

A Comparative Study of Hierarchical Routing Protocols in Wireless Sensor Networks

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Abstract – Wireless sensor networks (WSNs) consist of small nodes with sensing, computation and communications capabilities. Due to the limited processing power, and finite power available to each sensor node, regular ad hoc routing techniques cannot be directly applied to sensor networks domain. Thus, energy-efficient routing algorithms suitable to the inherent characteristics of WSNs are required. The hierarchical routing protocols for WSNs are considered energy efficient. Therefore, in the present paper, a comprehensive survey of hierarchical routing protocols for Wireless sensor networks has been presented. Another striking feature of the present exposition is the inclusion of hierarchical routing protocols for linear sensor networks which is an important subclass of wireless sensor networks.

Keywords-Energy Efficiency, Linear Sensor Network, Network Lifetime, Routing Protocols, WSN

I. INTRODUCTION

Wireless Sensor networks are self-organizing networks consisting of different types of sensor nodes capable of communicating wirelessly. Agriculture, battle field and military surveillance, habitat monitoring, security intelligence, health monitoring, warnings about natural disasters like forest fire, industrial process controlling and smart transportation are some of the major applications of Wireless sensor networks[1]. Wireless sensor nodes rely on inherent limited energy resource. These nodes are placed in wireless environment for gathering information. Besides saving power of a sensor node it is also preferable to prolong the lifetime of sensor nodes. The message routing is one of the major problems that need to be solved efficiently in WSNs.

Over the years, a lot of work has been done on the routing protocols in WSNs. Various energy-efficient routing protocols have been proposed, designed and developed for WSNs in order to support efficient data delivery to their destination. Thus, each energy-efficient routing protocol may have specific characteristics depending on the application and network architecture. The routing protocols can be classified as hierarchical and flat as per network structure. The hierarchical routing protocols works by splitting the network into clusters and to efficiently maintain the energy consumption of sensor nodes and perform data aggregation and fusion in order to

decrease the number of transmitted messages to the sink and as a result of that it produce scalable, efficient and effective solutions. Hence, the hierarchical routing protocols are considered to be more energy efficient because of their hierarchical structure. Therefore, in the present exposition, a survey of hierarchical routing protocols in wireless sensor networks has been presented. Recently, a sub class of wireless sensor networks named as linear wireless sensor network has been discussed [2]. In [2], various applications of linear sensor networks have been shown which includes monitoring of oil/gas/water pipelines (above ground and underground), rail road/subway monitoring, monitoring of a/c power lines, river monitoring and border monitoring. Linear sensor network is inherently having hierarchical structure. Therefore, the major routing protocols for linear sensor networks have also been discussed in the present paper.

The rest of the paper is organized as follows. In section II the various performance parameters has been discussed. Section III provides the classification of routing protocol used in wireless less sensor networks. In section IV and V Linear and non linear routing protocol has been discussed respectively, Section VI has been concluded the paper.

II. PERFORMANCE PARAMETERS IN ROUTING PROTOCOLS FOR WSNs

The main design goal of WSNs is to increase the lifetime of the network while continuously transmitting the data. In order to evaluate the performance of the routing protocols there are certain parameters [3] some of them are listed below.

- **Node Deployment:** Node deployment is totally dependent on the application. It affects the performance of routing protocol, and it can be either deterministic or randomized.
- **Energy Consumption:** Energy consumption should be minimum.
- **Scalability:** WSNs routing protocols should be scalable enough to respond to events, e.g. huge increase of sensor nodes, in the environment.
- **Network Dynamics:** Mobility of sensor nodes is necessary in several applications; despite the fact that most of the network architectures assume that sensor nodes are stationary.
- **Fault Tolerance:** In case of any node failure the overall task of the sensor network should not be affected.

- **Connectivity:** The sensor nodes connectivity depends on the random distribution of nodes.
- **Quality of Service:** Data should be delivered within a certain period of time. However, in a good number of applications, conservation of energy, which is directly related to network lifetime, is considered relatively more important than the quality of data sent.
- **Data Aggregation:** Data aggregation is the combination of data from different sources according to a certain aggregation function, e.g. duplicate suppression.

The WSN nodes consist of several modules such as Sensor Module, Processing Module, Wireless Communication Module and Power Supply Module. To make the sensor network operational all these modules work together in a WSN environment. So, in order to evaluate

the energy consumption of a WSN node, the study of the energy consumption of its modules is necessary[4].

Sensor Module: The consumption of energy in sensor module is due to a few numbers of operations i.e. signal sampling, AD conversion (Analogue signal to Digital signal) and signal modulation. The energy consumption is modeled as

$$E_{sensor} = E_{on-off} + E_{off-on} + E_{sensor-run} \quad (1)$$

In this relation the E_{on-off} is the one time energy consumption of closing sensor operation; E_{off-on} is the onetime energy consumption of opening sensor operation and $E_{sensor-run}$ is the energy consumption of sensing operation that is equal to the the working voltage multiplied by the current of sensors and the time interval of sensing operation.

Processing Module: The main function of this module is to control the sensor, the protocol communication and data processing. In most cases three operation states (sleep, idle,

run) are supported by this module. The Processo energy consumption, denoted as E_{cpu} is the sum of the state energy consumption $E_{cpu-state}$ and the state-transition energy consumption $E_{cpu-change}$.

$$E_{cpu} = E_{cpu-state} + E_{cpu-change} \quad (2)$$

Wireless Communication Module The total power consumption for transmitting PT and for receiving PR, is denoted as

$$P_T(d) = P_{TB} + P_{TRF} + P_A(d) = P_{T0} + P_A(d) \quad (3)$$

$$P_R = P_{RB} + P_{RRF} + P_L = P_{R0} \quad (4)$$

Where $P_A(d)$ is the power consumption of the power amplifier which is a function of the transmission ranged d . The $P_A(d)$, will depend on many factors including the specific hardware implementation.

Power Supply Module: The consumption of power in power module of the nodes is depending on the manufacturer and the model of each node.

III. CLASSIFICATION OF ROUTING PROTOCOLS IN WSNs

In [4], the authors have classified the routing protocols based upon network structure, communication model, topology and reliability. However, the linear sensor networks have not been included as a separate sub-class. Therefore, fig. 1 has been adopted to include linear sensor networks as a separate sub-class from the classification provided in [4]. Since, the focus of the paper is on hierarchical routing protocol, only the hierarchical routing protocols for linear as well as non-linear sensor networks have been discussed in following sections.

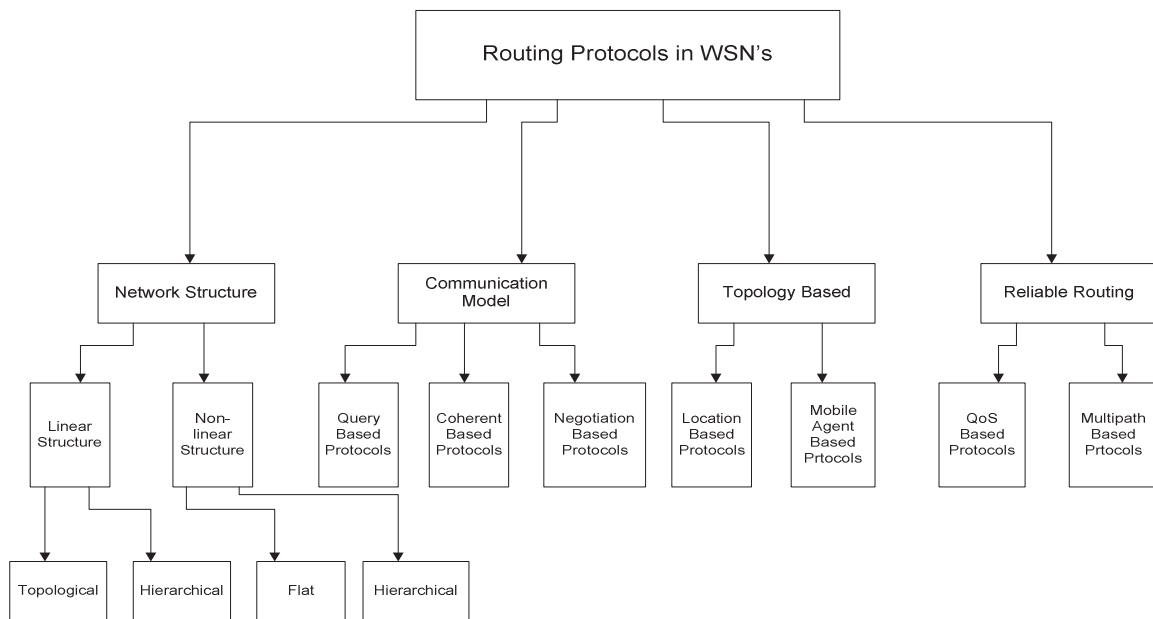


Fig.1. Classification of Routing Protocols

IV. ROUTING PROTOCOL FOR LINEAR WIRELESS SENSOR NETWORKS

Linear wireless sensor network is an important sub-class of WSNs. One of the following two conditions needs to be true for a WSN to be linear. (1) All the nodes are aligned on a straight line, strictly forming a line. (2) All of the nodes exist between two parallel lines [2]. The application area of linear sensor wireless networks includes monitoring of oil/gas/water pipelines (above ground and underground), rail road/subway monitoring, monitoring of a/c power lines, river monitoring and border monitoring.

In [2], the classifications of linear networks have been presented. There are three types of nodes in LSNs i.e. basic sensor nodes, data relay nodes and data dissemination nodes. Basic sensor nodes sense data and forward the data to the nearest data relay nodes while the data relay nodes are responsible for routing, aggregation, data compression and transmitting data. The data dissemination nodes are responsible for forwarding the data received from the data relay nodes to the base station. The linear sensor networks may be classified based on topology (thin, thick and very thick) or based upon hierarchy (one level, two level and three level) [2].

Some of the routing protocols used for LSNs are:

In [5] the routing algorithm MERR (Minimum Energy Relay Routing) has been discussed. The basic idea of this algorithm is to place the certain optimal number of relays at desired position to set up a minimum energy path. Each sensor node seeks locally for that downstream node within its maximum transmission range whose distance is closest to the characteristic distance. An Energy Balanced data Gathering algorithm has been presented in [6]. In this work, the idea has been taken from [7] and [8] apart from that two more contributions has been added in [6].

V. HIERARCHICAL ROUTING PROTOCOL FOR NON LINEAR WIRELESS SENSOR NETWORKS

In hierarchical routing protocols nodes are grouped into clusters while in flat protocols, all nodes are peer to each other and having unique global. In hierarchical every cluster has a cluster head and the election of a cluster head is depend on different election algorithms. The cluster heads are used for higher level communication, reducing the traffic overhead. Some major hierarchical routing algorithms are as follows:

Low-Energy Adaptive Clustering Hierarchy (LEACH): In LEACH the network has cluster-head nodes whose job is to collect data from surrounding sensor nodes and transmit it to the base station. The responsibility of being a cluster-head rotates between the sensor nodes so that the energy of each node reduced equally instead of draining out a single node. Cluster-heads first aggregate the data from the entire sensor node in the cluster and then sends it to the sink [9]. The LEACH protocol is a type of hierarchical protocol in which almost all the nodes transmit the data they gather to cluster heads [10], [11]. The LEACH protocol operates on the two following phases:

1. The first phase is called as Setup Phase and In this Phase, the nodes are Arranged in hierarchical order and finally a cluster head is selected. The functions of a cluster Head is to aggregate, compress and forwards the data to the base station. At each round a stochastic algorithm is used to determine whether a node can become a cluster head or not. A node can be a cluster head for a maximum of one time, once a node becomes cluster head for any round P then it cannot be a cluster head again, where P is the desired percentage of cluster heads. Therefore, the probability that a node can be a cluster head in each round is $1/P$. By the rotation of cluster heads, energy can be balanced and the balancing of energy gives a longer lifetime of the network.

2. The second phase is called as Steady State Phase and in this Phase, all the gathered data at cluster head is sent to base station. If any of the nodes does not belong to a cluster head, it chooses its closest cluster head and joins that cluster. Finally for transmitting the data from each node of its cluster a scheduling is to be done by the cluster head.

The main advantage of using LEACH is that it outperforms conventional communication protocols, in terms of energy Dissipation, ease of configuration, and system lifetime/quality of the network [12].

The major setback of LEACH is that it is not suitable for non-occasional events delivery and if overlapping clusters are formed [13].

Low-Energy Adaptive Clustering Hierarchy Centralized (LEACH-C): In This protocol the base station is used for the formation of clusters, while in LEACH protocol the nodes configure themselves into clusters [14]. After getting the information regarding level of energy and about the location of the nodes from different nodes in the network the Base Station (BS) use this information, to select the number of cluster heads and configures the network into clusters. Now the cluster grouping is to be done, so that when clusters send their information to the corresponding cluster heads, energy utilization should be minimum.

The advantages of using this algorithm over to LEACH are (1) The Base Station uses the overall information it gathered from network to create the clusters that require less energy for data transmission. (2) In LEACH-C the numbers of cluster heads in each cycle are equal to a fixed and almost best possible value, while in LEACH the quantity of cluster heads changes from round to round due to the shortage of global coordination among nodes.

Hybrid Energy Efficient Distributed (HEED): This protocol uses a distributed approach which selects the cluster-heads on the basis of available energy and communication cost instead of random selection. HEED is a good choice for unanticipated traffic patterns [15] and [16].

Adaptive Threshold sensitive Energy Efficient sensor Network (APTEEN): The enhancement of TEEN is APTEEN and its objective is to capturing periodic data collections and reacting to time-critical events [17]. As soon as the clusters are formed by the base station, all the attributes (transmission schedule and threshold value) are to be sent to all the nodes in the

network by the cluster head, for this cluster head uses broadcasting .finally the cluster heads perform data aggregation to save energy.The main advantage of APTEEN, compared to TEEN, is that nodes consume less energy. However, the main setbacks of APTEEN are the longer delay time because of complexity in the system.

Base-Station Controlled Dynamic Clustering Protocol (BCDCP): The basic idea behind BCDCP is to set up clusters so that they will be balanced [18]. In order to achieve this, the BS, before deciding the path for routing, it first gets the information regarding the current energy status from all the nodes in the network. Based on the response received from all the nodes, the base station first calculates the average energy level of all the nodes by adding the energy levels of all nodes divided by the no. of nodes that network had. After that the base station selects a number of nodes whose energy levels are more than the average value. Apart from that, at each cluster, the equal no. of nodes are divided in each cluster head so that:

- None of the cluster head become overloaded,
- Uniform positioning of all cluster heads throughout the whole network and
- Use of cluster head-to-cluster head (CH-to-CH) communication so that data can be easily transferred to the BS without using extra energy.

Virtual Grid Architecture Routing (VGA): To maximize the network life time and to save energy, in-network processing and data aggregation is to be done in VGA protocol [19]. This protocol divides its operation into two phases,

Clustering: In this phase all the nodes in the network are arranged in some topology, most of the time the topology is fixed because generally stationary sensors are used in applications. Inside each cluster a cluster-head is there which is used for aggregation and known as local aggregator (LA). A subset of this Local Aggregators (LA) is selected to perform global or in-cluster aggregation and its members are known as master aggregator (MA).

Data aggregation phase: In the data aggregation phase, some heuristic approach is used so that we can get some easy, fair, efficient and optimal solution. The main advantage of this protocol is that it may achieve energy efficiency and maximization of network lifetime, but the problem of optimal selection of local aggregators as master aggregators is NP-hard problem.

Hierarchical Power Aware Routing (HPAR): The HPAR is a power aware routing protocol in this the total nodes available in the networks is divided into a group called zones [20]. Each zone is created in such a way that all the nodes which are geographically closer to each other are kept in same zone and is treated as an entity. Functioning of this protocol is divided into two steps: First is the formation of the clustered zones and second is the function of routing scheme. In second step routing methodology is decided so that a message is routed across other zones hierarchically by which battery life of nodes in the system is maximized. This can be done by a message that is routed along a path with a maximum power over all minimum remaining powers. This path is called max-min path. The reason

of making such a decision i.e. max-min path is that it may be possible that the path with high residual power has more energy utilization than the minimum energy utilization path. This protocol uses an approximation algorithm called max-min ZPmin algorithm. The algorithm first finds a path with least power consumption by applying Dijkstra algorithm. The strength of this protocol is that it considers the transmission power and uses the minimum battery power of the node in the path so that the life of network can be maximize. Apart from that, it creates zones of the total nodes available in the network to take care of the large number of sensor nodes. But on the other side there will be some overhead on the network also due to the finding of the power estimation.

Distributed hierarchical agglomerative clustering (DHAC): The basic scheme in the DHAC routing is that for creating the clusters a node needs the knowledge of only one hop neighbor [21]. Following steps are to be followed in the DHAC when a cluster is to be formed:

- In first step each node present in the network represent itself as a cluster head and sends the information to each other by sending Hello messages, then a resemblance matrix is to be build on the basis of the input data received from nodes in the network.

In second step the DHAC algorithm is executed i.e. each cluster establishes its own private resemblance matrix and get the value of minimum coefficient, once the coefficient is find out then each cluster determines its minimum cluster head.

- The third step is to Cut the hierarchical cluster tree i.e. if a predefined maximum limit of clusters is reached, the control conditions correspond to the step of cutting the hierarchical cluster tree.

- In fourth step the size of the cluster can be controlled i.e. if after the execution of the DHAC algorithm the no. of clusters are less the no. of minimum limit then the clusters can be merged by performing the operation "MERGE CLUSTERS".

- Finally in fifth step the cluster heads is selected. To select the cluster heads, the DHAC choose the lower id node between the two nodes that join the cluster at the first step. The CH chosen does not require extra processing.

Novel Hierarchical Routing Protocol Algorithm (NHRPA): The NHRPA algorithm uses the suitable routing methodology for the nodes which is relative to the residual energy the nodes consumes, the density at which the nodes are distributed and the distance between nodes and BS (Base Station) [22]. A node in WSN is mainly deals with following three operations i.e. loop operations, judgment operations, and assignment operations, so the proposed routing algorithm should minimize the computation cost required in the above said three operations. Moreover, when a sensor network is deployed the initialization process of the node is done once in the whole life of the network. So if the suitable threshold value is selected then varying concerns like energy and security can be balanced among different situations.

Extending Lifetime of Cluster Head (ELCH): In ELCH protocol for the selection of cluster heads all the nodes available in the networks voted for their neighbors [23]. This

protocol uses a hybrid approach, resultant of that it achieves to consume lowenergy and thus extending the life of the network, this approach combines the cluster architecture, withmulti-hop routing. This protocol works in two phases:

- *Setup Phase*. In this phase, the clusters are formed and election of cluster-head is performed. All the nodes present in the network vote for theirneighbor sensors. The highly voted node becomes thecluster-head.
- *Steady-State Phase*. In this phase, the clusters are created then the information is flows from head to sink and sink to head. The clusters are formed in such a way that in any cluster some sensors and a cluster-head is there. The selection of sensors in

any cluster is depending on the location of the sensor, i.e. the sensors located in a radius less than theradio radius are selected. Then, the time slot TDMA foreach cluster member in each round is used. To minimize the transmission energy and to balance the energy efficiency as soon as the clusters have been created, a multi-hop routing backbone is formed by the clusterheads. Each node then transmitted its data directly to the cluster head. Moreover,for the communication between the cluster heads and the sink, a multi-hop routing is adopted. However, there are many others hierarchical routing protocols apart from the discussed in this paper ,that have been proposed for WSNs [24], [25],[26] and [27].

TABLE I.COMPARISON OF HIERARCHICAL ROUTING PROTOCOLS

S.No.	Protocol	Energy efficiency	Mobility	Scalability	Power Uses
1	LEACH	Good	Fixed Base Station	Good	High
2	LEACH-C	Good	Fixed Base Station	Good	High
3	HEED	High	Fixed Base Station	Moderate	Good
4	APTEEN	Good	Fixed Base Station	Good	High
5	BCDCP	Good	No	Limited	Low
6	VGA	Good	No	Good	Low
7	HPAR	Good	No	Low	High
8	DHAC	Moderate	No	Good	Good
9	NHRPA	Good	Fixed Base Station	Good	Low
10	ELCH	Good	Fixed Base Station	Limited	Low

In this paper, the major energy efficient hierarchical routing protocols: namely, LEACH, LEACH-C, HEED, APTEEN, BCDCP, VGA, HPAR, DHAC, NHRPA and ELCH have been discussed. The main concern of this survey is to examine the energy efficiency, mobility, scalability and power uses for these routing protocols. In Table I, the comparison of the protocols has been shown on the basis of above mentioned parameter.

VI. CONCLUSION

Due to limited battery capabilities and complexities in operations, the routing protocols designed for other distributed systems such as MANETs cannot be applied in WSNs. Hence, it is necessary to use any energy-efficient routing protocol(s) for WSNs. It has been widely accepted that hierarchical routing protocols are energy efficient. In this paper, a comprehensive study on the energy efficient hierarchical routing protocols have been conducted for linear as well as non linear WSNs.The comparison of the major hierarchical routing protocols has been compared based upon parameters such as mobility, energy efficiency, scalability and power uses. It is evident that as far as the energy efficiency is concerned, the hierarchical routing protocols perform better than non-hierarchical routing protocols both for linear as well as non-linear sensor networks. As a future work, we are planning to design more efficient hierarchical routing protocols for linear sensor networks which is a relatively unexplored area.

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