International Journal of Computing Academic Research (IJCAR)
ISSN 2305-9184, Volume 5, Number 5 (October 2016), pp.259-270

http://www.meacse.org/ijcar

Insight on Clustering based Energy Efficient Routing Protocols in WSN

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Abstract

Wireless Sensor Networks are constrained due to limited energy possessed by them. Thus prolonged use of these networks depends on optimal utilization of this energy. Energy spent in sending or receiving data needs to be minimized and for that routing protocols used must be improved. This work aims to explore various energy aware routing protocols available for these networks. Further, comparison of existing protocols has also been performed for better understanding.

Keywords: Wireless sensor networks, energy efficient routing protocols, clustering based routing protocols, routing protocols.

1. Introduction

Wireless Sensor Network consists of small sized sensor nodes with sensing, processing and communicating capability. These sensor nodes are battery operated and their battery level reduces with passage of time. But it is very difficult to recharge or replace these batteries. Sensor nodes are generally deployed in geographical areas inaccessible to human beings, thus they are useful for critical applications like mining of crude oil, military applications like battlefield surveillance, industrial process control and environmental monitoring [28]. Initially WSN were used for military applications but nowadays they are widely deployed for civilian applications like habitat monitoring, health care, home automation, traffic controls and environment monitoring. The WSNs came in limelight and gained popularity in beginning of twenty first century [27, 29]. Although WSNs are useful in hostile environments but their limited storage capacity and limited energy leads to numerous challenges [1] in their use. Since sensors become dead once their battery runs out, therefore extensive research is going on in WSNs to improve their design and deployment styles to help improve their life time and thus their utilization period.

A large sized WSN consist of thousands of low cost sensing nodes having limited power and limited computational ability to perform different type of functions depending on their environment. These small sized sensors are equipped with microprocessors, radio receivers and power components for enabling sensing, computation and communication tasks [13,24]. All these components are integrated to form a circuit on a single board. These integrated sensors can collect different types of information about their environment under different working modes such as continuous or event driven. Location information is obtained using local positioning algorithms and global positioning system (GPS). Information is collected throughout the network and is sent across the network for aggregation and processing at the base station which results in global monitoring of some object or phenomena. Every node in WSN has its own capability in terms of battery life for communication in the network.

Wireless channels are used by WSN [48] for communication over small distances for cooperative information processing. For applications such as habitat monitoring, military surveillance and for rescue and search operations, sensor nodes are densely spread in the environment. After deployment these sensor nodes organize themselves into infrastructure less network having multi hop connections among themselves.

In typical WSN architecture, query processing is used for information retrieval between user and the network. The basic goal of a WSN is to supply raw native information obtained (sensed data) by individual sensing mode to the base station, by prolonging the life time of WSN. The restricted power of sensing nodes mandates the use of energy-efficient communication protocols. However, routing in sensor networks is incredibly difficult because of many characteristics that distinguish them from contemporary communication and wireless ad-hoc networks [25, 30].

As sensor nodes are tightly constrained in terms of transmission power, on-board energy, process capability and storage, thus careful resource management is desired. Researchers have devised several protocols for communication and security in wireless sensor networks, mobile ad-hoc networks and traditional networks [15, 17]. Lot of research has been done for prolonging network life time using energy efficient routing protocols in WSN that includes tasks of data aggregation and filtering also [2, 3]. Clustering has been indicated as a useful technique for conserving energy in WSNs [20,21].

This paper focuses on exploring clustering based energy efficient routing protocols for wireless sensor networks and presents a comparison among many such existing algorithms. The paper is organized as follows: Section 2 represent energy-efficient clustering in WSN. Sections 3 elaborates clustering based energy-efficient routing protocols. Comparison of clustering based energy efficient protocols is represented in Section 4. Finally, Section 5 concludes this work.

2. Energy-Efficient Clustering in WSN

Traditional routing protocols mentioned in literature are not suitable for wireless sensor networks. For energy efficient routing forming clusters of sensing nodes is the key solution [7,38]. Clustering is used to minimize the energy consumption level of all nodes by aggregating information along the selected path along with load balancing among the nodes for prolonging the network life time. In clustered protocol nodes are arranged in layered structure of sensor nodes [36]. Each cluster has one header node that is called cluster head; cluster head is responsible for data transmission in its own cluster. All the nodes within the network will only communicate to its cluster head that is also called local coordinator for inter and intra cluster transmission and data aggregation. Sensor will send their sensed data to their cluster head, because there will be lesser distance between the cluster head and member nodes as compares to their distance from base station [8]. So it becomes beneficial in terms of lesser traffic rate at low bandwidth range in network. A kind of agreement is made between cluster head and sensor nodes about the sequence in which sensing nodes will transmit their sensed data to cluster head, so that not all the nodes start sending their data to cluster head simultaneously.

Clustering specify the local routing information within the cluster and reducing the routing overhead of each node as shown in figure 1. Clustering of sensor nodes gives compact presentation to the network. But data aggregated within a cluster might have redundant information with consumes network bandwidth. Sensor nodes consumes energy with different rates during inter and intra cluster communication that reduces the interference and collision in network. However, foremost issue is the cluster formation. Energy consumption level of CH is much higher than other member nodes. Therefore it becomes mandatory to repeat the cluster formation process periodically so as to divide the load uniformly among various participating nodes. Figure 1 given below indicates a clustered network.

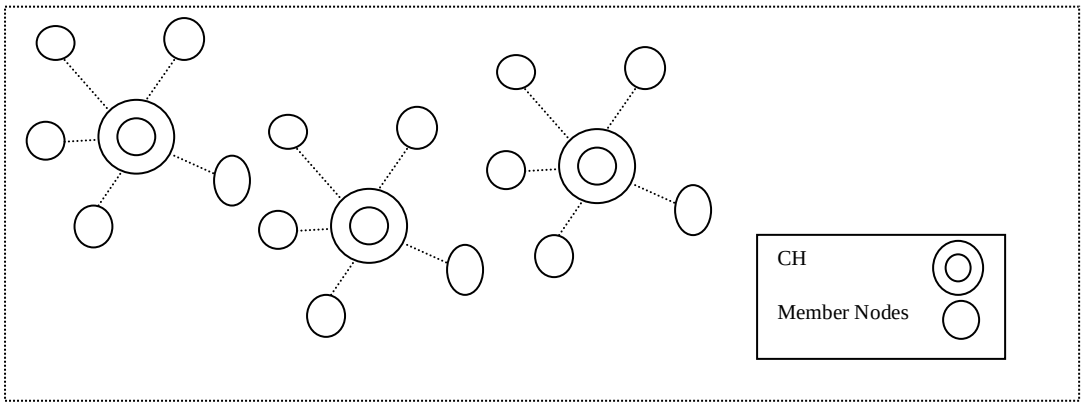

Figure 1 Clustered Wireless Sensor Network

2.1 Hierarchical Clustering Model

In hierarchical clustering model network is divided in the form clustered layers [37]. Sensor nodes at each layer are organized in the form of clusters and cluster head of one cluster is responsible for forwarding the data to its nearby cluster or to the cluster at higher level or to base station. Data moves from lower level to higher level. In hierarchical clustered arrangement, aggregated data by cluster is forwarded to cluster head at higher level [10]. In this type of arrangement data travels long distance with reduced travelling time as compare to traditional multi hop model. As data moves at faster rate as compare to multi hop model so latency is reduced [12]. Therefore cluster based model is highly suitable for critical time based applications. Besides these benefits of faster data travelling rate and low latency level, the energy consumption rate is high (twice to square of distance) during movement from one level to next higher level. However this model offers optimal routing for sensor networks.

3. Cluster-based Energy-Efficient Routing Protocol in Sensor Networks

Cluster based approach in traditional ad hoc networks don't work efficiently as is desired in sensor networks due to their unique features [4,6,9]. Unique distinguishing features of sensor networks are:

- In sensor networks number of sensor nodes is quite high but they have limited battery life, storage capacity and computational capacity.
- Sensor nodes are more prone to failure.
- Nodes are densely deployed in sensor networks.
- There is rapid change in topology of sensor nodes as their state changes frequently.
- Due to bulk deployment of sensor nodes their global identification is not a simple task.

Multi hop communication is possible in sensor networks due to their dense deployment [31, 32, 33, 34]. In sensor networks transmission power level could be reduced to a lower value with the help of clustering. As discussed already that in clustered WSNs, member nodes in a cluster communicate directly with their CH, which in turn transmits the collected data to the base station using multi-hop approach. A cluster is considered m hop, if all sensor nodes are on same path with length < m hopes [35]. To determine the optimal value of m for minimizing the energy consumption level of sensor networks, a mechanism has been developed which consider data packet size, allowable latency level, transmission frequency, database maintenance and computational processes [43]. Clustering is not only used for aggregation of sensed data; it also minimizes the energy consumption level within each cluster and results in reduction of channel traffic.

4. Energy-Efficient Hierarchical Clustering (EEHC) Algorithms

In EEHC algorithms, cluster head is elected periodically for balancing the energy consumption level of CHs. Many researchers have proposed various mechanisms for hierarchical clustering [39,42]. Thus, the EEHC algorithm is executed periodically for load balancing or it is triggered as the energy level of the CH falls

below a certain threshold. Many research projects in the last few years have explored hierarchical clustering in WSN from different perspectives [11]. A variety of protocols have been proposed for prolonging the life of WSN [50] and for routing the correct data to the base station. Each protocol has advantages and disadvantages. Battery power of individual sensor nodes being a precious resource remains the point of focus of these protocols [4, 5]. Some of the hierarchical protocols are LEACH, PEGASIS, TEEN, and APTEEN. All these protocols are discussed in detail one by one.

4.1 Low Energy Adaptive Clustering Hierarchy (LEACH): LEACH is one of the most prominent energy efficient clustering based routing protocol [3,7] for sensor networks. This protocol reduces energy consumption of sensor nodes by making rotation of cluster head among the sensor nodes. Each cluster head sends the data to base station depending on the type of application. This protocol uses aggregation approach for collecting the sensed data in packet form. Here the network is divided in the form of clusters, where clusters are formed on the basis of coordination and distance among the nodes, so as to reduce the communication overhead. This clustering approach also helps in scalable and robust routing. Energy consumption rate of sensor nodes depends upon data size and distance that have to be traversed by sensor node.

This protocol transmits the data over short distance thereby reducing the numbers of transmission and receiving operations. LEACH protocol focuses on rotation of cluster head, reducing the data size for long range communication (as small sized data can travel to long distance), coordination among sensor nodes for cluster formation and communication. Communication through LEACH comprises of various rounds where each round comprises of two phases: setup phase and steady phase. In set up phase nodes are arranged in the form of clusters, CH is elected and transmission schedule is maintained whereas in steady phase data aggregation, compressions and transmission of data to sink node is performed. CSMA-MAC protocol is being used by cluster heads to advertise their status. Cluster participants don't initiate communication with CH during setup phase. Probabilistic function is used for election of next CH. Once CH has been elected communication between CH and member nodes may start. TDMA (Time Division Multiple Access) scheme is being deployed for communication among CH and member nodes. Cluster based communication approach of LEACH protocol offers lower energy consumption rate as compare to direct communication. Dynamic cluster head selection of CH prolong the network lifetime.

4.2 LEACH-Centralized (LEACH-C): This is an improved version of LEACH protocol discussed above. Here clustering process has been Centralized that's why its name LEACH-C. In this approach each nodes sends information about its current location and current energy level to base station. Base station takes the decision about the cluster head. Base station uses global information for election of cluster head that

consumes less amount of energy for communication. In each round optimal numbers of cluster heads are being elected which is an improvement over traditional LEACH protocol.

4.3 Enhanced Low-Energy Adaptive Clustering Hierarchy (ELEACH): Enhanced LEACH protocol proposed by [7] is the improved version of traditional LEACH protocol with two more aspects. This version of LEACE elects node having non uniform energy consumption as the cluster head. Cluster head election algorithm proposed here will elect the cluster head to the node have non uniform energy consumption level among the sensor nodes. This algorithm assumes to have global information about the remaining energy level of all sensor nodes. This process is further optimized by constraining the number of cluster heads to be elected; here number of cluster heads to be elected will be square root of total number of sensor nodes in the network so as to reduce the energy consumption level of sensor nodes.

4.4 LEACH with Fixed Cluster (LEACH-F): LEACH-F protocol is an extension of traditional LEACH protocol with fixed number of cluster heads [42]. Cluster head is selected once but its position gets rotated with in the cluster. The major advantage of this approach is that setup phase is not required to be executed repeatedly in the beginning of each round. Cluster head selection done in similar way to that of centralized clustering algorithm. Fixed clustering approach in LEACH-F protocol doesn't allow new nodes to enter in the network and entrance of new nodes needs to get adjusted as per the dying nodes.

4.5 Multi-hop LEACH (M-LEACH): Modified LEACH (M-LEACH) increases the energy efficiency further by using multi-hop communication [39]. The concept of gateways is being introduced in the communication within cluster or outside the cluster [40]. Multi-hop communication approach proposed here reduces the overheads of long distance communication between cluster heads and sink; however this approach is being used by sensor nodes within the clusters as well as by cluster heads outside the cluster for communicating with sink. Data fusion process accomplished by CHs, reducing the amount of data transmitted in the network.

4.6 Power-Efficient Gathering in Sensor Information Systems (PEGASIS): It is another extension of LEACH protocol, where instead of multiple clusters chain of sensor nodes are formed so that node can only transfer data to its neighbor and one node is being selected for transmitting the data to base station [14]. Data is collected node by node and finally the aggregated data is sent to base station. The major difference between LEACH and PEGASIS is that there is no clustering concept and nodes are sending their data to their adjacent neighbor in place of cluster heads. This protocol assumes to have prior information about network specifically the position of nodes. The chain of nodes is based on greedy approach and it starts with most distant node to the closest node of sink. If any node dies in between due to lack of energy, it will move

out from chain and new chain is formed using greedy approach. This protocol reduces the communication overhead and prolongs the network lifetime as compare to LEACH protocol. PEGASIS is an optimal chain based algorithm because it supports only the local communication [41]. This protocol offers few advantages like increases the lifetime of network using shared technique and allows only the local coordination among the sensor nodes. But this protocol has few limitations like it assumes that all nodes should have similar energy draining level and should die at the same time. Location identification of sensor nodes is again a challenging issue here.

4.7 Hybrid, Energy-Efficient Distributed Clustering (HEED): It is an extended scheme of LEACH protocol based on residual energy of sensor nodes and counts the node degree for election of cluster heads [25,26]. HEED protocol have few major goals like prolonging the network lifetime, producing optimum cluster size, reducing the cluster head re-election iterations so thereby reducing the overhead. Cluster head election is accomplished on the basis of two parameters; residual energy and intra cluster communication cost. Here clustering process takes several rounds to get completed and within this duration a node can receive the message from its neighboring nodes [29].

Distributed energy consumption among sensor nodes extends the life time of the network and offers a stable set of neighbors. CH selection process of HEED offers extended life time as compare to traditional LEACH protocol. The overall communication cost gets reduced, thus this method is suitable for prolonging the network life time, ignoring other aspects of communication in sensor networks.

4.8 Threshold Sensitive Energy Efficient Sensor Network Protocol (TEEN): TEEN protocol comes under the category of hierarchical protocols that supports clustering of nodes [45, 46]. CH is again responsible for transferring the aggregated data to sink node. In this protocol nearby nodes are clubbed as clusters and this process continued till base station is reached. Data centric approach of TEEN protocol improves energy consumption rate (decreases), accuracy of data sent and response time of network [44]. A threshold parameter is being decided to make the transmission on or off. These threshold parameters are categorized as hard and soft threshold, each node senses this threshold value if this value reaches up to hard level it gets on its transmitter and start sending and receiving data.

This protocol is suitable for critical time based applications. However transmission of data takes long time as compare to sensing, so its energy consumption level is less as compared to proactive network.

4.9 Adaptive Threshold Sensitive Energy Efficient Sensor Network Protocol (APTEEN): An improved version of TEEN protocol proposed by that overcomes the shortcomings of TEEN protocol [46]. APTEEN uses hybrid clustering approach where data is collected periodically and cluster head reacts in case any change is observed in sensed data. Along with hard and soft threshold values APTEEN uses TDMA schedule for transmission. This protocol handles different scenario like analysis of old data, current view of

network and regular monitoring of the network. Though APTEEN claims prolonged network life time with high rate of live nodes, but simulation reflects that its performance lies between LEACH and TEEN. The reason behind the less popularity of these approaches is increased complexity of cluster formation process.

4.10 Improved Cluster Head Election algorithm for MWSNs: Gupta et al proposed an improved cluster head election algorithm suitable for mobile wireless sensor networks [47]. All above algorithms discussed above are suitable for static sensor networks, thus they are not suitable for MWSNs where nodes keep on moving and cluster head may move away from the cluster anytime leaving the cluster unattended. This algorithm presented technique of detecting absence of cluster head and its reelection. This technique re-elects a node having highest remaining energy as the next cluster head. This algorithm reduces energy consumption by deploying intelligent mobile agents in sensor nodes [18,19,22].

4.11 Optimal Cluster Head Election Algorithm for MWSNs: This is an improved version of algorithm mentioned above (no 4.10), it focuses on devising a technique through which existing cluster head will elect next CH before leaving its cluster and will hand over the charge of cluster to it [48]. For this purpose, mobile CH proactively calculates the remaining energy of participating nodes and their remaining time of stay in the cluster, when it has to move away from its cluster [23]. The idea is to elect the node having maximum remaining energy along with maximum remaining time of stay in the cluster as the next cluster head. Table 1 given below presents comparison of above discussed protocols based on their data collection, energy consumption rate and cluster reelection style.

Table 1. Comparison of Energy Aware Routing Protocols

Protocol	Data Collection	Energy Consumption Rate	Cluster Reelection
PEGASIS	Chain of nodes	Low	Chain of Nodes
EECH	Periodic	Very High	Yes
LEACH	TDMA	Low	Yes
TEEN	Hierarchical Data Centric	Average	Threshold value
Flooding	Data Centric	High	No cluster formation
Improved CH election for MWSN	Periodic	Low	When CH moves away leaving cluster unattended
OCHE for MWSNs	Periodic	Low	Proactive, existing CH elects new CH and hands over charge of cluster to it.

5. Conclusion and Future Scope

Due to scarcity of energy in sensors, energy efficiency is one the most important challenge focused by routing protocols for WSNs. The final objective of these protocols is to keep the sensors operational as long as possible, thereby increasing the network lifetime. This paper focuses on analyzing existing energy efficient routing protocols for sensor networks, both for static and mobile sensor networks. Literature highlighted that clustering is the advanced technique used for energy conservation in sensor networks, thus algorithms deploying clustering are focused specifically. This work tried to elaborate advantages and drawbacks of all discussed algorithm for their better understandability. However, in clustered sensor networks, information collected at the base station need to be aggregated and fused to eliminate redundancy, which also consumes energy. Thus techniques supporting efficient data filtering and fusion should also be explored and should be merged with routing protocol to reduce energy consumption even further.

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