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An Analytical Study on Variants of LEACH Protocol

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Abstract: ***There are many remote areas where traditional computer networks cannot render services due to unavailability of infrastructure. Among these infrastructure less networks, most popular choice for researchers are wireless sensor network in the modern era. Wireless Sensor networks perform the communication in remote areas where it is difficult to deploy the layout of network. Clustering hierarchy (LEACH) protocol is still a landmark as energy saving protocol for the researchers of wireless sensor network (WSN) even after 20 years of its existence. Since its inception, many modifications of LEACH protocol have been proposed. All the routing protocols have been divided into two categories namely single hop and multi hop scenarios. In this paper, we studied and surveyed various LEACH based routing protocols presented by researchers so far and discussed the advantages and functioning of them in comparison to LEACH protocol. The paper also discusses the merits and demerits of different successors of LEACH. In the end, paper concludes with future research directions in the Wireless sensor network area.***

Index Terms: ***LEACH, single hop and multi hop, Wireless Sensor Network, Clustering, Cluster Head, Routing protocol.***

I.INTRODUCTION

"A Wireless Sensor Network (WSN) is a collection of large numbers of autonomous sensor nodes with limited sensing ability, battery power, computing and communication capabilities." There are one or more than one base stations and many tiny sensor nodes deployed in the close proximity around them. Sensor nodes transmit the data packets and base stations receive them for the sake of forwarding it to external world. WSN has wide application prospects, for example, temperature, pressure, dampness, territory observing, calamity, military observation, backwoods fire-following, security reconnaissance, Underwater, Underground, agriculture and a lot more [21]–[23].Sensors are deployed in large/small areas in remote places, where infrastructure laydown is cumbersome. There may be one or more than one Base Stations. The selection of accurate routing protocol has a great impact in the delivery of gathered data from source to the BS node. The routing technique used in WSN should ensure low energy dissipation as battery change in sensors are rarely possible. Research community has proposed a large number of power-efficient routing methods developed for stationary and mobile WSN, based on the usage and size of network.

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Design of a routing protocol in wireless sensor network network is a difficult task, due to low computational power, low bandwidth, self-organization and computational overheads. As indicated by Pantazis et al. [23], routing methods might be ordered on four factors to be specific network system structure, topology, correspondence model and dependable routing plan. On the deployment premise, the network system structure plan can be additionally categorized into two sorts: flat and hierarchical schemes. With respect to as flat routing conventions are concerned, all sensor nodes have same functionalities in the system. Among flat routing plans, Flooding and Gossiping [24], Directed dissemination [25], Rumor [26], SPIN [27] are some popular routing plans. These kinds of networks are not scalable, as they are more suitable for small area networks. Hierarchical routing is capable to achieve more power efficiency and scalability on the basis of its architecture. The whole network is divided into clusters called as nodes. Among those nodes, some nodes are chosen as important entities called cluster heads (CHs), who performs the task of receiving, aggregation and compression of the information collected from member nodes. Ultimately CHs communicate the compressed data to Base Station. As cluster head offers extra types of assistance to different nodes in the cluster, it dissipates more power when contrasted with different nodes of the cluster. To balance the overall energy consumption, Cluster Heads should be rotated periodically deployed inside a cluster. Heinzelman et al. [28] proposed first hierarchical routing plan known as LEACH. A plenty of hierarchical clustering protocols have been presented around the LEACH as the primary routing protocol. Popular hierarchical clustering algorithms in WSNs are LEACH [28], HEED [29], PEGASIS [30], EECS [31], EEMC [32], TEEN [33], PANEL [34] and T-LEACH [35].

II.LEACH (LOW ENERGY ADAPTIVE CLUSTERING HIERARCHY) PROTOCOL

LEACH is a hierarchical cluster based routing protocol for WSN[14]. The primary goal of LEACH is to enhance the battery power efficiency by rotating CH selection through a random number generation technique. In LEACH, nodes are organized into local clusters. LEACH operates through several rounds and each round is comprised of two phases: set-up and steady-state [1,2]. In former phase, every sensor node generates a random number in the range 0 to 1, and makes the comparison with threshold value. If the generated number falls below the threshold value *T(n)* then that node declares itself as cluster head. At the point when a node is chosen as the cluster head, it communicates the message to all other sensor nodes.

Sensor nodes decide to join a CH based on the RSSI (received signal strength indicator) of the message for present round and communicates a join message to concerned CH.

When the group head gets demand message originating from a hub, CH declares node as its member node and records node's ID. Now each sensor nodes have information about their CH and cluster it belongs to. Once the cluster is formed, each cluster head generates a TDMA schedule table and broadcasts it to their cluster members. All member nodes get their time slot for communication. At the time when each sensor node realizes its TDMA plan, at that point set-up stage is finished and the consistent state stage begins. In steady-state phase, transmissions of gathered data are performed, from cluster nodes to the CHs and then CHs to the base station. Sensor nodes will send their data to CH as per plan of the TDMA schedule. CH will remove the redundancy of all accepted information sent by their member nodes and send them to base station. TDMA schedule table is also used in data transfer from the source CH to destination BS[18]. CH uses correlated data by applying data aggregation technique, which reduces energy consumption[19] due to eliminated data duplication. LEACH protocol uses clustering which poses less data transmission between member nodes and the base station, hence increasing the longevity of the network. Each member node sends their data in their time slot and other time they remain in sleep mode. The TDMA plan decreases the collision of information sent by member sensor nodes. Selection of cluster head is random. LEACH does not consider node energy for the election of CH, which forces some nodes to die early. Random distribution of nodes degrade the performance of this protocol, as in some clusters, CHs may be located at boundaries of the clusters. Those cluster heads which are far away from the base station, expend more battery power in contrast with those CHs which are close to the BS. Unnecessary energy consumption by high frequency of re-clustering may make LEACH a bad choice for routing in WSN. Following section discusses various routing protocols in Wireless Sensor Networks

III.SINGLE HOP COMMUNICATION PROTOCOL

A. C-leach (Centralized Leach) Protocol

LEACH-C is a centralized clustering protocol in which CH selection and Cluster formation are performed by the base station. LEACH-C also solves the problem of Leach, in which selection of cluster head is based on random cluster formation[3]. In LEACH-C, cluster formation at the base station is made by a centralized algorithm. This protocol has two phases. In set-up phase, the remaining energy and location information value of all the sensor nodes is being sent to the BS in every round. The base station calculates the mean power of sensor nodes. The nodes having more vitality have progressively opportunity to turn into the cluster head. If the sensor nodes have higher residual energy than average, the base station finds a group of cluster heads from the set of nodes. Now base station broadcasts the cluster head groups to sensor nodes in network. If the sensor node's ID is found in the cluster head group it received, the node will work as a cluster head otherwise behave like a simple node. In steady-state phase, the CHs will send the TDMA schedule to all member nodes of their corresponding cluster members. Data transmission begins in all clusters on the basis of the TDMA schedule [1,2]. As CH selection and Cluster formation are performed by the BS, energy consumption of CH nodes get reduced in comparison to LEACH. Costly device is used to know about location information of sensor nodes which consume more energy. It is centralized, so less scalable and cannot cover large area.

B. Q-Leach (Quadrant Leach) Protocol

Q-LEACH protocol is a quadrant-based routing protocol. It is combination of Q-DIR routing techniques and LEACH protocol. We partition the network into four quadrants. Sensor nodes are equally disturbed in each quadrant and the CHs and their cluster members are placed in the same quadrant[4]. In setup phase, the network is divided into four quadrants. Sensor node chooses a random number between 0 and 1. If this number is less than threshold T(n), then that node will become CH for current round. This process is repeated for all quadrant. Received Signal Strength Indicator (RSSI) are used for clusters selection. After clustering in each quadrant, TDMA schedule is sent by CHs to their cluster members in respective quadrant. Every node communicates to CH at its idle time interval. In steady-state phase, cluster heads receive all data from their member nodes in one round first. Afterwards data is aggregated and compressed before sending it to BS. Now one round completes and next round starts for cluster heads selection. Q-leach chooses shortest routes between source and destination, so network lifetime also enhances. Q-LEACH is used for energy conservation but CHs are not selected on the basis of residual energy and the CH changes in every round. To address the problem of Q-leach, enhanced Q-leach is proposed[5]. For cluster head selection, it uses threshold residual energy and CH does not change in every round. If the residual energy of the CH is larger than threshold residual energy then the cluster head same for the after that round.

C. T-Leach (Threshold-based Leach) Protocol

In the paper presented by Hong et al. in [6], a threshold of residual energy is used for cluster head selection. In traditional leach, CHs are selected in all the rounds but in T-leach, cluster heads are fixed for some rounds. In set-up phase, clusters are formed with the help of residual power based cluster creation method for selecting cluster head and balancing energy consumption for all sensor nodes. Steady-state phase is like traditional LEACH routing with one difference. If the current residual energy of cluster head is larger than threshold of residual energy then CH will be same for next round, otherwise, cluster head will change after current round. T-Leach protocol decreases cluster head selection and rotation cost. Threshold of residual energy is used for changing the CH which increase network lifetime, but main drawback of T-Leach is uneven energy consumption by sensor nodes[16].

D. TB-leach (Time-based Leach) Protocol

According to Junping et al.[7], TB-LEACH is distributed and time-based protocol to increase network lifetime. In this protocol, cluster head selected by time-based threshold, results in constant number of CHs. It consists set-up phase and steady state phase in every round. In set-up phase, A counter is used to get constant value of CHs. Every sensor node generates a random number and it checks its advertisement message when timer expires. If sensor node's value is less than constant value of CH then node becomes CH itself. Cluster formation is done using advertisement message and RSSI. Each CH sends TDMA schedule to their member nodes. In steady-state phase, first data transmission is performed from cluster members to cluster head, then after cluster head communicates the aggregated data to base station. Cluster formation is done without using global information. Using constant number of clusters, it improve network lifetime.

E. B-Leach (Balanced-Leach) Protocol

As indicated by tong et al.[8], B-LEACH is proposed to address the issue of uneven clusters of LEACH. Randomly generated value of cluster nodes and leftover energy of nodes, are utilized for choosing CH in this convention. It is ordered into rounds and each round spans over set-up and steady state phases. In set-up stage, a threshold value is chosen to decide the cluster head. A period span is determined by utilizing equation of t=k/e (where k speaks to a consistent factor and e speaks to remaining power of every node). In first round, Cluster heads are chosen by utilizing LEACH algorithm while cluster heads notify message and remaining energy to every other sensor nodes.
If the number of selected cluster heads is less than n*p (where n is number of sensor nodes and p is probability of CHs), then some nodes are selected as cluster heads which have less time interval. If the number of selected cluster heads are larger than n*p, then some CHs which have less residual energy are discarded and make number of CHs equal to n*p. Discarded CHs are converted into normal nodes. Steady-state phase is same as LEACH protocol[16]. In B-LEACH, equal load balancing and CHs are selected using residual energy, which improves energy efficiency.

F. V-LEACH (Vice-leach) Protocol

According to sasikala et al. [9], vice leach protocol improve the network lifetime using a vice cluster heads. We use vice cluster heads when without completing data transmission of current round, cluster head is out of energy. In this protocol, every cluster has CH, vice-CH and member nodes. Set-up phase and steady-state phase are two phases of V-LEACH. In set-up phase, CHs selection and clusters formation are done using same technique as in LEACH. Vice CH in each cluster is selected based on higher remaining battery power of member nodes. In steady-state phase, data communication is exactly same like LEACH protocol. V-LEACH guarantees the success of data delivery and enhances lifetime of network but it has the limitation of less scalability and high complexity[14] .

IV.MULTI-HOP COMMUNICATION PROTOCOL

A. MH-Leach (Multi-hop Leach) Protocol

According to V.Biradar et al. [10], Multi-hop leach is extended version of LEACH, which addresses the limitation of LEACH. Communication model suggests that power dissipation is proportional to distance between source and destination. It is directly proportional to d^4 in case of large distance (more than the threshold value) in contrast to d^2, where d denotes the distance between transmitter and receiver. Multi-hop LEACH increases energy efficiency of the wireless sensor network using intermediate node between CH and BS to shorten the distance below threshold value. Like traditional LEACH, Multi-hop LEACH is also divided into several rounds like LEACH algorithm. In setup phase, selections of CHs and clusters formation are performed. Cluster formation is done using advertisement message and TDMA schedule is send to member nodes. In steady-state phase, cluster nodes send data to CH using TDMA schedule. If distance between CH and base station is far away, then CH chooses an intermediate node to send data to base station, otherwise sends data directly to BS[20]. Multi-hop transmission between CHs and the BS, increases energy efficiency of WSN and provide high scalability. Due to inclusion of the intermediate nodes, computational complexity and network overhead increase in MS-LEACH.

B. TL-Leach (Two-Level Leach) Protocol

V.Loscriet al.[11] presented the concept of leach with two-level hierarchy of clusters to enhance the transmission of packets and network lifetime. In this protocol, cluster heads at top level are called primary CHs and cluster heads at bottom level are called secondary CHs. Data transmissions are performed from member nodes to secondary CHs, secondary CHs to primary CHs and finally, primary CHs to Base station. Partial local calculations is done by cluster head at secondary level and complete local calculations are done by cluster head at primary hierarchy. The operation of this protocol consists of four phases; in first phase, advertisement message is sent from primary CHs to secondary CHs and secondary CHs to normal nodes. In second phase, primary CHs know about their member nodes (secondary CHs) using join message from secondary CHs to primary CHs. Normal nodes choose their secondary CHs using join message. Clustering is performed in this phase. In third phase, the primary CHs send TDMA schedule and CDMA code to all cluster members at secondary level to transmit their data using this code and allotted time. Secondary CHs communicate this information to their member nodes. CDMA code and TDMA schedule are used by member nodes to transmit data. In fourth phase, Secondary CHs send aggregated data to primary CHs, finally primary CHs send data to base station. Even consumption of energy by nodes within same cluster, extend the lifetime of a sensor network. This protocol is suitable for large area in contrast to LEACH and LEACH-C.

C. Orphan-Leach

According to Jerbi et al. [12], this protocol allows the orphan nodes for transmission of data. Orphan nodes[17] are those sensor nodes which does not belong to any cluster. A member node of cluster acts as a gateway for orphan nodes. Orphan nodes send their data to gateway member node. This protocol is categorized into two phases: set-up phase and steady state phase. In set-up phase, cluster head selection and cluster formation are done using certain algorithm.
Cluster head sends TDMA schedule to their member nodes. Gateway or member of cluster tells about orphan nodes to CH. CH also allots a number of TDMA slot for orphan nodes. Gateway broadcasts TDMA schedule to orphan nodes. Member nodes and orphan nodes send data simultaneously. In steady-state phase, transmission of data takes place. Orphan nodes or neighboring members send their data to gateway. Gateway node aggregates the received data and sends it to their cluster head. CH collects data from their member and gateway nodes, removes the redundancy and ultimately sends to sink node. In O-LEACH, more availability of data transmissions is achieved due to orphan nodes. Maximum connectivity rate is provided due to high coverage of network. Gateways consume some time for searching the orphan nodes. It suffers from delay in delivering data when large number of orphan nodes are in the network.

D. MR Leach (Multi-hop Routing Leach) Protocol

Authors farooq et al. [13] proposed MR- Leach for enhancing overall life of network and reducing the power dissipation. In this protocol, whole network is divided into different layers of clusters. Clusters formation are of same size at each layers and sensor nodes send data to base station through equal number of relay nodes. Cluster heads receive data from their members and send them to CHs at upper layers. CHs also act as relay nodes for cluster heads at lower layers to transmitting data to base station. MR-Routing protocol works in rounds and every round is further divided into set-up and steady state phase. In former phase, sensors nodes join those CHs who have higher residual energy and higher RSSI value. A time (TDMA) schedule is being issued by BS to each and every CH in the layers and cluster head to their member nodes. In steady state phase, data transmission is from lower layers to upper layers. In this protocol, network is like rooted tree where BS is root node, CHs are intermediate nodes and sensor nodes at lower layer are called leaf nodes. MH-Routing provides equal distribution of load among the nodes. Complexity and Overhead are high [14] due to complex computations because excessive number of TDMA schedules are communicated. In steady state phase, data transmission happens from lower layers to upper layers. Multilayer architecture makes it more scalable as compared to its counterparts.

V.CONCLUSION

Comparison of various LEACH variants of single hop and multiple hop has been presented in table-I. All the routing algorithms presented in section III and section IV, are categorized on the basis of parameters viz. clustering type, overhead in cluster head selection, computational complexity, scalability and battery power efficiency. LEACH is a routing protocol which follows distributed clustering but it is suitable for small networks only. As for as power consumption is concerned, LEACH performs better till all the sensor nodes have sufficient battery power. To overcome these problems, some variants of LEACH routing protocol have been proposed in section-III and section-IV. All the mentioned routing protocols are better to leach in some criteria like energy dissipation efficiency, CH selection method, scalability and fixation of clusters. The survey summarizes the following conclusion based on presented Table-I.

1. As for as clustering approach is concerned, all the algorithms except LEACH-C use distributed clustering pattern. LEACH-C is capable to do massive calculations as it is equipped with fixed infrastructure having enough power. It can run complex algorithms to achieve optimized energy efficiency and increased network lifetime.
2. Use of non-conventional energy resources may very useful since all the sensor nodes are power constrained. Only one protocol Solar-LEACH uses solar energy as power source while all other protocols avoid it due to extra hardware cost and bulk size.
3. Network coverage issue has not been discussed in any of the tabulated protocols. More attention is needed to address this area.
4. Most of the applications require sensor nodes to be static. However mobile nodes are needed for some applications like tracking of wild life behaviour. The prime challenge in this area is frequent topology change. More extensive research is to be carried out for the mobility of both, sensor nodes and base stations.
5. Many successors of LEACH protocol use GPS device for efficient location monitoring. Though the GPS equipment cost makes the sensor nodes expensive, most of the routing algorithms are more comfortable to decrease the time complexity with the help of this device.
6. Security issues are not discussed in any of the listed routing algorithm. As the applications of WSN will increase, there will be more demand for security measures inclusion in these routing algorithms.

FUTURE CHALLENGES

The major challenges in the design of a good routing algorithm, includes increased power efficiency and elevated network lifetime. To achieve these objectives, many variants of LEACH are proposed by researchers. Most of these successor algorithms are distributed in nature, scalable due to distributed approach and vast network size. In some cases, network scalability may not be achieved due to centralised approach. Prime goals of successors of LEACH protocol are mentioned as below:

- Optimal cluster head selection.
- Network coverage.
- Energy efficiency.
- Security aspect.
- Reliability of routing protocols.
- Fault tolerant algorithms.
- Uniform load distribution.
- Quality of service.

- Sensor node deployment strategy.
- Placement of base station to increase scalability.
- Quality of service

The reviewed literature points that design of a LEACH successor protocol is concerned with user's application area. Since more than two decades, various researchers have investigated different aspects of LEACH protocol but many domains are yet to be discovered.

Table- I: Comparison of Routing Protocols

WSN Protocol	Energy Efficiency	Scalability	Complexity	Overhead	Clustering
LEACH	Moderate	Low	Low	High	Distributed
LEACH-C	High	Low	Moderate	Low	Centralized
LEACH-Q	High	High	High	High	Distributed
LEACH-T	High	High	High	Moderate	Distributed
LEACH-TB	Moderate	Moderate	High	High	Distributed
LEACH-B	High	Low	High	High	Distributed
LEACH-V	Very High	Low	High	Very high	Distributed
LEACH-MH	High	High	High	Moderate	Distributed
LEACH-TL	High	Low	Low	Low	Distributed
LEACH-O	High	High	High	High	Distributed
LEACH-MR	High	High	High	Moderate	Distributed

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