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PERFORMANCE COMPARISON OF CLUSTER-BASED PROTOCOLS IN WIRELESS SENSOR NETWORKS

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Abstract—To reduce the energy consumption is an important topic in the Wireless Sensor network (WSN). Many protocols have been designed for improving energy efficiency of the network. Clustering protocols have been proved to be one of the energy-efficient protocols in WSN. One of the basic and most popular protocols designed using the clustering approach is the LEACH (Low-Energy Adaptive Clustering Hierarchy).However, LEACH undergoes an issue of bad distribution of cluster heads, which is overcome by implementing a technique of selecting smart cluster head in LEACH known as SCHS (Smart Cluster Head Selection).Now both LEACH and SCHS is compared with another clustering protocol HEED (Hybrid Energy Efficient Distributed).In this paper, a performance analysis of three clustering protocols is carried out by keeping the network parameters same so as to conclude which protocol amongst the three utilizes the minimum energy and prolongs the network lifetime.

Index Terms—LEACH, SCHS, HEED, energy consumption.

I. INTRODUCTION

A Wireless Sensor Network consists of huge number of tiny sensors that are deployed in different areas where each node of that network senses the respective data and sends to base station directly or via cluster head by means of wireless communication. These sensor nodes have limited computational capabilities, very small battery life, etc. These batteries cannot be recharged nor can be replaced since the deployment of these sensor nodes may be such that human beings are deprived of the accessibility as the area could be more prone to natural calamities or may be hazardous to life. Once the nodes are deployed, they continuously do the job of sensing the data and transmitting to the destination, which drains the energy of the battery. More energy is drained while transmitting as compared to sensing of the data. Hence the communication distance should be as minimum as possible. The direct transmission protocol is the conventional scheme in which all nodes send the sensed data to the base station. As all the nodes will be traveling this distance to the base station, probably the entire network will be energy depleted at once and the wireless sensor network will be no more in existence [1].However, to reduce the transmission length efficiently organizing nodes into clusters is useful and it also reduces the energy consumption. In the clustering approach, sensors nodes are virtually grouped which comprises of one cluster head node that aggregates the sensed data from the rest of cluster members and forwards it to the base station. This reduces the energy consumption of each node as the transmission distance known as intra-cluster communication distance is short. However, traditional clustering approach sets the fixed cluster heads and it does not increase the lifetime of WSN [2]. However to enhance the network lifetime many techniques in clustering is implemented for proper cluster heads selections so that minimum energy is consumed. One of the popular protocols for energy –efficient WSN is proposed called as LEACH (Low-Energy Adaptive Clustering Hierarchy).In LEACH, the cluster heads are not fixed rather each node decides whether it will be cluster head for that particular round depending on probabilistic equation. However, probabilities make the distribution of cluster heads non-uniform [3]. SCHS was implemented on basic LEACH to overcome this non-uniformity. As well as another protocol known as HEED that follows the principle of LEACH but selects the cluster head on basis of residual energy of each node is considered for analysis.

II. LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY (LEACH)

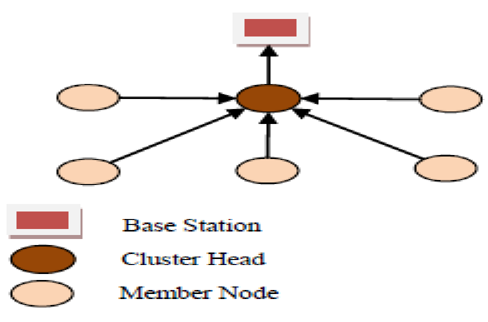

Fig: 1.Clustering [4]

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LEACH is the first hierarchical cluster-based routing protocol for wireless sensor network which partitions the nodes into clusters and in every cluster a cluster head node is elected as shown in Fig: 1.This cluster head is responsible for creating and manipulating a TDMA (Time division multiple access) schedule and sending aggregated data from nodes to the base station (BS) where these data is collected using CDMA (Code division multiple access). Remaining nodes are cluster members nodes [5].

This LEACH protocol is divided into rounds that have two phases;

Set-up Phase
(1) Advertisement Phase
(2) Cluster Set-up Phase
Steady Phase
(1) Schedule Creation
(2) Data Transmission

A. Set-Up Phase

In this phase, each node decides independently of other nodes if it will become a cluster head or not depending upon the below equation as:

$$T(n) = \frac{p}{1 - p \times \left(r \times \mathrm{mod} \times \frac{1}{p} \right)} \quad if\, n \in G$$

Where p is the number of clusters, r represents the round, T(n) is the threshold value (less than 1) and set of nodes that have not become the cluster-head in the last 1/p rounds is denoted by G. This decision takes into account when the node served as a cluster head for the last time (i.e, the node that hasn't been a cluster head for long time is more likely to elect itself than nodes that have been a cluster head recently).

In the following advertisement phase, the cluster heads inform their neighborhood with an advertisement packet that they become cluster heads. Cluster member nodes choose the advertisement packet with the strongest received signal strength.

In the next cluster setup phase, the member nodes inform the cluster head that they become a member to that cluster with "join packet" contains their IDs using CSMA. After the cluster-setup sub phase, the cluster head knows the number of member nodes and their IDs. Based on all messages received within the cluster, the cluster head creates a TDMA schedule, pick a CSMA code randomly, and broadcast the TDMA table to cluster members. After that steady-state phase begins.

B. Set-Up Phase

When data transmission begins the nodes send their data during their allocated TDMA slot to the cluster head. This transmission uses a minimal amount of energy (chosen based on the received strength of the cluster head advertisement). The radio of each cluster member node can be turned off until the nodes allocated TDMA slot, thus minimizing energy dissipation in these nodes. When all the data has been received, the cluster head aggregate these data and send it to the base station.

III. SMART CLUSTER HEAD SELECTION (SCHS)

This is a scheme that can be implemented with any distributed clustering approach. In SCHS, the area is divided into two parts: border area and inner area [6]. Only inner area nodes are eligible for cluster head role as shown in Fig: 2. This reduces the intra-cluster communication distance.

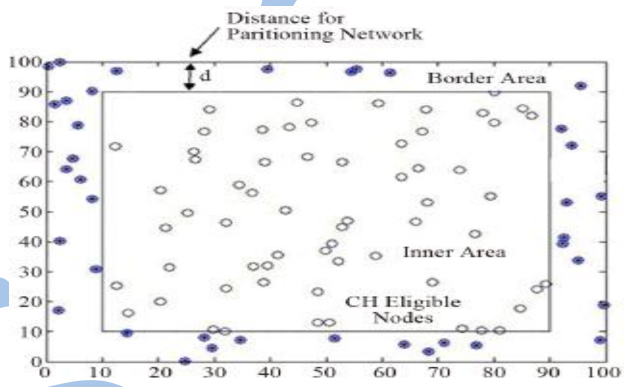

Fig: 2 Division of Network Area [6]

Division of area is an important factor in SCHS. Let d is the distance for partitioning of field. Area starting from boundary of the field up to the distance d is border area and the remaining inside area is inner area. The border area nodes do not participate in cluster head selection. Only the inner area nodes participate in cluster head selection. The border area nodes are always member nodes in each round. As the cluster head is always selected from the inner area in our scheme, therefore the cluster head is always close to center of the cluster. When this scheme is implemented on LEACH protocol, the bad- distribution drawback shown in Fig 3, is automatically vanished which perhaps reduces the intra –cluster communication distance and improves the energy efficiency of the WSN.

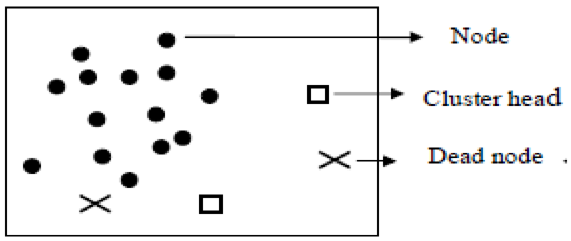

Fig: 3.Possible bad-distribution of cluster head in LEACH

In the set-up phase, each node is checked whether it belongs to border area or to inner area. If a node belongs to inner area, it will participate for cluster head role and if it belongs to border area then it will be a member node. Cluster heads announce their status message and wait for the response from nodes. Cluster head constitute the TDMA schedule for

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the cluster members. In the steady phase, the nodes wake up as the time slot allotted arrives and sends the data to cluster head. To conserve energy nodes go back to sleep state and wait for the next wake up slot. Cluster head aggregates the data and sends the data to base station. The steady phase is repeats itself till the round time is over. After completion of round time, set-up phase is executed again [6].The algorithm is as shown in fig.4.

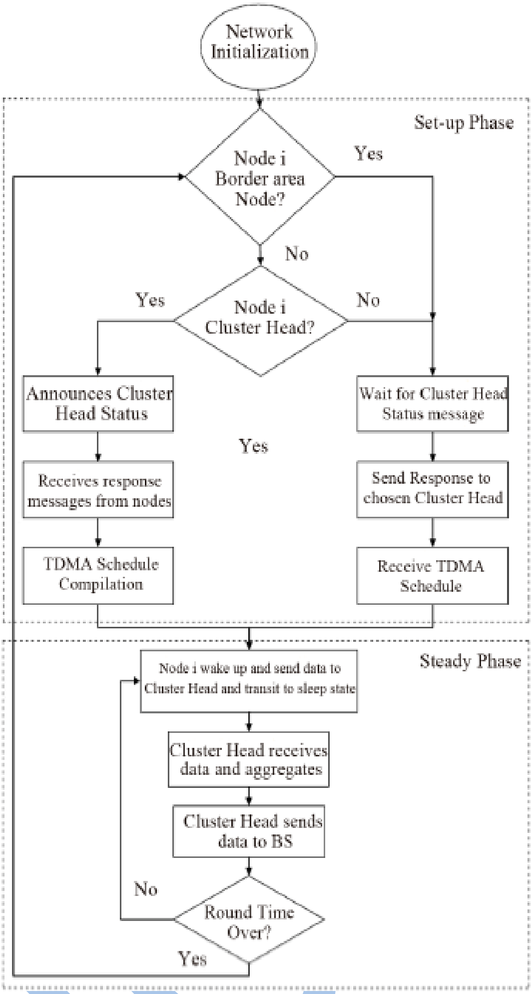

Fig: 4 Block diagram of clustering in SCHS [6]

IV. HYBRID ENERGY EFFICIENT DISTRIBUTED (HEED)

This is a distributed clustering scheme in which cluster heads are selected periodically according to a node residual energy and a secondary parameter, that is, intra-cluster communication cost. Cluster head is selected in HEED depending on the highest residual energy and minimum communication distance. The average minimum power required by M nodes within the cluster to reach cluster head is given by equation as:

$$AMP = \frac{\sum_{i=1}^{M} \min(pi)}{M}$$

Where min(pi) is the minimum power level required by a node Vi and M is the number of nodes within the cluster. HEED undergoes three phases as [7]

A. Initialization Phase

In HEED clustering is triggered in every $T_{CP} + T_{NO}$ seconds to select new cluster heads where T_{CP} is time required to create a cluster and T_{NO} is the time interval between the end of a T_{CP} and start of a subsequent T_{CP}. In each iteration, before the start of execution each node sets its probability of becoming a cluster head which is given as

$$CHprob = Cprob * \frac{Eresidual}{E\max}$$

where Cprob = Initial percentage of cluster heads among all n nodes, and Eresidual = Estimated current residual energy in the node, Emax = Maximum energy.

B. Repetition Phase

In repetition phase, every sensor goes through several iterations until it finds the cluster head which will use the least transmission power (cost). If it hears from no other cluster head, the sensor elects itself as a cluster head and sends an announcement message to its neighbors informing them about the change of status. Finally, each sensor doubles its CHprob value and goes to the next iteration of this phase. It stops executing this phase when its CHprob reaches one.

C. Finalization Phase

At last, each sensor makes a final decision on its status. A node can either elect to become a cluster head according to its CHprob or join a cluster according to overheard cluster head messages within its cluster range. HEED has a worst case processing time complexity of O(n) per node, where n is the number of nodes in the network. Also is has a worst case message exchange complexity of O(1) per node, that is, O(n) in the network. The probability of becoming cluster head for two nodes within each other's cluster range is very less. HEED protocol, which terminates after a constant number of iterations, is independent of network diameter.

V. ENERGY MODEL

In Wireless sensor networks, sensor nodes are deployed randomly to monitor certain area and forward the sensed data to base station via cluster head. Most of the energy is dissipated during communication in sensor networks as it depends on the distance between the two nodes. Hence an Energy dissipation model is shown in fig: 5.

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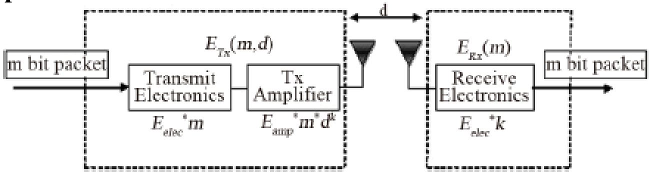

Fig: 5. Radio energy dissipation model [6]

According to the energy model proposed in [8], energy is consumed while transmitting and receiving the sensed data. For sending m-bit of data over a distance d, the total energy consumed by the node in transmitting is given by

$$E_{Tx}(m,d)=\begin{cases} m\times E_{elec}+\left(m\times E_{fs}\times d^{2}\right) & d<d_{0} \\ m\times E_{elec}+\left(m\times E_{amp}\times d^{4}\right) & d\geq d_{0} \end{cases}$$

While the energy expended on receiving the data is given by

$$E_{Rx}(m)=m\times E(elec)$$

Where do is the crossover distance which is given by

$$do=\sqrt{\frac{Efs}{Eamp}}$$

VI. Simulation Results

Performance of the three clustering algorithms with the help of simulations is presented in this section. This work uses MATLAB as the simulation tool where all simulations are conducted considering a wireless sensor network with 100 nodes which are randomly distributed in a 100 ×100 m^2 field. The base station is placed 75 m away from the sensing region. For SCHS a distance of 10m is considered. Simulation parameters are listed in Table 1.

Table I. Simulation Parameters

Network area	100*100m^2
Number of nodes	100
Distance of base station	75 m
Number of clusters	10
Initial Energy	0.5J
Eelec	50nJ/bit
Efs	10pJ/bit/m^2
Eamp	0.0013pJ/bit/m^4

A) Simulation results for Node death rate is presented in following Table 2 .

Table II. Simulation results for Node Death Rate

Number of rounds	Number of alive nodes		
	LEACH	SCHS	HEED
0	100	100	100
100	100	100	100
200	100	98	100
400	69	81	97
600	30	61	82
800	15	38	53
1000	3	30	34
1200	1	23	20
1500	1	19	16
1800	1	9	15

Following fig: 6, is about the node death rate, where node death rate is defined as number of alive nodes at a time.

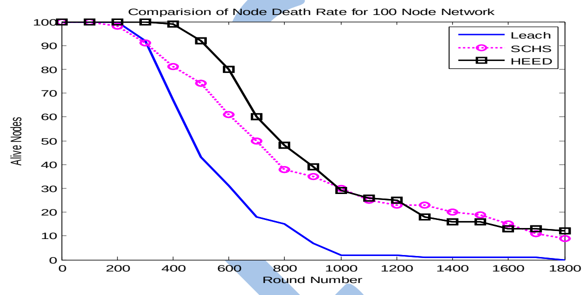

Fig: 6. Comparison of Node death rate of LEACH, SCHS and HEED

B) Similarly Table3 gives the simulation result for energy consumption rate followed by its respective comparative graph shown in fig:7. Energy consumption rate is defined as the energy consumed by the whole network against time.

Table III. Simulation results for Energy Consumption Rate

Number of rounds	Energy Consumption Rate in Joule		
	LEACH	SCHS	HEED
0	0.13	0	0.04
100	10	4	4
200	21	7	8
400	39	15	16
600	47	22	25
800	49	29	28
1000	50	33	29
1200	50	38	30
1500	50	44	30
1800	50	51	30

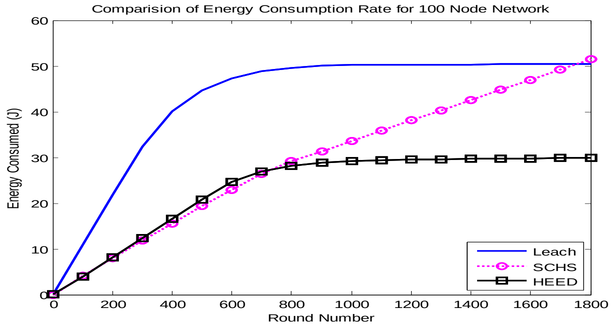

Fig: 7. Comparison of energy consumption rate of LEACH, SCHS and HEED.

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VII. CONCLUSION

The basic LEACH protocol have the disadvantage of cluster head been elected at the borders or edges of a wireless sensor network. Thus, the problem of bad distribution of cluster heads is overcome by subdividing the area as border area and inner area. Thus cluster members have to communicate with the cluster head within the inner area, reducing the communication distance which results in less energy consumption. HEED follows the principle of LEACH but it chooses the cluster head by considering basically the residual energy of each node, this helps to reduce the communication overhead which likely takes place in LEACH while electing cluster head. The performance evaluation of all these three protocols concludes that for the same network size and rest all parameters considered to be same, the node death rate of HEED is lower than both LEACH and SCHS. Also the energy consumption of HEED is far lower thus prolongs the network lifetime as compared to LEACH and SCHS.

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