An analysis of LEACH Protocol in Wireless Sensor Network: A Survey

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Abstract— **Wireless Sensor Network is composed of numbers of tiny sensors (nodes) which have the capability of gathering the data about environmental activities and making certain computations on them so that they can be communicated to the next node & finally to the Base Station. All the sensors work in co-ordination with each other to make communication successful. These sensors have to be continuously in active mode in order to receive and transmit data which increases their energy requirement. As these sensors are battery-powered, this continuous monitoring activity reduces their lifespan. Efficient management of energy is a critical requirement for the optimal design of a wireless sensor network. Thus, a protocol is critically needed that can make the wireless sensor network energy efficient. In this paper a detailed view and analysis of LEACH Protocol will be discussed. LEACH Protocol is a cluster-based hierarchical protocol which creates an energy balance in the network, saves the node energy and hence increases the lifetime of the network.**

Keywords- **Wireless sensor network, LEACH Protocol, Cluster-head node, Base Station, Energy efficient.**

I. INTRODUCTION

In the past decades Wireless Sensor Network has been one of the emerging technologies to gather information needed by a smart environment. Wireless sensor network is actually a network of battery-powered, low-power, low-cost & multi-functional nodes called sensors. These sensors have the capability of Sensing, Computation & Communication. The number of sensors may vary from few tens to thousands depending upon the requirement of the application. These tiny sensors are spatially distributed to observe an event of interest. When individual power of a tiny sensor is considered, it is limited but when the aggregate power of thousands of sensors is considered, it offers new technological possibilities. This is the basic principle behind WSN. These sensors must have self-organizing capability because once deployed, they remain unattended for a long period of time. Apart from this, high power-consumption, lower energy efficiency, memory constraints and difficulty in recharging or replacing batteries pose many challenges to the effortless development & application of WSNs.

Since a wireless sensor network consists of tiny sensor nodes which have a limited power & their lifetime depends upon how frequently & fast they transmit data a sensor node has no identity when its battery dies. Continuous research works are being done to develop new technologies to extend the lifespan of sensor node & to make them use their power only when it's needed & LEACH Protocol is one of them which will be discussed in this paper.

II. CONSTRAINTS ON ROUTING PROTOCOLS IN WIRELESS SENSOR NETWORKS

As the wireless sensor networks use low power tiny sensors, the routing protocols must be capable to satisfy the following requirements:

1) *Autonomous operations*: A dedicated unit to control the routing decisions cannot suit the architecture of Wireless sensors network because they can be attacked very easily. So the routing procedures need to be transferred among the sensor nodes.

2) *Energy efficient & scalable:* A Wireless sensor network consists of several thousands of nodes and therefore the routing protocol must be able to work efficiently with this number of nodes. And also when the number of nodes further increases the protocol should be able to maintain the performance along with a fair communication among the nodes.

3) *Fault tolerant:* If at any time the sensor fails, the routing protocol should execute alternative decisions in order to leave the other nodes unaffected and to make the Wireless sensor network work continuously and gracefully.

4) *Adaptable to mobility:* Different applications of Wireless sensor network demand the mobility of sink & source. In this case the routing protocol is needed to provide support for the sensor nodes to adapt according to the mobility.

III. CATEGORIES OF WIRELESS SENSOR NETWORK ROUTING PROTOCOLS/ ARCHITECTURES

Different categories of the routing protocols are given in the following table:

TABLE I. WSN ROUTING PROTOCOLS

Categories	Routing Protocols
Data-centric	Flooding, Gossiping, SPIN, Directed Diffusion, Rumor Routing, Energy-aware routing for low-energy ad-hoc WSN, STCP, Gradient-based, COUGAR, ACQUIRE, Information dissemination by negotiation, EAD, Information-directed
Hierarchical	LEACH, PACT, HEED, PEGASIS, Hierarchical-PEGASIS, TEEN, APTEEN, Energy-Aware Routing for Cluster-based WSN, SecRout, SCR
Location-based	GAF, SPAN, GEAR, GeRaF, TBF, ALS, BVGF, MECN, SMECN, Geographic Routing in Lossy WSNs
Mobility-based	SEAD, TTDD, Joint Mobility and Routing, Data MULEs, Dynamic Proxy Tree based dissemination, MMAC, MS-MAC, VBF
QoS	SAR, SPEED, Energy-Aware QoS, RL-MAC, MMSPEED, DAPR
Network flow	Max Lifetime Energy, Max Lifetime Data Gathering and Aggregation, Min Cost Forwarding
Multipath-based	Node-disjoint, Braided Path, N-to-1 Multipath Discovery, SEEM, REER,HMPR
Heterogeneity-based	CADR, IDSQ, CHR, HDMRP, SEP, EEHC

A. Data-Centric Architecture

In this category of protocols the sink node sends a request query in response of which the source node sends an event query and the sink routes to the event. There is no global network identification. The source and the sink communicate with each other through the network of nodes and the most efficient and least cost route is chosen for communication. In other words the entire network needs to get involved in the data transfer so in the parameters of power these protocols are inefficient.

B. Hierarchical Architecture

Data-centric architecture is not suitable for a Wireless sensor network with large number of nodes. It may lead to performance degradation. This issue can be addressed by the Hierarchical architecture where the entire network is divided into clusters with a cluster head whose main responsibility is to maintain communication among the nodes in the same cluster, to aggregate data received from the sensors and transfer them in a multi-hop manner. This architecture very efficiently maintains network scalability and energy.

C. Location-based Architecture

This architecture addresses the sensors by their locations which are obtained by embedded GPS receivers. Distance between the nodes is calculated in order to estimate the energy consumption due to which it provides efficient data routing.

D. Mobility-based Architecture

In this architecture it is assumed that the position of source, sink and all the intermediate nodes changes over time. So it presents a new problem of delivering data correctly in a network exhibiting sink and source mobility.

E. QoS Architecture

Qos architecture minimizes energy consumption and requires certain quality of service requirements like delay, reliability, and fault tolerance. This architecture is generally used for delivery of real time data or data with certain predefined metrics. The complexity level of this architecture is comparatively high because of maintenance overhead.

F. Multipath-Based Architecture

Data transmission between source and the sink can be done via two ways – single path and multi path. In single path data transmission, data travels through only a single shortest path between source and sink. But in multi path routing, multiple routes are selected for transmission. The data payload is distributed evenly among the paths which make this architecture power efficient.

G. Network Flow Architecture

Links among the nodes in wireless sensor network have certain cost parameters like delay to transfer data, energy or power to transfer data, etc. To find the optimal link among the nodes is the main goal of this architecture. Optimization process needs to be defined across the links between source and sink.

H. Heterogeneity-Based Architecture

As the name implies, this architecture is based on the presence of different types of sensors in the wireless sensor network. Some sensors are powered – they have no energy constraints and some are battery powered – they depend on the power of battery & have a limited lifespan. The main goal of this architecture is utilize this heterogeneity present in the network and improve the performance.

IV. LEACH PROTOCOL

LEACH is hierarchical protocol which allows the nodes to transmit data to the cluster heads of the cluster to which they belong. The cluster heads aggregate the data received from the non-cluster head nodes & forward it to the Base Station (Sink). It is a cluster-based routing protocol whose main aim is to increase the lifetime of the wireless sensor network. It is a very good example of self-adaptive & self-organised protocol. Its overall operation is based on rounds & each round consists of two stages- set up stage & steady state stage. The core idea of LEACH protocol lies in dividing the whole network into various clusters. In each cluster, a cluster head is selected in hierarchical manner & this role is rotated among the nodes in the cluster in order to homogeneously distribute the power load in every round. This protocol allows scalability & robustness in the network & also helps in compressing the size of information to be sent to the Base Station. The basic architecture is depicted in figure no. 1.

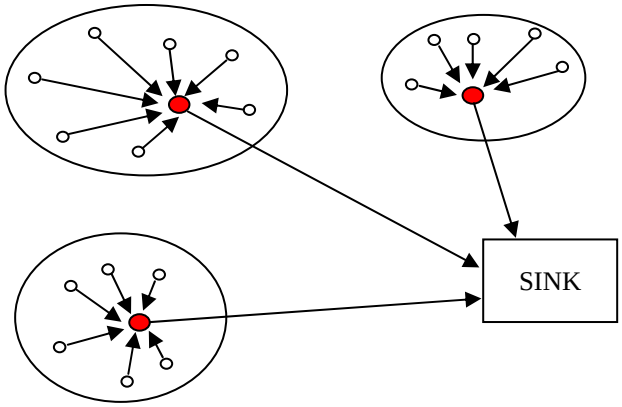


Fig.1. Architecture of LEACH Protocol

A. Phases of LEACH Protocol

LEACH Protocol is cluster-based protocol that uses the "round" concept. Each round is divided into two phases –

1. Set-up Phase
2. Steady State Phase

Set-up Phase

In LEACH protocol, clusters are formed by making use of a distributed algorithm & there is no communication with the Base Station required. Each node uses a stochastic algorithm at each round to determine whether it will become a cluster head in that round. The algorithm for cluster formation in the LEACH protocol carries out the task of cluster formation, cluster head node selection & notification to non-cluster head nodes. This phase can be further sub-divided into two parts-

i. Advertisement
ii. Cluster set-up
iii. Transmission schedule creation

The algorithm is designed in such a way that the same node should not get chosen as cluster head node every time. The cluster head node is selected on the basis of a random number. This random number is chosen by the sensor node whose value lies between 0 & 1. Let a threshold value, T(n), is considered & it is calculated as :

$$T(n) = \begin{cases} p/1-p(r \bmod p^{-1}) & \text{if } (n \in G) \\ 0 & \text{otherwise} \end{cases}$$

where p is the cluster head probability, r is the current round & G is the set of nodes that have not been cluster heads in the last 1/p rounds.

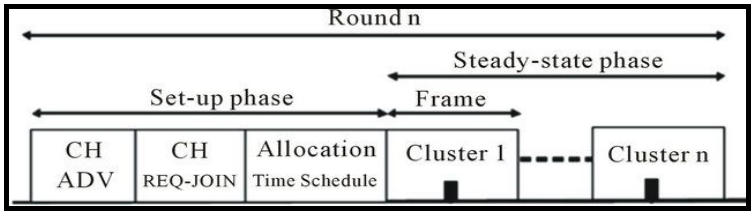


Fig.2. Timeline Showing LEACH Protocol Operation

If the random number selected by the node is less than the threshold value, T(n), then that particular node is chosen as the cluster head node for the current round.

After the node has announced itself as the cluster head node, it broadcasts an advertisement message to all the other nodes in the cluster using CSMA MAC Protocol. This message is small in size which basically contains node's ID & a header that characterizes this message as an announcement message. The other nodes in the cluster receive this message with strong signal strength. The nodes decide on the basis of strength of advertisement signal to which cluster they belong on the basis of minimum communication required to communicate with the cluster head node. This decision needs to be communicated to the cluster head node using CSMA MAC Protocol, so the nodes send a Join-Request message back to the cluster head node. It is not guaranteed that the nodes are evenly distributed among the cluster head nodes. The size of cluster in the network is highly variable in LEACH Protocol. In the set-up phase, the cluster head nodes are randomly selected from all the sensor nodes and several clusters are constructed dynamically. On the basis of the messages received from the sensor nodes the cluster head node allocates TDMA schedule to every node of the cluster. This is done in order to avoid collision among the non-cluster head nodes for data transmission. It also enables the radio components of non-cluster head nodes to be turned off during their time except their transmit time. This, to a great extent, minimizes the energy dissipation.

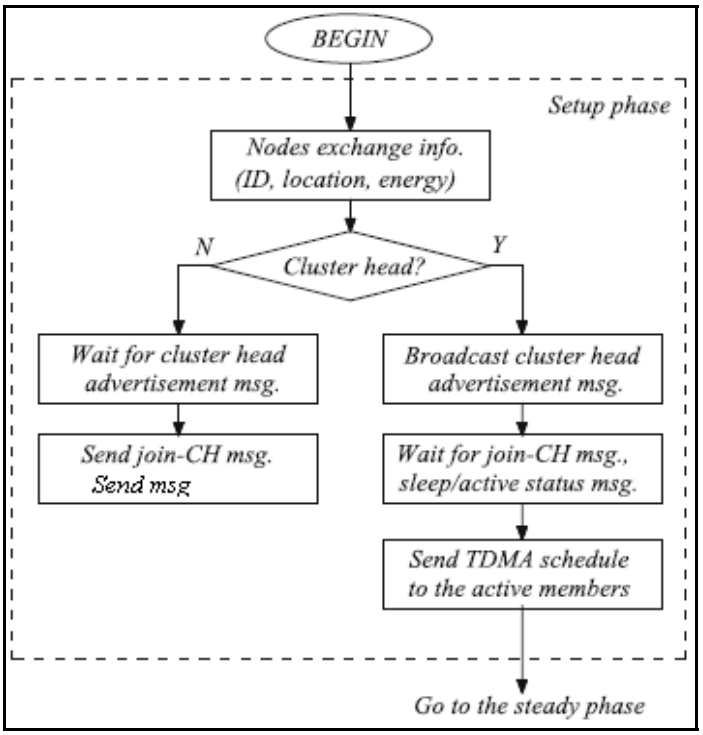


Fig.3. Flow-chart of LEACH Protocol in Set-up Phase

Steady State Phase

In Steady State Phase, the actual transmission of data takes place. On the basis of functionalities performed in this stage the Steady State Phase can be sub-divided into three parts -

i. Data transmission to cluster head

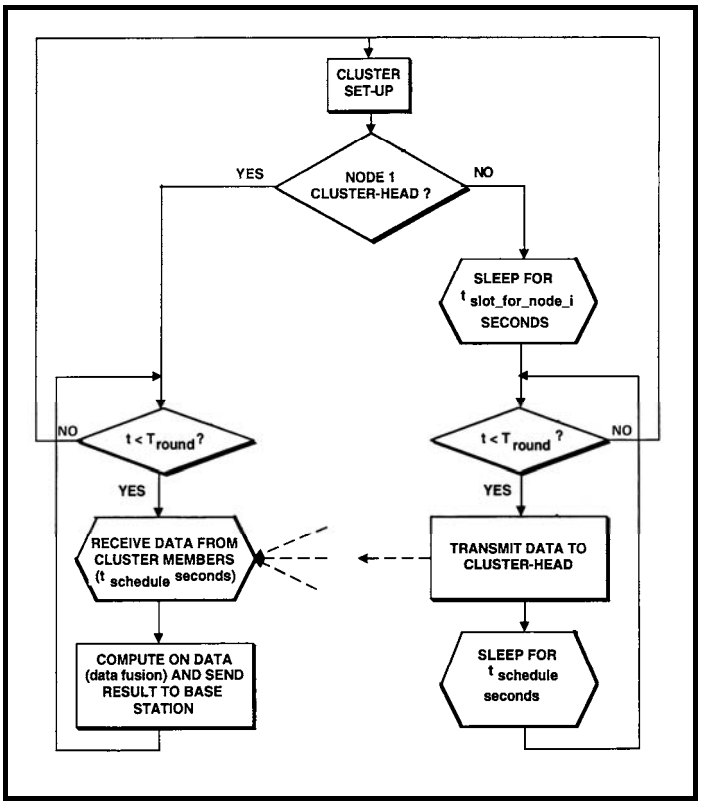
ii. Data fusion (Signal Processing)

iii. Data transmission to base station

Within each cluster the cluster head node creates a TDMA schedule, randomly picks a CSMA schedule & broadcasts it to the non-cluster head nodes. After this step, the member nodes start sending their respective data to the cluster head node during their allotted TDMA slot. The radio of all the other nodes except the active member node is turned off which minimizes their energy dissipation. But the cluster head node has to keep its radio on in order to receive the messages from the member nodes. After all the nodes have completed sending their data to the cluster head node, it aggregates the collected data, called data fusion, and transmits the fused data to the Base Station (Sink). The process of aggregation is required so that the amount of data transmitted to the Base Station can be as compressed as possible. Apart from being energy-efficient it also makes fair utilization of bandwidth since the bandwidth for communication is fixed.

To minimize the energy cost, the steady state phase is composed of multiple frames. So the steady state phase is longer than the set-up phase.

After a certain period of time, the overall system goes back into the set-up phase again & another round gets started & a new cluster head node is chosen. Each cluster communicates with a different CDMA code to minimize the interference among different clusters.



. Fig.4. Flow-chart of LEACH Protocol in Steady State Phase

V. ENERGY CALCULATION IN LEACH PROTOCOL

For calculation of energy in LEACH Protocol, we will consider first order radio model. For this, some assumptions have to be made:

- Sensors, communicating with each other as well as with the Base Station, lie within the communication range.
- Base Station lies at the center of the network.
- Energy dissipation is neglected.
- All the sensors are of same capability.

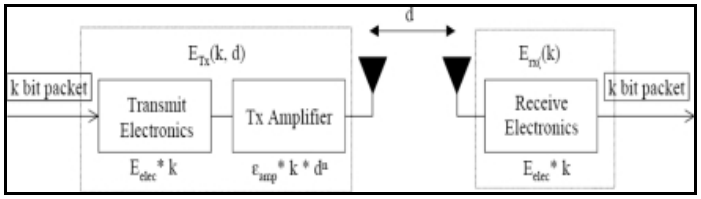


Fig.5. First Order Radio Energy Model

Thus, energy required to transmit k-bit message in a distance d is given by-

$$E_{Tx}(k,d) = k * E_{elec} + k * E_{fs} * d^2 \qquad d < 0$$

$$k * E_{elec} + k * E_{amp} * d^4 \qquad d \geq 0$$

VI. DRAWBACKS OF DISTRIBUTED LEACH PROTOCOL

Though there are various advantages offered by the distributed LEACH protocol, it carries with it some disadvantages that can't be neglected. The problems with the LEACH protocol can be listed as follows:

1. The cluster head node is selected on random basis due to which some shortcomings occur. After some rounds the chances of each node to become a cluster head node is same. The nodes of different energy levels have the same chances of becoming cluster head node. In case if a node with less energy remaining becomes cluster head node then it will die earlier & will consequently make the network lifetime shorter.
2. The clusters are formed dynamically in each round which also affects the overall performance of network. Some clusters have more nodes while some will have lesser nodes. In some clusters, the cluster head remains at the center while in some clusters it has its position at the circumference. This uneven distribution of clusters indirectly creates an unbalanced energy loads on the cluster head nodes.
3. In the steady state phase of LEACH protocol, the cluster head node of each cluster sends the fused data to the Base Station directly. Different cluster head nodes are located at different distances from the Base Station. The cluster heads which are located at farther distances from the Sink consume more energy to communicate with the Sink than the energy needed by the nearer cluster heads. This drawback gets highlighted more in the larger network.
4. The radio of cluster head nodes is always on and their energy keeps on dissipating continuously. Due to this they are more prone to failure & when any cluster head node fails, then the cluster to which it belongs will collapse & the data aggregated by the head node will get lost & will never reach the base station.
5. Random selection is done for the cluster heads, so there is a possibility that many cluster head nodes are concentrated in the same area.
6. Extra overhead is required for repeated cluster formation, cluster head selection, advertisement messages, etc.

VII. CONCLUSION

The main concern of this paper is to analyze the role of LEACH protocol in balancing & managing the energy load in wireless sensor network. In this paper we have studied only the LEACH protocol, it can also be compared with other protocols which may or may not be hierarchical in nature. We studied the positive effects of this protocol & also its disadvantages. LEACH protocol is good enough to manage the energy requirement but still it needs some improvement. The field of Wireless Sensor Network is rapidly growing & hence it needs protocols that in addition to efficient communication also reduce the energy dissipation and balance the energy load in the network which in turn will prolong the life-time of the network.

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