of transmitted data bits
d - Distance between a sensor node and its respective CH or between CH and BS.

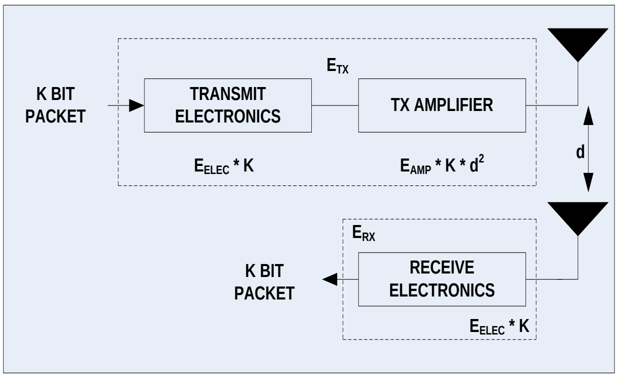


Fig. 6 Schematic diagram of the first order radio model

IV. SIMULATION PARAMETER & PERFORMANCE METRICS

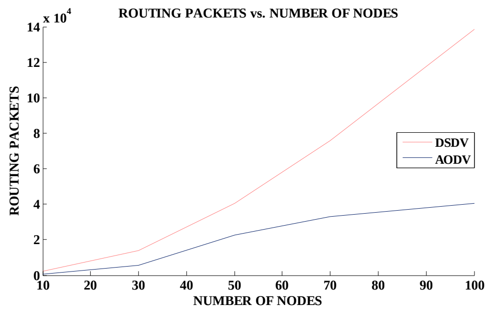
TABLE I
SIMULATION SETUP

SIMULATION PARAMETER	
Topology	Fixed
Number of Nodes	100 or (varied when required)
Area	100 * 100
Antenna	Omni-directional
MAC Protocol	IEEE 802.11
Propagation Model	Two Ray Ground, Friss Model
Energy Model	Radio
Maximum Simulation Time	3600
Base Station Energy	Maximum
Base Station Location	(50,175) - (varied when required)
Number of Cluster	5 or (varied when required)
R_b	1 X 10^6 bps
E_{FRISS}	9.6716 X 10^{-12} J/bit/m^2
E_{AMP}	1.3037 X 10^{-15} J/bit/m^4
Round Time	20 secs
E_{ELEC}	50nJ/bit

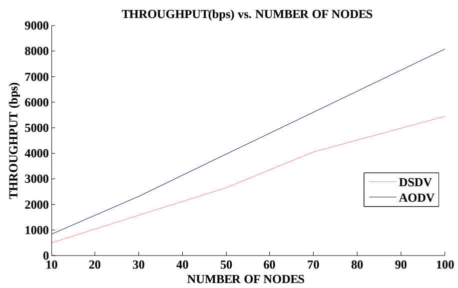
The major simulation parameters are shown in Table 1. We have performed this experiment on *ns-2* tool [9] (codes are omitted here). During experiments, we considered performance metrics such like as Throughput, Routing Overhead, Network Life Time, and Number of alive Nodes and Energy Consumption, as shown in [10] [11].

V. SIMULATION RESULTS AND PERFORMANCE ANALYSIS

In order to compare different protocols, it is important to have good models for all aspects of communication. In this simulation we have used network model and radio model for computation of energy dissipation as discussed earlier. Figures 7(a) and 7(b) respectively show routing packets, throughput related to the number of nodes for routing protocols AODV and DSDV. To eliminate the experimental error caused by Randomness, the experiment was repeated for 10 times and the average was taken as the final result. As seen from the graphs, the routing overhead for DSDV was higher than the AODV protocol because DSDV is *Proactive* routing protocol and therefore it broadcasts routing message before communication starts and it updates routing table of each node. In contrast, AODV floods routing messages only when route is needed so that routing packets exponentially increases with number of nodes for DSDV. It is clear from the figure that throughput is lowest for *Proactive* than the *Reactive* protocol. Figure 7(c) shows clearly that routing overhead for the protocol AODV is directly proportional with the load of the network. It uses the table of routing to determine the optimal path after having made calculations within each node to look for the shortest way and therefore leading to more routing overhead in AODV.



(a)



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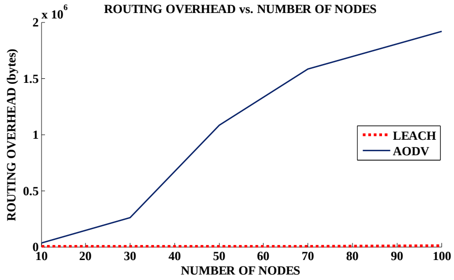

(c)

Fig. 7 (a) Routing packets vs. Number of nodes. (b) Throughput vs. Number of nodes. (c) Routing overhead vs. Number of nodes.

For LEACH protocol, we saw that routing packets is inversely proportional with the number of nodes. Figure 8 illustrates the influence of the network load on the quantity of energy consumption by the network. Finally, we have observed that the *Reactive* protocol is far better than *Proactive* protocol in terms of performance metric like routing overhead and throughput. On the other hand, hierarchical scheme namely LEACH, consumes less energy than *Reactive* routing protocol. Now next set of experiments are related to STATIC, MTE, Distributed Clustering (LEACH) and CENTRALIZED Routing algorithms.

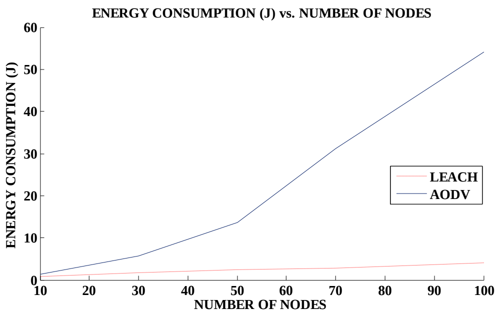

Fig. 8 Energy consumption vs. number of nodes

A. Nodes Begin with Equal Energy

For the first set of experiments in which each node begins with same 2J of energy and an unlimited amount of data to send to the BS. Since all nodes begin with equal energy in these simulations, each node uses the probabilities in equations to determine its CH status at the beginning of each round and each round lasts for 20 seconds.

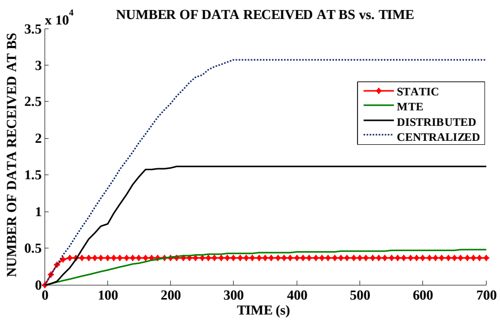

Fig. 9 Number of data received at BS vs. Time

Figure 9 shows the total number of data received at the BS over time. The Distributed (LEACH) and Centralized Clustering algorithm send much more data to the BS in the simulation time than MTE routing and therefore achieve low latency. The reason MTE requires so much time to send data from the nodes to the BS, is that each message traverses several hops. In other protocols, each message is transmitted over single hop to the CH, where data aggregation occurs. The aggregate signals are then sent directly to the BS. Therefore much less data needs to be sent the long distance to the BS.

Figure 10 show that Centralized Clustering algorithm delivers about 50 % more data per unit energy than Distributed Clustering. This is because the BS has global knowledge of the location and energy of all the nodes in the network, so it can produce better clusters that require less energy for data transmission. On other side STATIC Clustering performs poorly because all CH nodes die quickly, ending the lifetime of all nodes belonging to those clusters as shown with arrow point in figure 10.

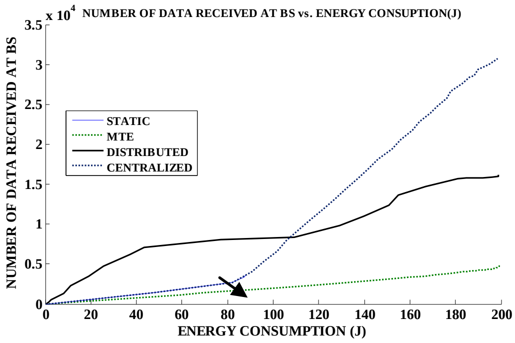

Fig. 10 Number of data received at BS vs. Energy consumption

In addition the Centralized Clustering algorithm ensures that there are k =5 clusters during each round of operation as shown in figure 11. Whereas in Distributed Clustering algorithm some rounds have as little as 1 cluster and some rounds have as many as 10 clusters due to probabilistic model. Therefore, Centralized routing algorithm, which always ensures 5 clusters, should perform better than Distributed Clustering.

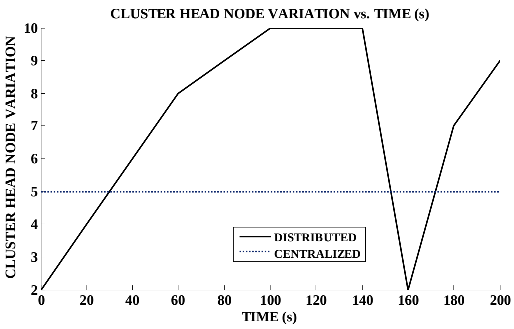

Fig. 11 Cluster head node variation vs. Time

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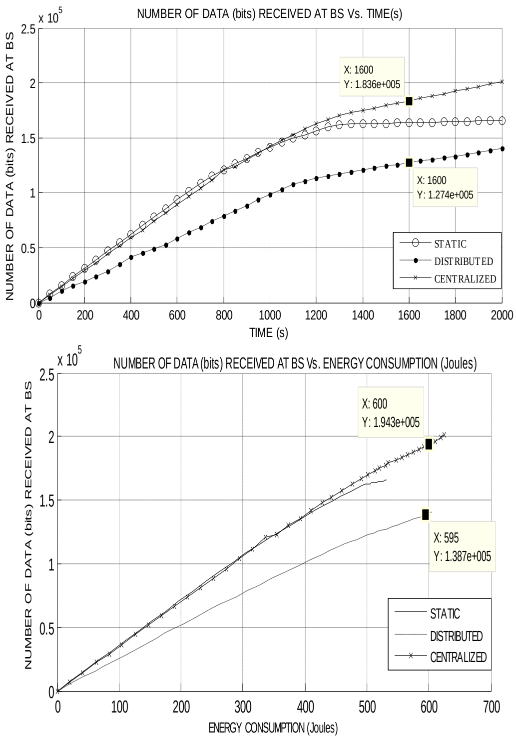
B. Nodes Begin with Unequal Energy

To see how well Distributed Clustering scheme can utilize any high-energy nodes that are in network, we ran simulations. During simulations we have fixed the number of sensor nodes up to 100 in network, amongst them 90 nodes were having initial energy of 2 J and 10 sensor nodes were having initial energy 200 J. Figure 12(a) and 12 (b) show that Centralized Clustering approach is an order of magnitude more energy-efficient than Distributed and STATIC routing. STATIC routing gives better performance than Distributed Clustering due to fixed cluster with fixed cluster-head having higher energy (200 J).



(a)

(b)

Fig. 12 (a) Number of data received at BS vs. Time. (b) Number of data received at BS vs. Energy Consumption.

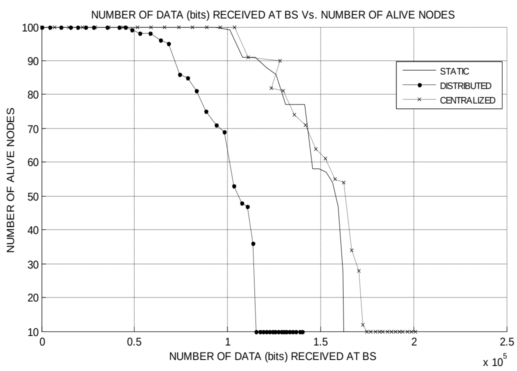


Fig. 13 Number of data received at BS vs. Number of alive nodes

Nodes in Distributed Clustering dies earlier since the routes do not take any advantage of high energy nodes whereas Centralized Clustering takes. This can be seen in figure 13 the number of nodes that are alive over time and the number of nodes that are alive per data received at the BS. This analysis reveals that nodes in Distributed Clustering algorithm die after delivering only a small amount of data to the BS. Whereas nodes in STATIC and Centralized routing take advantage of higher nodes, those remained alive and deliver 50 % more amount of data for the same number of node death.

C. Varying the BS Location

The results presented in the previous section show that Centralized Clustering routing is more energy efficient than other algorithms. Centralized algorithm is not just a function of simulation parameter, but it is also a function of BS location.

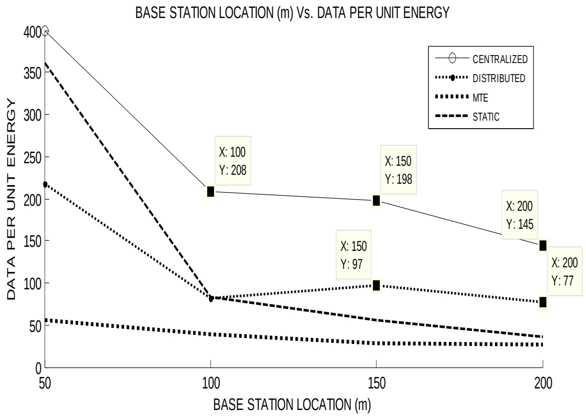


Fig. 14 Base station locations vs. Data per unit energy

Figure 14 shows the amount of data per unit energy that each of the protocols delivers to the BS as the location of the BS varies from (x=50, y=50) to (x=50, y=200). From this plot, we see that when the BS is in the centres of the network (y=50), Centralized Algorithm delivers 7 times the amount of data per unit energy whereas Distributed algorithm delivers 4 times the amount of data per unit energy as MTE routing. As the BS moves further away from the network, the Centralized routing algorithm performs better than other routing by at least a factor of 7 times. MTE routing performs significantly better when the BS is located within the network.

This is because when the BS is located within the network, there is no long-distance hop across which nodes need to send data. This saves a large amount of energy. Since MTE routing has more data to send to the BS the above saves a large amount of energy. However Centralized is still able to perform at least seven times better than MTE routing, even for the case when the BS is far away from the network

D. Network with Cluster-Head Variation

It can be seen from the figure 15 that as the CHs increases beyond the 5% of the total nodes, the data received at sink and as well as Network lifetime would decrease.

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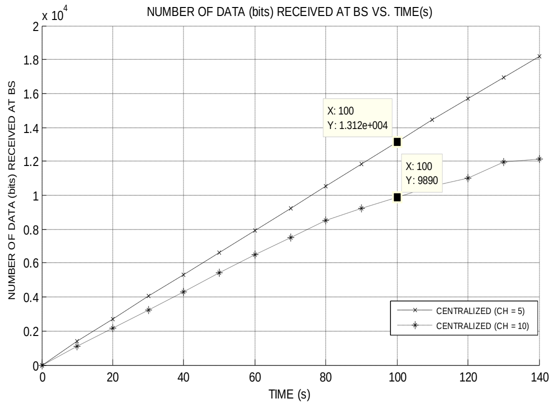
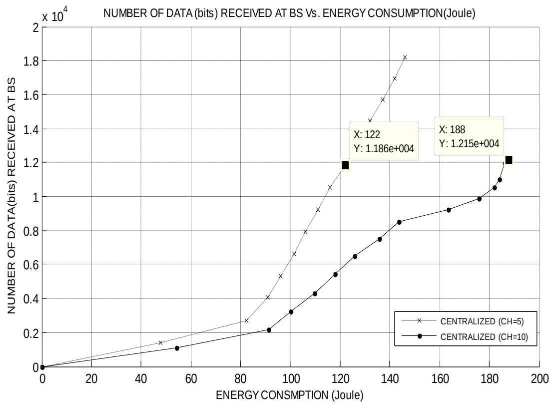


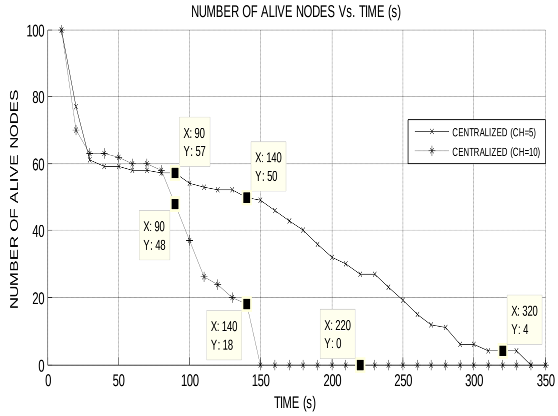
(a)



(b)

Fig. 15 (a) Number of data received at BS vs. Time. (b) Number of data received at BS vs. Energy Consumption.

It can be clearly seen that the network having 5% CH received the more amount of data compared to the other. The number of CH is a key factor that affects the performance of routing protocols. If the number of CH is less, the meaning of layering would be lost. In contrast with increase in the number of CH more energy is consumed, as the communication distance between CH to BS is higher than common node to CH that needs more energy. Thus, for the efficient performance of the network for the particular application, the CHs are 5% of the total nodes would be appreciated. It can be seen from the figure 16 that as the CHs increase beyond the 5% of the total nodes than the network lifetime would be decrease. The line with the CH 5 % of the total nodes of the network represents the longer the lifetime of the network. The network would be alive near about 350 sec (simulation time as the network lifetime.) In comparison, the network having 10% cluster head of the total nodes of the network would be alive only for 150 sec (simulation time as network lifetime.). The network lifetime improved by 2.5 times (approximately) than the network having 10% of the CHs. Thus, to prolong the network lifetime of the network, the CH should be 5% of the network's total nodes.



(a)

Fig. 16 Number of Alive nodes vs. Time.

VI. CONCLUSION

We have started activity based on various routing related issues pertaining to WSN and extensive survey is done to understand the various approaches proposed by researchers to overcome routing inefficiency in WSN. Based on this survey, we identify the promising routing protocols such as DSDV, AODV, MTE, STATIC CLUSTER, LEACH and its ameliorated algorithm LEACH-C protocol and evaluated their performance contrastively by using the *ns-2* tool. The simulation activities, we concluded with the imperative observations.

- We found out that *Hierarchical* routing protocols offer a better solution to energy efficiency usage in a WSN when compared to other technique such as AODV, DSDV, MTE and non hierarchical technique.
- Numbers of the CH in % also effect the routing of LEACH in network. The 5 % CH of the total nodes of the network is appreciated for the better result and greater network life for the network.
- The simulation results suggest that the LEACH-C protocol can effectively solve the problems such as the uncertainty of the number of the CH, lack of consideration of the energy state of the nodes in the construction stage of dynamic cluster.

In the foreseeable future, the factors in *hierarchical* routing protocol which affect the cluster building, communication of CHs and data fusion of clusters will be one of the research directions which can be more helpful to enhance a network lifetime of the WSN.

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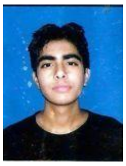
BIOGRAPHY



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