ISSN 2047-3338

Comparative Study of Cluster Head Formation Techniques in WSN

Iqra Abdul Ghaffar[1], Hafiz Muhammad Zahid[2], M. Junaid Arshad[3]
[1,2,3]Department of Computer Sciences and Engineering, University of Engineering and Technology, Lahore, Pakistan

***Abstract*— In Wireless Sensor Networks (WSNs), power utilization is a primary concern. WSN devices called Sensor Nodes are powered by small batteries. These batteries provide limited energy resources. In most cases and deployment settings, it is not possible to replace or recharge these batteries. Therefore, these nodes are designed to use energy resources as an efficiently as possible so that long lifetime of network is achieved. Major portion of power resource is consumed for wireless communication during Transmitting (TX) state and Listening or Receiving (RX) state. So, the nodes of WSN are grouped together and only one node in a group, called Cluster Head (CH) is responsible to transmit data to sink Base Station. The grouping or clustering of these nodes is done by various techniques. Some techniques put extra control overhead and processing to the network.**

***Index Terms*— Wireless Sensor Network (WSN), Energy Efficient, Clusters (EEC), LEACH, LEACH-B, Optimization Algorithm, Normalized Residual Energy Clustering (NREC) and Low-Energy Adaptive Clustering Hierarchy (LEACH)**

I. INTRODUCTION

IN today's world, small and low power devices have been developed which can collect, store process and transmit data using wireless channel. These devices are called wireless sensor devices and they together make wireless sensor network. Due to its many applications, lot of research is done in this field. WSN has many applications in military, environment monitoring, industry and in smart home. In WSN, there are four main components Sensor nodes, Base station, Wireless medium and Sensor field. Sensor node is basic component which consist of power supply, sensor, memory, processor and communication module [1].

Together all these components, Sensor node is made which senses the environment and then transfers data to Base station. Data is transferred from sensor to BS using single hop or multiple hop. When distance between node and BS is less than single hop is feasible but if the distance is larger than single hop is not feasible because nodes which are far from BS consume more energy to communicate with Base Station. As they consume more energy, so they die earlier as compare to nodes which are close to BS. So, in that case multi-hop is feasible. There are many parameters which must consider for WSN design e.g., security of data, power consumption/network lifetime, scale-ability, throughput etc. But mostly research is done for energy efficiency. There are many routing protocols which have been used for efficient utilization of energy in WSN e.g., flat based, location based and hierarchical based protocols. The WSN is divided into groups called as clusters to improve network efficiency and scale-ability is known as hierarchical based routing algorithm. In multi-hops routing algorithm SNs near to BS die earlier compare to SNs away from BS due to overwhelming remove it. The idea behind hierarchical based routing protocol is that the SNs also called member nodes directly communicate with their leader known as Cluster Head (CH). Then CH aggregates data received from its member nodes and finally forward compressed data to sink directly or with help of other neighboring CHs.

In hierarchical based routing protocol additional responsibilities of CH causes extra energy consumption, however, to overcome this problem the CHs are selected in rotation manner to energy consumption should be equally distributed among the SNs. Low-energy adaptive clustering hierarchy (LEACH), Power-Efficient Gathering in Sensor Information System (PEGASIS), Threshold-sensitive Energy-Efficient Sensor Network (TEEN), Adaptive Threshold-sensitive Energy-Efficient Sensor Network (APTEEN) and Hybrid Energy-Efficient Distributed Clustering (HEED) are some popular hierarchical-based routing protocols among many others [2].

II. RELATED WORK

A very good routing protocol is very important to achieve maximum performance of WSNs. As SNs (Sensor Nodes) are limited resource devices, so to save power, A technique is used in WSNs in which different Sensor Nodes are grouped together to make cluster and one node is chosen as cluster head(CH). CH (Cluster Head) collect data from its member nodes, aggregates it and then send that data to BS. In this way, member SNs can use low power transmission to send their collected data to cluster head SNs.

If proper remove it clustering algorithm use, then network lifetime can be improved. Various methods are used for cluster head selection. These methods may be single hop or multi-hop A lot of work has been devoted to CH selection process, so far, many clustering algorithms have been suggested. LEACH protocol is one of the first protocols that uses clustering to organize SNs into clusters. Since LEACH, many improvements to LEACH were proposed by many researchers. In this section, some popular routing algorithms of hierarchical type are explained [2].

A). Low Energy Adaptive Clustering Hierarchy (LEACH)

Leach is first hierarchical based routing protocol [2]. Main objective of Leach is energy efficiency. It selects cluster head on random basis so, that energy is efficiently utilized, and no sensor node die earlier because of responsibilities of CH. LEACH Protocol has two phases. One is setup phase and other is steady-state phase. During setup phase, cluster formation, CH selection and assignment of TDMA (Time Division Multiple Access) slot is done. In setup phase, each node chooses a random number between 0 and 1. Then that no is compared with threshold value, if it is less than threshold value then it is selected as CH. Otherwise not. That threshold value is calculated using following equation (1).

$$T(n) = \begin{cases} \dfrac{P}{1 - P * \left(r * mod\ \left(\frac{1}{p}\right)\right)}, & if\ if\ n \epsilon\ G \\ 0, & O.W \end{cases} \quad (1)$$

where,

P is the probability of nodes
r represents current round
G is number of nodes that not participate in CH election from previous 1/P rounds

After CH selection, each CH broadcast an advertisement message to all sensor nodes in its cluster. Sensor nodes then connect to CH using signal strength. After this TDMA (Time Division Multiple Access) schedule is created so that data not collide. After this steady state phase start and each node send data to its CH in its allocated time slot. When data reached at CH, CH aggregates that data and sends it to BS. CH also uses TDMA schedule for this purpose. LEACH is energy efficient protocol which increases network lifetime. It reduces significant amount of energy by applying aggregation techniques on data. It prevents intra-collision because when one sensor is transmitting data, other go in sleep mode. In Leach, CH are selected on random basis, so each node has equal chance to become CH.

In Leach, after some rounds, nodes which have low energy and nodes which have high energy have equal chances to become CH so, if low energy node is chosen then this is disadvantage. It is single hop-based communication between CH and BS. If BS is far away from node then more energy is consumed. Research paper which is entitled as A survey on successor of LEACH discusses LEACH and it's all variants like LEACH-C, SLEACH, Sec-LEACH, LEACH-B and many more.

B). Power-Efficient Gathering In Sensor Information System (PEGASIS)

Enhancement on LEACH was proposed in [3]. This protocol was also proposed to increase network lifetime. In PEGASIS, clusters are not formed, chain is formed, and data is transferred to BS through that chain. Chain is formed using greedy algorithm in which node select its nearest neighbor node as next hope. After chain formation, leader is chosen which send data to BS and that leader is selected based on residual energy. In this way, average energy per node is reduced and PEGASIS does not make clusters like LEACH. This approach reduces overhead on BS because only one node send data to BS [4].

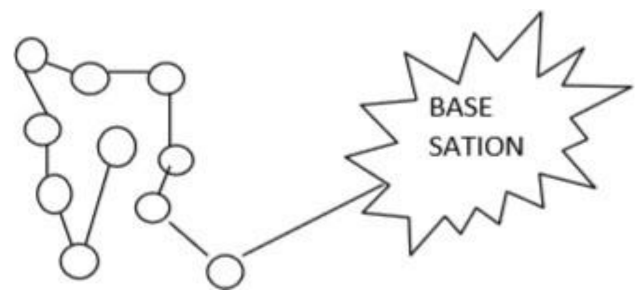

Fig. 1: PEGASIS chain formation [4]

C) Threshold-Sensitive Energy-Efficient Sensor Network

This is event-based protocol in which data send to BS, when any event occurs. TEEN is different from LEACH, PEGASIS which periodically send data to BS [5]. TEEN is based on hard and soft threshold value. It sends data to BS when sensed value is greater than hard threshold. Sensor node also store data in its memory. It further compares sensed value with its soft threshold. So, hard threshold reduces unnecessary transmissions and soft threshold further eliminate unnecessary transmissions if value of SV not change. TEEN make two level clusters. Sensor nodes first make first level cluster then those first level clusters further make second level cluster. Those second level cluster then transmit data to BS. Its advantage is all nodes need only to transmit data to their immediate CH. Only CH perform aggregation on data.

D) Adaptive TEEN

This is the improved version of TEEN. In TEEN, data does not send periodically to CH but in APTEEN, data send periodically. After cluster formation, Hard threshold, Soft threshold, transmission schedule and count time parameter broadcast to all nodes. Nodes are sensing data constantly and when it is greater than HT, they send data to CH [6]. In this approach even if SV is not greater than HT then sensor node sends data to CH and it is done based on count time. Count time is maximum time span in which data must send. It's all working is same as TEEN, only difference is it send data periodically. It sends data based on HT, ST and CT. If SV is not greater than HT then in TEEN, data does not send but in APTEEN, it sends based on CT.

E). Efficient Energy Unequal Clustering (EEUC)

EEUC use multi-hop communication and address hot spot problem. In multi-hop communication, nodes send data to another node and through nodes, data reach to BS. So, nodes near the BS transfer their own data as well as other nodes data (nodes for which it acts as relay). When these relay nodes die then data does not reach to BS. This is called hot-spot problem. EEUC address this issue by doing clustering at two stages. At first stage, Tentative Heads are selected just like CHs selected in LEACH. Then second competition is between these tentative heads and non-cluster nodes go to sleep mode until competition is ended. In second stage, final CH is selected in such a way that their competition radius (Rcomp) not overlap. This radius controls the size of cluster and it is determined in such a way that the clusters near BS are smaller in size. Rcomp is calculated using following equation (2):

$$sn_i * R_{comp} = \left(1 - c\,\frac{d_{\max} - d(sn_i, BS)}{d_{max} - d_{min}} + \frac{r}{n}\right) * R^0{}_{comp} \quad (2)$$

Where,
d_{max} is a is maximum distance of nodes from BS
d_{min} is minimum distance of nodes from BS
d (sn_i, BS) is distance of ith node from BS, R0comp is maximum allow competition radius and c is constant

If one sensor node is in competition radius of another sensor node then sensor node which has lower residual energy broadcast quit competition message. After final selection of CH, setup phase start in which final CH broadcast message and clusters are formed. Then after receiving join request message from member nodes, CH schedule TDMA and data transferring start but unlike LEACH, it uses multi-hop if distance is large, otherwise it sends data in single-hop.

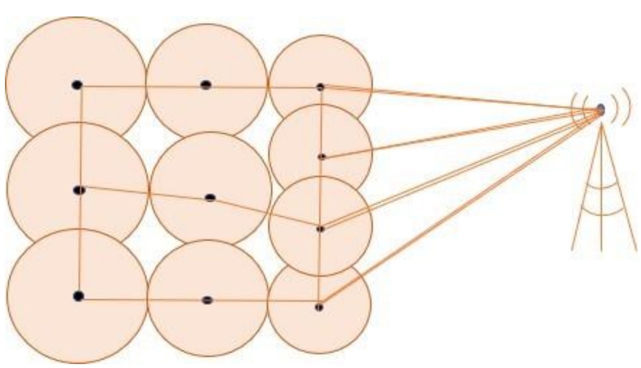

Fig. 2: Final EEUC formation of clusters

F). LEACH-B

This is improved version of LEACH which is called LEACH-B or LEACH-Balanced [8]. In LEACH, there is no guarantee, in each round, exactly k number of cluster heads are selected but in LEACH-B, no of CH are fixed. If P is desired percentage of each node and N is number of nodes, then exactly K=N*P CHs are selected in each round. If no of CHs are greater than N*P, then some nodes must resign from CH ship. So, the nodes which have low residual energy resign from CH-ship. If no of CH are less than $N*P$ then more nodes are selected as CH so, the nodes which have greater residual energy are elected themselves. This is done using following equation (3):

$$T_{wait} = \frac{K}{E_{residual}} \quad (3)$$

Where,
k is factor which limits maximum wait time. Nodes which have less wait time are selected as CH. After CH selection, steady state phase starts which is same as LEACH.

G). Residual Energy (ResEn)

Tuah et al. proposed Residual Energy (ResEn) algorithm which modifies the cluster selection criteria of LEACH. This protocol also considers percentage of remaining energy in Cluster Head formation. ResEn protocol has three phases: - Cluster Head Selection, Cluster Creation and Data Transmission. In CH selection phase, each node chooses random number between 0 and 1 then this no is compared with threshold value. If no is less than threshold value, then it is selected as CH [9]. Its threshold value is calculated as:

$$T_i(t) = \begin{cases} \frac{P}{1-P\left(r*mod\left(\frac{1}{P}\right)\right)} * \frac{E_{cur}}{E_{init}}\ , & if\ i\ \mathcal{E}\ G \\ 0, & O.W \end{cases} \quad (4)$$

Where,
P is random number which is also called desired probability of node.
G is set of nodes not selected as CH in previous 1/p rounds.

This equation is same as Leach except percentage of remaining energy also included in CH selection. Cluster formation and data transmission phase is same as LEACH, but network lifetime is improved over LEACH.

H). Normalized Residual Energy Clustering

NREC modifies cluster head selection criterion of Residual energy [10]. It uses residual energy. It also uses residual energy like ResEn, but it uses normalized energy instead of remaining energy. Based on normalized energy it ranks the node in local region. Disadvantage of ResEn is with the network ages remaining energy of node is less and low energy node is chosen as cluster head. But in NREC, a normalized percentage of remaining energy is used which is essentially the ranking of a node based on its remaining energy. This protocol also has two phases. In steady state phase, cluster formation for first round is same as LEACH. During first round, when nodes send JOIN-REQ message with that they also send their energy status. A sensor node maintains a set of nodes who share their energy status by listening their control packets. Let Ej is remaining energy of jth node in set Si of sni, the normalized energy or ranked remaining energy is given by [11].

$$E^{n}{}_{i} = \frac{E_{i-\min(E_j, E_i)}}{\max(E_j, E_i) - \min(E_j, E_i)} \quad (5)$$

E^n = Normalized remaining energy of ith node
E_j = Normalized remaining energy of sn_j nodes
S_i = Set of sensor nodes whose energy was learned by sni node

E^n_i gives value between 0 and 1. It is 0 if sn_i have energy lowest from all nodes and 1 if it has high energy. In this way it gives ranking of node in network. Its new threshold value for next rounds can be calculated as following equation (6):

$$T_i(t) = \begin{cases} W_1 * \frac{P}{1-P\left(r*mod\left(\frac{1}{p}\right)\right)} + W_2 * E^n{}_i, & if\ C_i(t) = 1 \\ 0: & C(t) = 0 \end{cases} \quad (6)$$

Where,

p =Percentage of CHs, W1, W2 =Weights of function W1 + W2 = 1,
E^n = Normalized remaining energy of ith node as given by above equation.
$C_i(t)$ = Flag if sni has been CH in the previous 1/p rounds or not.

Sensor nodes get a random number and that number is compared with new threshold. I f it is less than threshold then it is selected as CH. After CH selection for current round, CH sends advertisement message to all its member nodes and they send JOIN-REQ message. Then after all this, steady state phase starts which is same as LEACH and ResEn. A Research paper entitled Energy-Efficient Cluster Formation Techniques: A Survey was published [12]. This paper is comparative study of some clustering algorithms (LEACH, LEACH-C, K-Means, Optimization algorithm, Particle Swarm Optimization). This paper concludes that PSO is better than others.

A Research paper entitled Comparison of Energy Optimization Clustering Algorithms in Wireless Sensor Networks was published [13]. In this paper, author discusses different energy optimization clustering algorithm based on different parameters. Based on this comparison, we can use better optimization technique according to situation. A Research paper entitled A Review Study on Energy Efficient Protocols for Wireless Sensor Network was published [14].

This paper gives review on energy-efficient protocols. A Research paper entitled A Study on Energy Routing Algorithms Using Clustering in Wireless Sensor Networks [15] was published. This is just study of energy routing algorithm. Main objective of this study is to provide highest throughput and network lifetime improvement.

III. COMPARATIVE ANALYSIS

There are many routing techniques that are discussed above in literature survey. In this section we do comparative analysis of three techniques which are latest and discussed in the last of above section. These three techniques are LEACH-B, ResEn and NREC and these techniques are compared in terms of network lifetime, lone nodes count, data packets received at BS and energy consumption. Network lifetime is the life of network in which it remains operational and network remains operational until its last node is dead [15]. Time is represented as number of rounds so network life time is number of rounds before all nodes are dead. Network lifetime of above three clustering techniques is represented in Fig. 3:

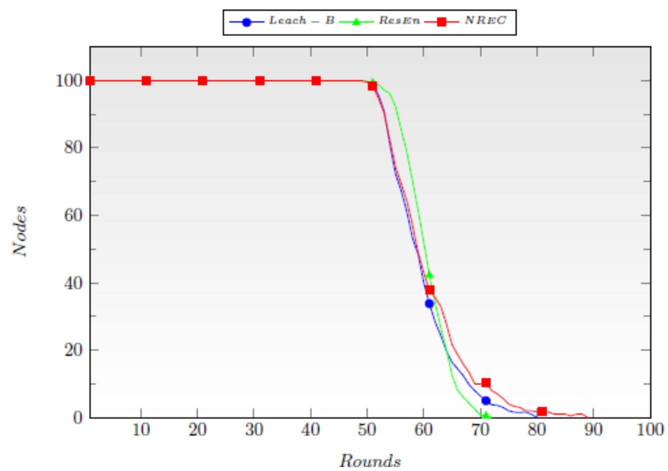

Fig. 3: Live Nodes vs. Rounds

It is clear from above graph NREC performs better than other two algorithms. It can be seen from above graph that 50 percent of nodes die at 60th round but last node of ResEn die at 70th round, last node of LEACH-B die at 80th round and last node of NREC die at 89th round so network lifetime of NREC is better than other two. Next parameter is Number of lone nodes in above three algorithms. How many lone nodes are left in each routing technique is shown in Fig. 4:

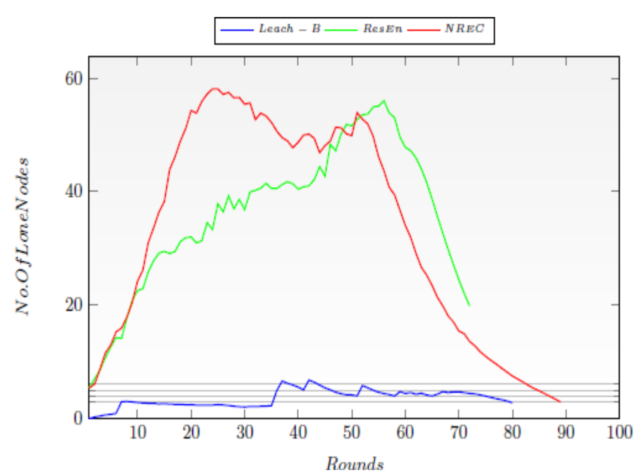

Fig. 4: Lone nodes vs. Rounds

It can be seen from above graph that Leach-B has minimum number of lone nodes during the network life, while ResEn and NREC has more lone nodes in the network life time. Although NREC has more lone nodes but it tries to conserve energy by activating the node when it must send data otherwise it remains in sleep mode. This above graph shows that Leach-B achieves better clustering than the rest of two methods. Data packets received at BS using all three algorithms are shown in Fig. 5:

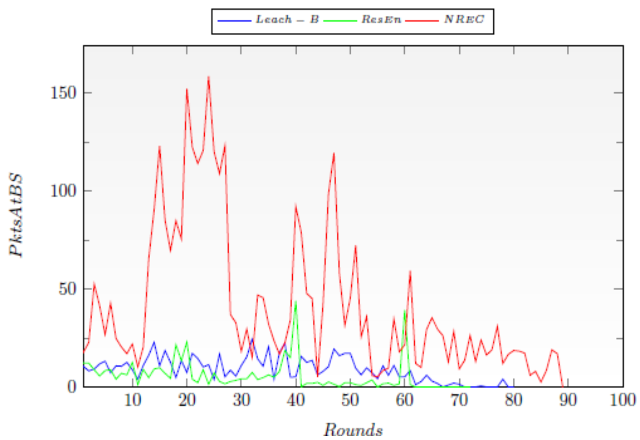

Fig. 5: Packets at BS vs. Rounds

It can be seen from above graph that Data packets received at BS using NREC are more than other two algorithms. NREC spent less energy to send useful information to BS and this is shown in Fig. 6.

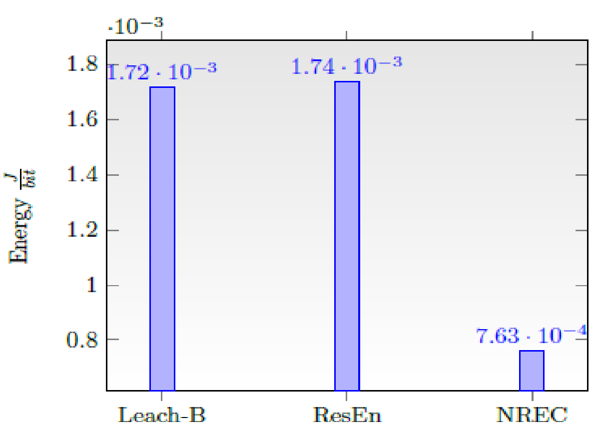

Fig. 6: Energy spent by each technique

The summary of results is given in the Table I:

Table I: Summary of Results

Parameters	LEACH-B	ResEn	NREC
Network lifetime	Good	Average	Better
Lone nodes	Less	More than Leach-B	More than ResEn
Packets at BS	Average	Low	High
Energy consumption	Less than ResEn	High	Low

IV. CONCLUSION

In this paper, we have studied different routing protocols for efficient utilization of energy of Sensor nodes. We compared three types of algorithms ResEN, LEACH-B and NREC. It is obvious from results that are shown in above section that NREC is best than other two algorithms in terms of network lifetime, data packets received at BS and energy consumption.

REFERENCES

[1]. R. Anitha and P. Kamalakkannan, "Energy efficient cluster head se-lection algorithm in mobile wireless sensor networks," in Computer Communication and Informatics (ICCCI-2013) International Conference, pp. 1-5, 2013.

[2]. S. K. Singh, P. Kumar, and J. P. Singh, "A survey on successors of LEACH protocol," IEEE Access, Vol. 5, pp. 4298-4328, 2017.

[3]. Lindsey S, Raghavendra CS, "PEGASIS: Power-efficient gathering in sensor information systems", Aerospace conference proceedings, 2002 IEEE; 2002.

[4]. V. Kumar, S. Jain, and S. Tiwari, "Energy efficient clustering algorithms in wireless sensor networks: A survey," IJCSI International Journal of Computer Science Issues, vol. 8, 2011.

[5]. J. Ferdous, M. J. Ferdous, and T. Dey, "A Comprehensive Analysis of CBCDACP in Wireless Sensor Networks," JCM, Vol. 5, pp. 627-636, 2010.

[6]. O. Buyanjargal and Y. Kwon, "Adaptive and energy efficient clustering algorithm for event-driven application in wireless sensor networks (AEEC)," Journal of Networks, Vol. 5, pp. 904-911, 2010.

[7]. M. S. Manshahia, "Wireless Sensor Networks: A Survey," International Journal of Scientific Engineering Research, Vol. 7, pp. 710-716, 2016.

[8]. Q. Liao and H. Zhu, "An energy balanced clustering algorithm based on LEACH protocol," in Applied Mechanics and Materials, 2013, pp. 1138-1143.

[9]. Nada Alhumidi, "Comparative analysis of clustering algorithm for routing protocols in wireless sensor network", Conference Paper, October 2017.

[10]. A. Sabri and K. Al-Shqeerat, "Hierarchical cluster-based routing protocols for wireless sensor networksa survey," IJCSI International Journal of Computer Science Issues, Vol. 11, pp. 93-105, 2014.

[11]. S. Mahajan and P. K. Dhiman, "Clustering in Wireless Sensor Networks: A Review," International Journal, vol. 7, 2016.

[12]. J. Patel and A. Sakadasariya," Energy-Efficient Cluster Formation Tech- niques: A Survey," Energy, vol. 4, 2015.

[13]. N. A. O. Al-Humidi and G. V. Chowdhary, "Comparative Analysis of Clustering Algorithms for Routing Protocols in Wireless Sensor Networks," 2017.

[14]. Mukhdeep Singh Manshahia, A Review Study on Energy Efficient Pro- tocols for Wireless Sensor Network, International Journal of Scientific Engineering Research, Vol. 7, Issue 4, April 2016.

[15]. S. M. Priya and A. Jeevarathinam, "A study on energy routing algorithms using clustering in wireless sensor networks," International Journal of Advanced Research in Computer Science and Software Engineering, Vol. 5, 2015.