Analysis of energy efficiency and lifetime in clustered wireless sensor Network

N R Wankhade
Associate Professor, Department of Computer Engineering, Pune University
Late G N Sapkal College of Engineering, Nashik, India

Abstract— Clustering is one of the most popular approaches used in wireless sensor networks to conserve energy and increase node as well as network lifetime. LEACH is among the most popular clustering protocols proposed for wireless sensor networks. Recent advances in wireless sensor networks have led to many new protocols specifically designed for sensor networks where energy awareness is an essential consideration. These sensor nodes have some constraints due to their limited energy, storage capacity and computing power. There are a number of routing protocols for wireless sensor networks. In this paper, an analysis of network lifetime of the proposed energy efficient hierarchical cluster based routing protocols is carried out in Wireless Sensor Networks.

Keywords- Wireless sensors; protocols; routing; energy efficiency; clustering

1. INTRODUCTION

WSN typically consists of a large number (tens to thousands) of low-cost, low-power,[1][7] and multifunctional sensor nodes that are deployed in a region of interest. These sensor nodes are small in size, but are equipped with embedded microprocessors, radio receivers, and power components to enable sensing, computing, communication, and actuation. These components are integrated on a single or multiple boards, and packaged in a few cubic inches. With state-of-the-art, low-power circuit and networking technologies, a sensor node typically powered by 2 AA batteries can last for up to three years with a 1% low duty cycle working mode.

A WSN communicates over a short distance through wireless channels for information sharing and cooperative processing to accomplish a common task. WSNs can be deployed on a global scale for environmental monitoring and habitat study, over a battlefield for military surveillance and reconnaissance, in emergent environments for search and rescue, in factories for condition based maintenance and process control, in buildings for infrastructure health monitoring, in homes to realize smart homes, or even in bodies for patient monitoring. Figure 1 shows a typical schematic of WSN. The basic philosophy behind WSNs is that, while the capability of each individual sensor node is limited, the aggregate power of the entire network is sufficient for the required mission. In a typical scenario, users can retrieve information of interest from a WSN by injecting queries and gathering results from the so-called base stations (or sink nodes), which behave as an interface between users and the network. In this way, WSNs can be considered as a distributed database.

Thus, the fundamental goal of a WSN is to produce information from raw local data obtained (sensed data) by individual sensor node by prolonging the life time of WSN as much as possible. The resource constrained nature of sensor nodes pose the unique challenges to the design of WSNs for their applications. The limited power of sensor nodes mandates the design of energy-efficient communication protocol.
scheme for the deployment of sheer number of sensor nodes. Therefore, classical IP-based protocols cannot be applied to sensor networks. Second, in contrast to typical communication networks almost all applications of sensor networks require the flow of sensed data from multiple regions (sources) to a particular sink. Third, the generated data traffic has significant redundancy in it since multiple sensors may generate same data within the vicinity of a phenomenon. Such redundancy needs to be exploited by the routing protocols to improve energy and bandwidth utilization. Fourth, sensor nodes are tightly constrained in terms of transmission power, on-board energy, processing capacity and storage. Thus, they require careful resource management. Due to such differences, many new algorithms have been proposed [1],[5] for the routing problem in WSNs. Based on the network structure adopted, routing protocols for WSNs can be classified into flat network routing, hierarchical network routing, and location based network routing. In flat network routing, all nodes have the same functionality and they work together to perform sensing and routing tasks. Hierarchical network routing divides the network into clusters to achieve energy-efficiency and scalability. Naturally, grouping sensor nodes into clusters has been widely adopted by the research community to satisfy the above scalability objective and generally achieve high energy efficiency and prolong network lifetime in large-scale WSN environments. The corresponding hierarchical routing and data gathering protocols imply cluster-based organization of the sensor nodes in order that data fusion and aggregation are possible, thus leading to significant energy savings. In the hierarchical network structure each cluster has a leader, which is also called the cluster head (CH) and usually performs the special Tasks referred above (fusion and aggregation), and several common sensor nodes (SN) as members. Hierarchical clustering in WSNs can greatly contribute to overall system scalability, lifetime, and energy efficiency. One of the famous and attractive hierarchical network routing protocols is low-energy adaptive clustering hierarchy (LEACH), which has been widely accepted for its energy efficiency and simplicity. In location-based network routing, the location information of nodes is used to compute the routing path in the clustering environment, data gathered by the nodes is transmitted to BS through cluster heads (CHs). As the nodes will communicate data over shorter distances in such an environment, the energy spent in the network is likely to be substantially lower compared to when every sensor communicates directly to BS. Most algorithms are heuristic in nature, and aim at generating the minimum number of clusters and minimum transmission distance.

1.1 Routing Protocols in Wireless Sensor Networks

Protocols defined for Ad Hoc Networks are generally not suitable for wireless sensor networks [34],[38]. As aggregate sensor data for any event is more important than individual node data, the communication is more data-centric than address-centric. Energy and bandwidth conservation is the main concern in WSN protocol design since power resources of sensor nodes are very limited as well as computation, communication capabilities. Among the other design factors and challenges for wireless sensor networks’ protocol are robustness to dynamic environment, and scalability to numerous number of sensor nodes. Some recommended solutions to these challenges are as follows: a reduction in the active duty cycle for each sensor node, a minimization of data communications over the wireless channel and maximization of network life time (i.e. minimum energy routing) Scalability, on another hand; may be enhanced by organizing network in a hierarchical manner (e.g., clustering) and utilizing localized algorithms with localized interactions among sensor nodes.

In this paper various energy-efficient hierarchical cluster based routing protocols for wireless sensor network are discussed and compared. The paper is organized in the following way. In Section 2, the energy-efficient clustering structures in WSN are briefly explained. In Sections 3, the energy-efficient cluster-based routing protocols are discussed. In Section 4, various energy-efficient clustering routing protocols are discussed. Finally, concludes the analysis.

2. ENERGY EFFICIENT LUSTERING

A hierarchical protocol is an approach to the balance between scalability and performance. In hierarchical routing, energy consumption of sensor nodes is drastically minimized when the sensor nodes are involved in multi-hop communication in an area of cluster and performing data aggregation and fusion so as to reduce the number of transmitted information to the sink. The clusters formation is based on the energy reserve of sensor nodes and its proximity to the cluster head (Akkaya and Younis, 2005; Lin and Gerla, 1997). In hierarchical routing, data moves from a lower clustered layer to higher region, hopping from one node to another which covers larger distances, hence moving the data faster to the sink faster. Clustering provides inherent optimization capability at the cluster heads. A view of the architecture of hierarchical network
Traditional (or flat) routing protocols for WSN may not be optimal in terms of energy consumption. Clustering can be used as an energy-efficient communication protocol. The objectives of clustering are to minimize the total transmission power aggregated over the nodes in the selected path, and to balance the load among the nodes for prolonging the network lifetime. Clustering is a sample of layered protocols in which a network is composed of several clumps (or clusters) of sensors. As shown in Figure 2, each clump or cluster is managed by a special node or leader, called cluster head (CH), which is responsible for coordinating the data transmission activities of all sensors in its clump. All sensors in a cluster communicate with a cluster head that acts as a local coordinator or sink for performing intra-transmission arrangement and data aggregation. Cluster heads in turn transmit the sensed data to the global sink. The transmission distance over which the sensors send their data to their cluster head is smaller compared to their respective distances to the global sink. Since a network is characterized by its limited wireless channel bandwidth, it would be beneficial if the amount of data transmitted to the sink can be reduced. To achieve this goal, a local collaboration between the sensors in a cluster is required in order to reduce bandwidth demands.

LEACH, TEEN, APTEEN [34][38] are cluster based routing protocols they have similar features and their architectures are to some extent similar. They have fixed infrastructure. The performance of APTEEN lies between TEEN and LEACH with respect to energy consumption and longevity of the network. TEEN only transmits time-critical data, while APTEEN performs periodic data transmissions. In this respect APTEEN is also better than LEACH because APTEEN transmits data based on a threshold value whereas LEACH transmits data continuously.

2.1 Cluster-based Hierarchical Model
As shown in Figure 3, a hierarchical approach breaks the network into clustered layers [35][36]. Nodes are grouped into clusters with a cluster head that has the responsibility of routing from the cluster to the other cluster heads or base stations. Data travel from a lower clustered layer to a higher one. Although, it hops from one node to another, but as it hops from one layer to another it covers larger distances. This moves the data faster to the base station. Theoretically, the latency in such a model is much less than in the multi hop model. Clustering provides inherent optimization capabilities at the cluster heads. In the cluster-based hierarchical model, data is first aggregated in the cluster then sent to a higher-level cluster-head. As it moves from a lower level to a higher one, it travels greater distances, thus reducing the travel time and latency. This model is better than the one hop or multi-hop model.

A cluster-based hierarchy moves the data faster to the base station thus reducing latency than in the multi-hop model. Further, in cluster-based model only cluster-heads perform data aggregation whereas in the multi-hop model every intermediate node performs data aggregation. As a result, the cluster-based model is more suitable for time-critical applications than the multi-hop model. However, it has one drawback, namely, as the distance between clustering level increases, the energy spent is proportional to the square of the distance. This increases energy expenditure. Despite this drawback, the benefits of this model far outweigh its drawback. A cluster-based hierarchical model offers a better approach to routing for WSNs.

2.2 Probabilistic Clustering Approaches
As the need for efficient use of WSNs on large regions increased in the last decade dramatically, more specific clustering protocols were developed to meet the additional requirements (increased network lifetime, reduced and evenly distributed energy consumption, scalability, etc.). The most significant and widely used representatives of these focused on WSN clustering protocols (LEACH, EEHC, and HEED) and their most valuable extensions are presented in the main part of this section. They are all probabilistic in nature and their main objective was to reduce the energy consumption and prolong the network lifetime. Some of them (such as LEACH, EEHC, and their extensions) follow a random approach for CH election (the initially assigned probabilities serve as
the basis for the random election of the CHs), whereas others (like HEED and similar approaches) follow a hybrid probabilistic methodology (secondary criteria are also considered during CH election—i.e., the residual energy).

3. Popular Probabilistic Hierarchical Energy Efficient Clustering Protocols

3.1 Low Energy Adaptive Clustering Hierarchy (LEACH):
LEACH [1][9] is a clustering based protocol that includes the following features:
- Randomized adaptive self-configuring cluster formation.
- Localized control for data transfers.
- Low energy media access and application specific data processing such as data aggregation.

LEACH is organized in rounds, each of which consists of a setup phase and a steady state phase. In the setup phase, each sensor node randomly chooses a number between 0 and 1. If the chosen number is less than the value of the threshold denoted by T(n), the node n declares itself a CH. Where p is the desired percentage of CHs (e.g. 0.05); r represents the number of current round; and G refers to the set of nodes that have not served as the CH in the last \(1/p\) rounds.

\[
T'(n) = \begin{cases} 
\frac{P_n}{1-P_n(r_{mod} \frac{1}{p})} & \text{if } n \in G \\
0 & \text{otherwise}
\end{cases}
\]

Sensor nodes join the CHs that are closest to them based on the signal strength of the CHs, and thus, several clusters may be formed. The CH arranges a TDMA (Time Division Multiple Access) schedule for its cluster members and assigns different time slots to cluster members accordingly. In steady state phase, cluster members transmit the collected data in the allocated time slot, while the CH processes data aggregation before passing the obtained data to the BS via single-hop. The advantages of LEACH include the following: (1) CHs collect data forwarded by cluster members before passing the data to the BS, power consumption decreases; (2) any node that served as a CH in a certain round cannot be selected as the CH again, so each node can equally share the load imposed upon CHs; (3) utilizing a TDMA schedule prevents CHs from unnecessary collisions; and (4) cluster members can open or close communication interfaces in compliance with their allocated time slots to avoid excessive energy dissipation.

3.2 Two-Level Hierarchy LEACH (TL-LEACH)
It is a proposed extension to the LEACH algorithm. It utilizes two levels of cluster heads (primary and secondary) in addition to the other simple sensing nodes. In this algorithm, the primary cluster head in each cluster communicates with the secondaries, and the corresponding secondaries communicate with the nodes in their sub-cluster. Data-fusion can also be performed as in LEACH. In addition, communication within a cluster is still scheduled using TDMA time-slots. The organization of a round will consist of first selecting the primary and secondary cluster heads using the same mechanism as LEACH, with the a priori probability of being elevated to a primary cluster head less than that of a secondary node. Communication of data from source node to sink is achieved in two steps:
1) Secondary nodes collect data from nodes in their respective clusters. Data-fusion can be performed at this level.
2) Primary nodes collect data from their respective secondary clusters. Data-fusion can also be implemented at the primary cluster head level.

The two-level structure of TL-LEACH reduces the amount of nodes that need to transmit to the base station, effectively reducing the total energy usage.

3.3. Energy Efficient Clustering Scheme (EECS) is a clustering algorithm in which cluster head candidates compete for the ability to elevate to cluster head for a given round. This competition involves candidates broadcasting their residual energy to neighboring candidates. If a given node does not find a node with more residual energy, it becomes a cluster head. Cluster formation is different than that of LEACH. LEACH forms clusters based on the minimum distance of nodes to their corresponding cluster head. EECS extends this algorithm by dynamic sizing of clusters based on cluster distance from the base station. The result
is an algorithm that addresses the problem that clusters at a greater range from the base station require more energy for transmission than those that are closer. Ultimately, this improves the distribution of energy throughout the network, resulting in better resource usage and extended network lifetime.

3.4 Hybrid energy-efficient distributed clustering (HEED)
HEED (Younis and Fahmy, 2004) is an extension of LEACH which uses node density and residual energy as a metric for cluster selection so as to balance the network energy. Hybrid Energy-Efficient Distributed Clustering (or HEED) is a multi-hop clustering algorithm for wireless sensor networks, with a focus on efficient clustering by proper selection of cluster heads based on the physical distance between nodes. The main objectives of HEED [38] are to Distribute energy consumption to prolong network lifetime; Minimize energy during the cluster head selection phase; Minimize the control overhead of the network. The most important aspect of HEED is the method of cluster head selection. Cluster heads are determined based on two important parameters: 1) The residual energy of each node is used to probabilistically choose the initial set of cluster heads. This Parameter is commonly used in many other clustering Schemes. 2) Intra-Cluster Communication Cost is used by nodes to determine the cluster to join. This is especially useful if a given node falls within the range of more than one cluster head. In HEED it is important to identify what the range of a node is in terms of its power levels as a given node will have multiple discrete transmission power levels. The power level used by a node for intra-cluster announcements and during clustering is referred to as cluster power level. Low cluster power levels promote an increase in spatial reuse while high cluster power levels are required for inter-cluster communication as they span two or more cluster areas. Therefore, when choosing a cluster, a node will communicate with the cluster head that yields the lowest intra-cluster communication cost. The intra-cluster communication cost is measured using the Average Minimum Reach ability Power (AMRP) measurement. The AMRP is the average of all minimum power levels required for each node within a cluster range R to communicate effectively with the cluster head i. The AMRP of a node i then become a measure of the expected intra-cluster communication energy if this node is elevated to cluster head. Utilizing AMRP as a second parameter in cluster head selection is more efficient then a node selecting the nearest cluster head.

3.5 Threshold sensitive energy efficient sensor network protocol (TEEN)
TEEN (Akkaya and Younis, 2005; Lou, 2005; Manjeshwar and Agrawal, 2002) is a hierarchical protocol [34][38] whose main aim is to respond to sudden changes in the sensed attributes such as temperature. The protocol combines the hierarchical technique in line with a data-centric approach. It then involves the formation of clusters along with cluster leaders which broadcast two thresholds to the nodes; the hard and soft thresholds. Hard threshold have the minimum values of an attribute for sensor node to trigger to power on its transmitter so as to transmit to the cluster head. It is normally not suited in applications where continuous data is needed, since it is threshold dependant.

3.6 Adaptive threshold sensitive energy efficient sensor network protocol (APTEEN)
APTEEN (Manjeshwar and Agrawal, 2002) is an improved version of TEEN, whose main function is not limited to the formation of clusters, but also aim at both capturing periodic data and reacting to time dependant events. In APTEEN, cluster leaders perform aggregation as well as conserve energy. Three queries are supported in the protocol; historical for analysis of past information values, persistent for monitoring of events for some time duration, and one-time for snapshot view of the sensor network. Simulation results show that it outperforms LEACH, having the problem of overhead and complexity in clusters formation in multiple levels, and implementation of the threshold based functions.

4. PERFORMANCE BASED ON NETWORK LIFETIME
When analyzing the performance of the proposed clustering algorithms, there are two major areas that will be examined. Power, Energy and Network Lifetime. Due to the limited energy nature of the sensor nodes, network lifetime is dependent on the efficient use of this energy. The primary comparison measurement when looking at the efficiency of a given algorithm is the network lifetime. • Quality and Reliability of the Links: When comparing clustering algorithms, the quality of the links is an important comparison. Each clustering scheme proposes various recovery mechanisms.

A. Power, Energy and Network Lifetime
1) LEACH: It provides the following key areas of energy savings:
   • No overhead is wasted making the decision of which node becomes cluster head as each node decides independent of other nodes,
   • CDMA allows clusters to operate independently, as each cluster is assigned a different code.
• Each node calculates the minimum transmission energy to communicate with its cluster head and only transmits with that power level. LEACH provides the following improvements over conventional networks:
  • LEACH reduces transmission energy by a factor of 8 versus MTE and direct-transmission.
  • The first death occurs in LEACH 8 times later than that of MTE, direct-transmission and static clustering. In addition the final death of a node occurs more than 3 times later than that of the other listed protocols.

2) TL-LEACH: The energy improvements are achieved from smaller transmission distance for the majority of nodes. This network configuration requires that merely a few nodes transmit large distances. Simulations have shown that the addition of the two-level hierarchical algorithm TL-LEACH results in an improvement of network lifetime by approximately 30% versus its basis algorithm LEACH.

3) PEGASIS: The minimization of energy in this algorithm is achieved from four areas:
  • During a given round, only 1 node in the network is transmitting data to the base station. Since the transmission range to the base station is large, this can result in an improvement with regards to energy savings.
  • Since each node communicates with its nearest neighbor, the energy utilized by each node is also minimized.
  • Each node performs data-fusion, effectively distributing the energy required for this task across the network.
  • The overhead associated with dynamic cluster formation during each round is eliminated. Simulations in C have shown that PEGASIS can result in a 100% to 300% improvement over LEACH for a variety of different network sizes and configurations.

4) EECS: Minimization of energy consumption in EECS is accomplished in a similar manner to that of LEACH, however the algorithm attempts to improve on LEACH. This is accomplished by creating dynamic cluster sizes which are a function of the distance from the base station to the cluster. This addresses the larger transmission power requirements for nodes at a greater range from the base station.

It is the ratio of the total energy consumed in the network at the time the first node dies, to the total initial energy. This measurement is related to the efficient spread of energy in the network. EECS was found to be approximately 93% while LEACH had only of 53% . The EECS protocol has shown a 35% improvement in network lifetime versus the original LEACH in a simulation environment.

5) HEED: In this algorithm, network life time is prolonged through:
  • Reducing the number of nodes that compete for channel access;
  • Cluster head updates, regarding cluster topology; and Routing through an overlay among cluster heads, which has a small network diameter. Comparing HEED to a generic weight-based clustering (GC) protocol such as WCA. When using a GC algorithm, the number of iterations grows quickly as the cluster radius increases, so each node has more neighbors. Implies a node has to wait longer for higher weighted nodes to decide which cluster to join. Therefore, we have more energy consumption. Clustering in GC takes 85 iterations for a cluster radius of 400. Whereas, HEED takes only 6 iterations for all cluster ranges. This means less energy consumption. HEED improves network lifetime over generalized LEACH because generalized LEACH randomly selects cluster heads, thus resulting in a faster death of some nodes. HEED avoids this by well distributing cluster heads across the network.

B. Quality and Reliability of Links

1) LEACH & TL-LEACH: When examining the reliability of both the LEACH and TL-LEACH protocols, we can observe the several key features that have been built into the protocol to improve the reliability of transmission. The CSMA mechanism is used to avoid collisions. CDMA is utilized between clusters to eliminate the interference from neighboring clusters.

2) PEGASIS: It offers promising improvements with relation to network lifetime, however reliability may not be as promising. In PEGASIS, each node communicates with its nearest neighbor. This implementation may be more susceptible to failure due to gaps in the network.

3) EECS: It extends on the capability of LEACH by utilizing dynamic cluster sizing. In terms of recovery mechanisms, EECS offers similar reliability as that of LEACH. However, since EECS offers improved energy utilization throughout the network [21], full connectivity can be achieved for a longer duration. This results in reliable sensing capabilities at the range extremes of a network for a longer period of time.

4) HEED: This algorithm produces balanced clusters compared to GC, where it has a higher percentage of non-single node clusters than GC. HEED also reduces the likelihood that cluster heads are neighbors within the cluster range. This is
because HEED uses intra-cluster communication cost in selecting its clusterheads. Therefore the node distribution does not impact the quality of communication.

5. CONCLUSION
In this paper we have examined the hierarchical cluster based routing protocols, specifically with respect to their power and reliability requirements. Selection of a routing protocol for a wireless sensor network depends on various factors like network lifetime, and stability period. In my work, first I have gone through a comprehensive survey of Energy efficient protocol for clustered routing techniques in wireless sensor networks. We have also examined the current state of proposed clustering protocols, specifically with respect to their power and reliability requirements. In wireless sensor networks, the energy limitations of nodes play a crucial role in designing any protocol for implementation. Protocols presented in this paper offer a promising improvement over conventional clustering; many energy improvements thus far have focused with minimization of energy associated in the cluster head selection process or with generating a desirable distribution of cluster heads. Future perspectives of this survey are focused towards modifying one of the above routing protocols such that the modified protocol could minimize more energy for the entire system.

6. ACKNOWLEDGMENTS
THANKS TO DR. D N CHAUDHARY FOR HELPFUL COMMENTS AND DIRECTIONS THAT REALLY INSPIRE ME TO COMPLETE THIS STUDY.

7. REFERENCES
5. Ahmad Najari Alamuti “SPAR: Shortest Path Adaptive Routing for Wireless Sensor and Actor Networks” Darolfoonoon Private High Educational Institute, Qazvin, Iran.
13. Tao Liu, Qingrui Li, Ping Liang,"An energy-balancing clustering approach for gradient-based routing in wireless sensor networks” Computer Communications 2012
29. Dung Van Dinh1, Minh Duong Vuong2, Hung Phu Nguyen3, Hoa Xuan Nguyen4 “WIRELESS SENSOR ACTOR NETWORKS AND ROUTING PERFORMANCE ANALYSIS”