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Energy Efficient Routing Protocols in Wireless Sensor Networks: A Survey

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***Abstract*- This paper presents a review on energy efficient clustering protocols for heterogeneous wireless sensor network. Energy consumption is the critical design issue in the wireless sensor network since each node has a battery and each battery has limited lifetime. Therefore using the battery in efficient way became an important task for prolonging the lifetime and stability of the wireless sensor network. Clustering based protocols are the best way to enhance the network lifetime. LEACH protocol is the first hierarchical clustering protocol for homogeneous wireless sensor network in which all nodes are having the same energy. The clustering protocols for homogeneous WSN do not performed well for heterogeneous WSN because the nodes in heterogeneous WSN have different energy levels. Thus for energy efficiency in heterogeneous WSN clustering protocols like SEP, DEEC etc was proposed. In this paper, we have discussed the working of heterogeneous protocols and present the comparative study of different clustering routing protocols for heterogeneous wireless sensor network.**

Index Terms—Heterogeneous Wireless Sensor Networks, Cluster Head, Energy-efficient Clustering Protocols.

I. INTRODUCTION

Wireless sensor network is a wireless network consisting of spatially distributed sensors nodes to monitor physical or environmental conditions. The sensor nodes can be deployed either inside or very close to the sensed phenomenon, they sense the environment and send the sensed data to the base station. The sensor nodes are scattered in a sensor field. Each of these scattered sensor nodes has the capabilities to collect data and route data back to the sink and the end users. The sink may communicate with the task manager node via Internet or Satellite [17]. Each sensor node consist four components: a sensing unit that contains a sensor and ADC, a processing unit containing a processor and a storage, transceiver and power source. One the basis of application for which sensor nodes are deployed, they may contain additional components like location finding system and a mobilizer.

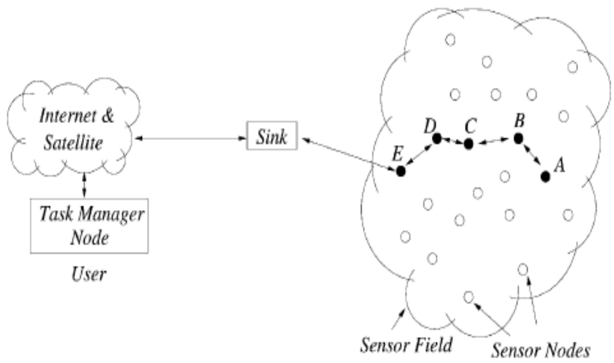

Fig. 1. Architecture of WSN [17]

The analog signals produced by the sensors based on the observed phenomenon are converted to digital signals by the ADC, and then fed into the processing unit. The processing unit manages the procedures that make the sensor node collaborate with the other nodes to carry out the assigned sensing tasks. A transceiver unit connects the node to the network. Power units may be supported by a power scavenging unit such as solar cells [17]. If the user requires the knowledge of location with high accuracy then the node should pusses Location finding system and mobilizer may be needed to move sensor nodes when it is required to carry out the assigned tasks.

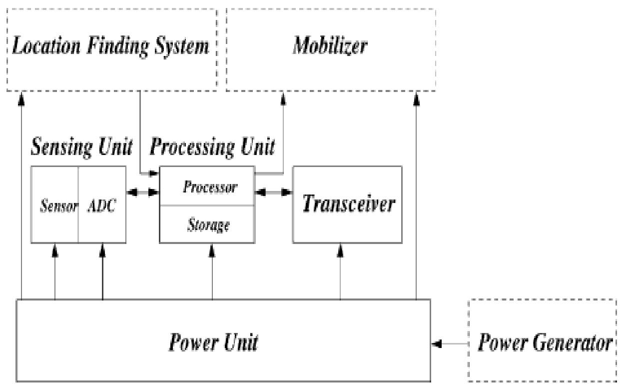

Fig. 2. Component of Wireless Sensor Node [17]

A. Design Issues

A sensor network design is influenced by many factors such as fault tolerance, scalability, power consumption. These factors are important because they serve as a guideline to design a protocol or an algorithm for sensor networks. On the basis of these factors, different routing techniques are compared and their performance is evaluated. Following are the major design issues faced while designing any routing protocols for wireless sensor network system.

- *Fault Tolerance*

Fault tolerance is defined as the ability to sustain sensor network functionality without any interruption due to sensor node failures. Senor node may fail due to the lack of power, physical damage or environmental interference. The level of fault tolerance depends on the application of sensor network; hence the protocols are designed keeping in mind the level of fault tolerance. The routing protocol has to such that the failure of the particular node does not affect the operation of the network.

- *Scalability*

After the initial formation of clusters, the CH should be able to adapt to either increase or decrease in its cluster member's count. The member count of a cluster may change due to various factors. For example a cluster member may fail due to environmental threat. During this time the CH should adapt t a decrease in its member count. On the flip side, increase in the member count may also happen during circumstances like addition of new sensor nodes, failure of an existing CH etc. Similarly the sensor network itself should be capable of adapting to either increase or decrease in the number of clusters.

- *Energy Consumption*

Since the life-time of the WSN depends on energy resources and their consumption by sensors, the energy consideration has a great influence on route design. The power consumed during transmission is the greatest portion of energy consumption of any node. Direct communication consumes more power than multi-hop communication; however the multi-hop communication introduces extra topology management and medium access control. Replacement of the power resources is not possible in some applications hence energy consumption become important as the sensor node lifetime depends on battery lifetime. Death of sensor node results in changes in network topology and re routing of the path.

- *Node deployment:*

Node development can be done through two ways: deterministic or randomized. In deterministic deployment, the sensors are manually placed and data is routed through predetermined paths and in random node deployment, the sensor nodes are scattered randomly. The route determination in the random developed network is a challenging issue. Node deployment in WSNs is application dependent. Depending upon the resultant nodes distribution, optimal clustering protocols is required to allow connectivity and energy efficient network operation.

- *Data Delivery Models:*

There are three type of data delivery model: continuous, event-driven, query-driven, or hybrid. Data delivery models are application dependent. In continuous data deliver model, there is a periodically delivery of sense data by each sensor. When the transmission of data began only on the occurrence of some event or query generated by sink, such type of model is called event-driven and query driven data delivery models. Continuous, event driven and query-driven data delivery models combined together makes the hybrid data delivery model.

- *Data Aggregation*

The amount of energy consumed in communication is very high than the energy consumed in sensing, hence to save energy the data is aggregated before sending it to base station. Aggregation is required to reduce the size of the data to be transmitted by aggregating the similar packets from the sensor nodes.

- *Network Dynamics*

Most of the network architectures assume that sensor nodes are stationary. However, mobility of both BS's or sensor nodes is sometimes necessary in many applications. Routing messages from or to moving nodes is more challenging since route stability becomes an important issue, in addition to energy, bandwidth etc. Moreover, the sensed phenomenon can be either dynamic or static depending on the application, e.g., it is dynamic in a target detection/tracking application, while it is static in forest monitoring for early fire prevention.

B. Applications of Wireless Sensor Network

Applications of wireless sensor networks are almost limitless. They are finding their way into numerous applications in military target tracking and surveillance, natural disaster relief, biomedical health monitoring, and hazardous environment exploration and seismic sensing. Some of the applications of wireless sensor network are given below.

- *Military Applications*

  Some of the characteristics of sensor networks like self-organization and fault tolerance of make them a very promising sensing technique for military applications. Military applications in which sensor networks are used includes monitoring friendly forces, equipment and ammunition; battlefield surveillance; reconnaissance of opposing forces and terrain; targeting; battle damage assessment and nuclear, biological and chemical (NBC) attack detection and reconnaissance.

- *Environmental Applications*

  Environmental applications of sensor network include forest fire detection, bio-complexity mapping of environment, flood detection, precision agriculture and air and water pollution.

- *Health Applications*

  Sensor networks provide tele-monitoring of human physiological data in which sensor nodes monitor humans' behavior and collected physiology data is stored and used for medical exploration. Other than tele-monitoring the sensor networks are used in drug administration in hospitals and tracking and monitoring doctors and patients inside a hospital.

For effective routing in WSN different routing protocols have been proposed. Cluster based routing is one of the most famous routing protocol in which the sensor nodes organized themselves into small clusters followed by the cluster head selection. Sensor nodes sense the required parameters and forward it to the cluster head that is responsible for the collection of sensed data from its cluster member and send it to the base station after aggregation to reduce the amount of redundant data.

Many existing clustering schemes consider homogeneous WSNs in which all sensor nodes are designed with the same battery energy. On the other hand, in a heterogeneous WSN, two or more different types of sensor nodes with different battery energy are used. The energy saving schemes developed for homogeneous WSNs do not perform efficiently when applied to heterogeneous WSNs. Therefore new energy efficient clustering protocols should be designed for the characteristic of heterogeneous WSNs. Putting a few more powerful sensor nodes can improve the network lifetime and stability with marginal increase in the cost of network deployment [11]. Due to the above mentioned reasons the heterogeneous WSN are becoming very important and are used in wide variety of applications hence the research in this area is highly desirable.

Recently, heterogeneous networks received more attention by researchers than homogeneous networks, because if we look into the real world applications viz., habitat target tracking, monitoring, and disaster relief and so on, heterogeneous WSNs are a better option than homogeneous WSNs. An example application of our study is a WSN that is being deployed in a battlefield because in a battlefield, sensor nodes need to be equipped with different energy resources to perform multiple tasks [11].

II. Literature Review

Farouk et al. [1] proposed a multi level stable and energy–efficient clustering protocol in heterogeneous wireless sensor networks. In SEEC the static clustering is used that is the number of clusters and cluster heads formed in the first round are not changed for the entire lifetime of the network. SEEC is two-level heterogeneous network consist of two type of nodes advance node and normal node. Only Advance nodes can became the cluster heads and they are placed at the predefined distance and angle with respect to the base station. Normal nodes are distributed into the clusters based on the shortest distance from cluster heads and there should be no normal nodes between advance nodes and base station. Normal nodes sense the data and forward it to the associated cluster head and cluster head after aggregating the sensed information transmit it to the base station. In this paper the mathematical model for optimal number of advanced nodes has been presented. In proposed work the stability of the SEEC is two times more than the stability of the LEACH. This work can be extended by the addition of mobile nodes between advanced nodes and base station and using the concept of hybrid clustering.

Malluh et al. [2] introduced An Efficient Modified Stable Election Protocol (EM-SEP). EM-SEP is the modification of SEP protocol proposed to improve the stability period of SEP and reduce the communication overhead. EM-SEP aims to maintain the well balanced energy consumption and thus increasing the stability period of SEP by choosing the advance nodes to become CH more often than the normal nodes as the SEP protocol does. In this protocol the nodes are evenly distributed between the selected cluster heads by taking into consideration the number of nodes that are associated with the each cluster heads. The stability of EM-SEP is 5% more than the SEP. EM-SEP chooses the sensor node with the highest energy to become the cluster head if there are more than one sensor nodes available to be the cluster head at certain round.

Verma et al. [3] proposed a Energy Efficient Zone Divided And Energy Balanced Clustering Routing Protocol (EEZECR). In EEZECR protocol there are double cluster head in a cluster which results in reducing the load on the cluster head and hence makes this protocol suitable for the real time applications. Two cluster heads used are - Assistant Cluster Head (ACH) and Main Cluster Head (MCH). ACH residual energy is less than the MCH and its function is to collect the data from all nodes in the cluster, removes the redundant data and forwards it to the MCH. This results in reducing the load on the MCH. The MCH forward the data to the adjacent MCH which is near to the base station to make multi hop transmission more energy efficient. In this protocol, network is divided into different zones according to the distance between the nodes and the base station and each node gets a zone number to specify to which zone the node belongs. Zone number is decided on the basis of distance from base station larger the zone number farther the zone is from the base station. Minimum zone number is 1. EEZECR balance the load in the network better than ZECR and have longer network lifetime too.

Anitha et al. [4] proposed Enhanced Cluster Based Routing Protocol (ECBR) which is an enhanced algorithm for LEACH-M protocol. In this protocol base station selects the new CHs after certain period of time based on the parameters of highest residual energy, lowest Mobility and least Distance from the Base Station. ECBR is a reactive protocol and it consists of five phases: Initialization Phase, Cluster Formation Phase, Cluster Head Selection Phase, Data transmission Phase and Re-Routing Phase. In the Initialization phase, the nodes send hello message which is consists of Node Id, Destination Id, Residual Energy, Mobility factor and Distance to the base station to base station in a single hop. The next phase is cluster formation phase in which clusters formation is done on the basis of Density based spatial clustering of applications with noise algorithm. In Cluster Head Selection Phase the cluster heads are chosen by the base station depending upon the residual energy, mobility and the distance to the base station. The transmission of data between CHs and Base station occur through multi-hops. Reclustering occurs after each round and new routes are determined in the same way as earlier in data transmission phase.

Rehman et al. [5] proposed a Energy Consumption Rate based Stable Election Protocol for WSNs (ECRSEP). ECRSEP is introduced for the two level heterogeneous wireless sensor network containing advance and normal nodes. In ECRSEP, CH selection is based on energy consumption rate (ECR) which depends on residual energy and initial energy of the node. Nodes with low ECR is chosen as the CH. CH selection of the current round will be based on the ECR in previous round. Node selected as a CH in previous round will not became the CH for the next round as its ECR is high compared to the other non CHs

Khan et al. [6] investigated a Heterogeneity-aware Hierarchical Stable Election Protocol for WSNs (HSEP). HSEP is proposed to reduce the transmission energy between the CH and base station by reducing the distance between them. The reduction in distance is important because as the distance increases, it increases the transmission energy. As energy required in transmission is higher than the energy required in sensing and reducing transmission energy will prolong the network lifetime. In HSEP there are two types of CHs: primary CHS and secondary CHs. Only primary CHs can take part in the secondary CHs selection. Primary CHs are selected on the basis of threshold; advance nodes have the higher chances to become primary CHs. For secondary CHs selection the primary CHs check the distance between each other's and send data to only CHs which are at minimum distance, these minimum distance CHs are consider as secondary CHs. Data is transmitted from nodes to the primary CHs which perform aggregation function and then forward the data to secondary CHs. Secondary CHs send data to base station.

Kashaf et al. [7] proposed a Threshold-sensitive Stable Election Protocol for WSNs (TSEP). TSEP is a reactive protocol in which data transmission is done only when certain threshold is reached. TSEP is the three level of heterogeneous protocol consists of normal nodes, intermediate nodes and advance nodes. In TSEP at cluster change time, the following parameters are broadcast by the CH:

- Report Time (TR): Time period during which reports are being sent by each node successively
- Attributes (A): The physical parameters about which information is being sent.
- Hard Threshold (HT): An absolute value of sensed attribute beyond which node will transmit data to CH.As if sensed value becomes equal to or greater than this threshold value, node turns on its transmitter and sends that information to CH.
- Soft Threshold (ST): The smallest sensed value at which the nodes switch on their transmitters and transmit.

Data transmission is based on the soft and hard threshold. For the first time transmission the sensor node will transmit the data to CH only when hard threshold is reached and this sensed value is stored in sensed value(SV). For the rest of the time, data is transmitted only if the sensed value is greater than hard threshold or the difference between the current sensed value and stored sense value is equal or greater than the soft threshold.

Karim et al.[9] introduced a Energy Efficient and Fault Tolerant Routing Protocol for Mobile Sensor Network(FTCP-MWSN). The working of FTCP-MSWN is divided into three phases: cluster formation and cluster head selection, steady phase and nodes mobility determination. In FTCP-MWSN the CH selection is based on mobility factor which is defined as the ratio of the number of times a node enters different clusters to the number of times a node changes position within the cluster. If the node residual energy is above the threshold value and its mobility factor is lowest in a cluster then that node is selected as a CH. The node will have least mobility factor if it enter the other cluster least number of times. In the steady phase, CHs assign timeslots to the member in whom nodes transmit data, receive acknowledgements from the CH, and count their movements inside and outside of the cluster. If a node is alive or is in the communication range of CH, node keep on sending the special packet to CH incase node does not have a sensed data of interest. CH responds to the special packet by sending the ACK packet. Node moves out of the cluster if CH does not receive the special packet or data. If node does not receive the ACK packet than node assumes that it is no longer attached to the CH and broadcast a JOIN-REQUEST packet. In response to JOIN-REQUEST, CH which is having the free timeslots and who is within the communication range sends the ACK-JOIN packet. Node joins the cluster from where it receives the ACK-JOIN packet with highest signal strength.

Zou et al. [10] proposed a zone-divided and energy-balanced clustering routing protocol for wireless sensor networks (ZECR). ZECR protocol is based on LEACH and EECU protocol. In ZECR the network is divided into the zones Cluster head selection in ZECR is based on average energy of the node around the small region and residual energy of the node and it is selected in each zone independently. ZECR removes the energy hole problem of the EECU protocol by considering the distance, average energy and residual energy for choosing the next hop in inter-cluster routing phase. Each node gets a node number which depends upon their distance from base station. The farther the zone is from the base station, the larger is the zone number and the minimum allowed zone number is 1. The principle of choosing the next hop in ZECR should be such that the average energy of cluster that is located for the next hop is high and the energy of next hop as CH is high.

Elbhiri et al. [11] proposed Developed Distributed Energy-Efficient Clustering (DDEEC) for heterogeneous wireless sensor networks. DDEEC uses the concept of residual energy for the selection of CHs. Nodes having more residual energy have high chances to become CHs than the nodes having low residual energy this ensure that advance nodes will become CHs more often than normal nodes. DDEEC introduced a threshold residual energy concept to make sure that the advanced node does not become CHs over and again when their residual energy became equal to that of normal node after some rounds. Threshold residual energy is define as

$$Th_{REV} = E_o\left(1 + \frac{aE_{disNN}}{E_{disNN} - E_{disAN}}\right)$$

Advanced and normal nodes use same probability to become CH when their energy level became equal or lower than the threshold residual energy. The probability of advanced and normal nodes to became a CHs is defined as

$$p_i = \begin{cases} \dfrac{p_{opt} E_i(r)}{(1+am)\bar{E}(r)} & \text{for Normal nodes, } E_i(r) > Th_{REV} \\[2ex] \dfrac{(1+a) p_{opt} E_i(r)}{(1+am)\bar{E}(r)} & \text{for Advanced nodes, } E_i(r) > Th_{REV} \\[2ex] c\dfrac{(1+a) p_{opt} E_i(r)}{(1+am)\bar{E}(r)} & \text{for Advanced and normal nodes, } E_i(r) \le Th_{REV} \end{cases}$$

DDEEC is better than DEEC with 15% in term of First Node Died and 30% better than SEP in terms of network lifetime.

Saini et al. [12] investigated a Energy Efficient Scheme for Clustering Protocol Prolonging the Lifetime of Heterogeneous Wireless Sensor Networks (TDEEC). TDEEC is an extension of DEEC protocol and uses the same concept of CH selection and average energy estimation as defined in DEEC. Nodes choose a random number between 0 and 1 at each round, if the number is less than the threshold (Ts) then that nodes became the CH for a given round. Threshold value (Ts) is defined as

$$T(s) = \left\{ \frac{p}{1 - p\left(r \bmod \frac{1}{p}\right)} * \frac{\text{residual energy of a node} * k_{opt}}{\text{average energy of the network}} \right.$$

Threshold value is modified, based on the ratio of residual energy and average energy of that round in respect to the optimum number of cluster heads. This threshold value ensures that the node with high energy will become CH.

Heinzelman et al. [11] proposed an application-specific low energy adaptive clustering hierarchical protocol (LEACH). LEACH is the first hierarchical clustering routing protocol in which node organized them into the cluster and select one node as cluster head in each formed cluster. The function of the cluster head is to collect data from their member ode and aggregates it to reduce redundant data and then forward the information to the base station. LEACH balance the energy load of the network by selecting the new CHs in each round by giving the equal chances to all nodes to became a CH. The data transmission from node to CHs is done in the given timeslot allocated by the CHs to each node. The node transmitters are on only when to send the data and remains off during non transmission this helps in energy saving. LEACH operation is divided into two phases: Set- up phase and Steady state phase. In the setup phase, the nodes group themselves into clusters and select one node as the cluster head where as in steady state phase data transmission takes place.

Table I shows the results of different protocols are on the basis of First Node Dead (FND) and Last Node Death (LND). Through results it is clear that SEEC outperform other protocols in terms of stability and energy efficiency.

TABLE I
COMPARISON OF ROUTING PROTOCOLS

Protocol	Rounds of FND	Rounds of LND
SEEC	1626	7824
DDEEC	1470	6180
DEEC	1117	5588
DEC	1134	1170
SEP	891	6010
LEACH	853	4632

III. CONCLUSION

In this paper, a detailed review on various clustering protocols for wireless sensor network has been provided with the consideration of energy as an important issue. Designing energy efficient protocol is very important. Due to the scarce energy resources of sensors, energy efficiency is one of the main challenges in the design of protocols for WSNs. Many clustering protocols for maximizing the lifetime of WSNs has been presented in this work and it can be concluded that introducing the heterogeneity in WSNs results in prolongation of the lifetime of sensor network. As per Table I SEEC outperform very well as compared to other existing clustering protocols. This can be also visualized in Fig.3. As per section II SEEC is based on static clustering so the future scope of this work can be the hybridization of static and dynamic clustering in single

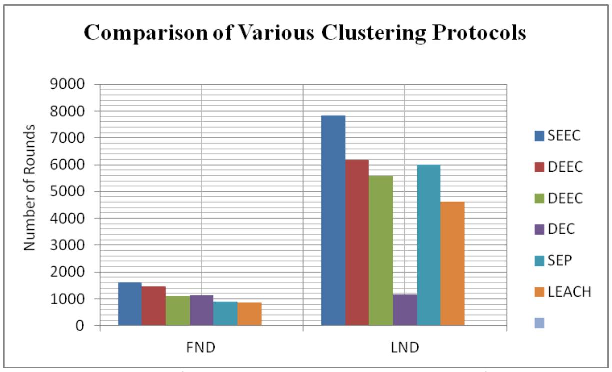

Fig. 3. Comparison of clustering protocols on the basis of FND and LND

protocol with the inclusion of mobile sensor node which also improves the stability period of the network.

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