Comparative Study of Variants of Low Energy Adaptive Clustering Hierarchy (LEACH) Protocol in Wireless Sensor Networks

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Abstract— Wireless Sensor Network (WSN) is an emerging technology that shows great promise for various futuristic applications both for mass public and military. The sensing technology combined with processing power and wireless communication makes it lucrative for being exploited in abundance in future. They are very useful for military, environmental, and scientific applications to name a few. Routing is a very important phase in any type of communication. Moreover, Routing procedure consumes more power than any other phase. Therefore, if some changes are made in this phase, then drastic changes in energy consumption may be observed. LEACH (Low Energy Adaptive Clustering Hierarchy) is designed in such a way that it consumes less energy comparatively. If still, changes are done then it can be improved. In this paper, LEACH protocol functioning is explained. In addition to this, variants of LEACH are discussed in brief.

Keywords: Wireless sensor network, routing, routing protocols, energy efficiency, issues, applications

I. Introduction

Wireless Sensor Networks have recently emerged as a premier research topic. They have great long term economic potential, ability to transform our lives, and pose many new system-building challenges. Sensor networks also pose a number of new conceptual and optimization problems, some of these such as location, deployment, and tracking, are fundamental issues, in that many applications rely on them for needed information. Coverage in general, answers the questions about quality of service (surveillance) that can be provided by a particular sensor network. The integration of multiple types of sensors such as seismic, acoustic, optical, etc. in one network platform and the study of the overall coverage of the system also presents several interesting challenges[1].

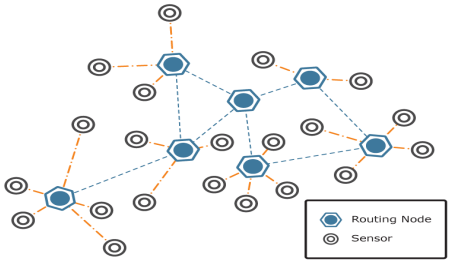

Fig. 1: Flow of Routing in WSN

With the refinement of energy harvesting techniques that can gather useful energy from vibrations, blasts of radio energy, and the like, self-powered circuitry is a very real possibility, with networks of millions of nodes, deployed through paintbrushes, injections, and aircraft. Also, the introduction of an additional type of sensor nodes allowing the network to self-organize and "learn", by embedding s mart and adaptive algorithms. On the other hand, the use of adaptive power control in IP networks that utilizes reactive routing protocols and sleep-mode operation, more powerful mobile agents, QoS (Quality of Service) to guarantee delivery, security mechanisms, robustness and fault-tolerance. Wireless sensors have become an excellent tool for military applications involving intrusion detection, perimeter monitoring, and information gathering and smart logistics support in an unknown deployed area. Some other applications: sensor based personal health monitor, location detection with sensor networks and movement detection.

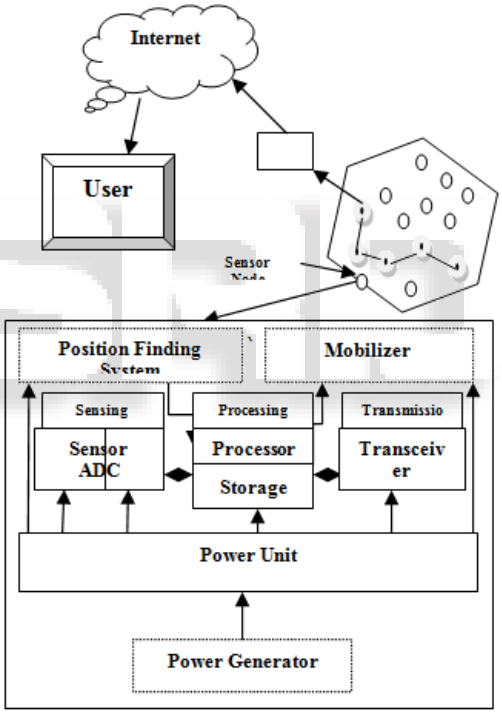

Fig. 2: Architecture of WSN Node

In this paper, we try to survey the Wireless Sensor Networks Issues and numerous Applications that utilize wireless sensor networks and classify them in appropriate categories. As the on-going interest for this research area is intense, we feel that a recording of these recent applications and trends will be useful for perceiving new applications, or relevant research problems, especially from the point of view of control and systems science[1][2][3].

II. Applications and Issues

A. Applications

Applications of Wireless Sensor networks are:

- Security applications
- Industrial control
- Environmental monitoring

– Traffic control

B. Issues

The design of routing protocols for WSNs is challenging because of several network constraints. WSNs suffer from the limitations of several network resources, for example, energy, bandwidth, central processing unit, and storage. The design challenges in sensor networks involve the following main aspects:[5]

– Limited energy capacity
– Sensor locations
– Massive and random node deployment
– Network characteristics and unreliable environment
– Data Aggregation
– Diverse sensing application requirements
– Scalability

III. Network Characteristics and Design Issues

The characteristics of sensor networks and application requirements have a decisive impact on the network design objectives in term of network capabilities and network performance [5][6].

A. Network Characteristics:

As compared to the traditional wireless communication networks such as mobile ad hoc network (MANET) and cellular systems, wireless sensor networks have the following unique characteristics and constraints:

– Dense sensor node deployment
– Battery-powered sensor nodes
– Severe energy, computation, and storage constraints
– Self-configurable
– Unreliable sensor nodes
– Data redundancy
– Application specific
– Many-to-one traffic pattern
– Frequent topology change

B. Network Design Objectives:

Most sensor networks are application specific and have different application requirements. Thus, all or part of the following main design objectives is considered in the design of sensor networks [7]:

– Small node size
– Low node cost
– Low power consumption
– Scalability
– Reliability
– Self-configurability
– Adaptability
– Channel utilization
– Fault tolerance
– Security

IV. Functioning of Leach and Its Variants

There are many types of routing in WSN. Mainly classified in , Hierarchical Routing, Data Centric Routing, Flat Network Routing, Location Based Routing, Quality of Service based Routing etc. LEACH (Low Energy Adaptive Clustering Hierarchy) protocol is energy efficient protocol among all other hierarchical routing protocols. Therefore, if some changes can be made, the LEACH protocol can be more energy efficient protocol. LEACH and Variants of LEACH are described below.

A. Functioning of LEACH:

Low Energy adaptive clustering hierarchy (LEACH)[11] is a popular energy efficient adaptive clustering algorithm that forms node clusters based on the received signal strength. The cluster head (CH) aggregates the sensed data from all transmits it to the BS LEACH assumes that the base station is immobile and is located far from the sensors. All nodes are capable of communicating with the BS directly. At any point of time, all the nodes have data to send and nodes located close to each other have co-related data. The cluster head (CH) can perform data aggregation and data dissemination.

In LEACH the nodes form local clusters with one of the nodes acting as a local sink or cluster head. If the same node would remain as the cluster head throughout the working of the network, it would die quickly because of the extensive load from the participating sensors in the cluster. Hence the rotation of the cluster head in every round is necessary to distribute the load uniformly. Further energy dissipation can be reduced by aggregating the data from various sensor nodes at the cluster head. The operation of LEACH is broken up into rounds where each round begins with a setup phase, followed by a steady state phase.

The set up phase follows the following sequence

1) CH Selection:

Every round begins with a CH selection each node in the network decides whether to become the CH for the current round or not. Depending on the required percentage of cluster heads for the network and the number of times the node has been a cluster head.

2) Cluster Formation:

Once the CHs have been selected, they advertise themselves to the remaining nodes. Based on the signal strength, the nodes decide which cluster to join.

3) Transmission Schedule Creation:

Based on the number of nodes in the cluster, the CH allots different time slots for each node to transmit by adopting the basic time division multiple access (TDMA) scheduling.

In the steady state phase, the nodes transmit the sensed data to the CH and the CH aggregates the original data to carry only meaningful information. The aggregated data is then transmitted to the BS by CHs. LEACH enhances the network lifetime by utilizing the resources efficiently, distributing the load uniformly, aggregating data at the CH to contain only the meaningful information, rotating the CH randomly to achieve balanced energy consumption. Also, the sensors do not need to know the location or distance information.

Leach was proposed for the reduction of the power consumption. Leach involves the data aggregation (fusion) process which combines the original data into a smaller sized data[8] Leach is completely distributed which requires the global knowledge about the network. In order to

achieve the design goal the key tasks performed by Leach are as follows[8][9]:

- Randomized rotation of the cluster heads and the corresponding clusters
- Global communication reduction by the local compression
- Localized co-ordination and control for cluster setup and operation
- Low energy media access control
- Application specific data processing

The main drawbacks in Leach are as follows:

- The time duration of the setup phase is non-deterministic and the collisions will cause the time duration too long and hence the sensing services are interrupted. Due to that Leach may be unstable during the setup phase that depends on the density of sensors.
- Leach is not applicable to networks that are deployed in large region as it uses single hop routing where each node can transmit directly to the cluster head and the sink
- The cluster heads used in the LEACH will consume a large amount of energy if they are located farther away from the sink.
- Leach does not guarantee good cluster head distribution and it involves the assumption of uniform energy consumption for the cluster heads.
- Leach uses dynamic clustering which results in extra overhead such as the head changes, advertisement that reduces the energy consumption gain.

B. Variants of LEACH Protocol:

1) LEACH-A (Advanced Low Energy Adaptive Clustering Hierarchy):

In LEACH-A, the data is been processed using mobile agent technique which is based on LEACH protocol. This protocol proposed a heterogeneous energy protocol for decreasing the node's failure probability and for prolonging the time interval before the first node dies which called as stability period. By the use of a synchronized clock, each sensor node would about to know the starting of each round for transferring of information. The maximum energy nodes are selected as cluster head for each cluster and these nodes are called as CAG node. Leach-A protocol having the following advantages compared to LEACH [7, 11],

a. The fusion of the data is done to reduce the amount of information that been transmitted to the base station. b. Maximum energy can be saved by using TDMA/CDMA techniques that allows hierarchy and makes clustering on several levels. c. The CAG nodes continue to send data to the sink after the death of other normal nodes also.

2) LEACH-B (Balanced Low Energy Adaptive Clustering Hierarchy):

In LEACH-B for the cluster formation purpose it uses the de-centralized algorithms in which each sensor node only knows about its own position and the destination node position where actually the information will going to receive, and it does not know about any other sensor node position. In LEACH-B, Cluster formation and data transmission are done with the help of multiple accesses to different nodes. After this how much the energy is been dissipated in the path between destination node and originating node is being calculated and based on this only each of the sensor nodes would choose its own cluster heads. Compared to LEACH efficiency of LEACH-B is much higher [9, 11].

3) LEACH-C (Centralized Low Energy Adaptive Clustering Hierarchy):

LEACH-C uses a centralized clustering algorithm and same steady-state protocol as LEACH. In the set-up phase of LEACH-C, each node would send its current locationposition and energy level information to the sink node. Based on this information from the sensor nodes the BS will determine the different clusters along with CH node and non-CH nodes of each and every cluster. The BS would able to produce better clusters by utilizing its global information of the whole network and by this process less energy is being consumed for data transmission purpose. In LEACH-C the number of CHs in each round is equals to a predetermined optimal value, whereas in LEACH the number of CHs would varies from round to round because of the lack of global coordination between different nodes in the network [2, 6, 7, 8, 9, 11, 12, 13].

4) C-LEACH (Cell Low Energy Adaptive Clustering Hierarchy):

In C-LEACH sensor network would divided in different sections called as cell and each cell includes several sensors. One sensor node in the cell is selected as cell head. Cluster is being formed by combing seven nearby cells, and each cell would have a cluster-head (CH). The cell-heads and CHs would change dynamically in every round of transmission of information in the network. Cell- head would allocate a time to each sensor nodes on the basis of TDM (Time Division Multiplexing), and each cell should transfer its data to the cell-head in this sliced time only. The same would apply for transferring of data from cell-head to cluster-head also. In the time of transmission of information in the network, the entire cell will remain off except the node which has been given the slice time for transmission of information to the cell-head. The cell head will aggregate the information and it send to its respective CH, and process would repeated in the CH also [4, 6, 11, 12,].

5) E-LEACH (Enhanced Low Energy Adaptive Clustering Hierarchy):

E-LEACH would able to improve the LEACH protocol in two main aspects of routing and transmission of information in the network. E-LEACH would choose a cluster head for the clusters in the sensor networks that having non-uniform starting energy level among all the sensor nodes. It also able to determine that the required number of cluster heads has to scale as the square root of the total number of sensor nodes to minimize the total energy consumption in the network. All the other aspects rather than these two above mentioned aspects of E- LEACH are the same as LEACH protocol [2, 6, 11, 12].

6) LEACH-F (Fixed no of cluster Low Energy Adaptive Clustering Hierarchy):

In LEACH-F clusters are formed at the beginning of the network setup and after that are being fixed. The cluster head position rotates among the nodes within the cluster that

is same as LEACH. The advantage of this process compared to LEACH is that, there is no set-up overhead at the beginning of each round. For clusters formation, LEACH-F uses centralized cluster formation algorithm that is same as LEACH-C. The disadvantage of this protocol is that the fixed clusters in LEACH-F do not allow new nodes to be added to the network and do not adjust their behavior when any node dies in the network [2, 9, 11].

7) I-LEACH (Improved Low Energy Adaptive Clustering Hierarchy):
In I-LEACH protocol two main functions it serves are, a) Detection of Twin nodes and b) Assignment of Sub- Cluster Head (SCH) nodes. The two nodes closes to each other in the network are called as Twin node. These kinds of node would sense the same information. Therefore it is necessary to keep one of the two twin nodes in sleep mode until the first node would run out of energy. I-LEACH addresses the uniform distribution of CH in the network so that it does not run out of energy for longer distance of transmission. It also addresses the matter of managing the threshold no of cluster members by every CH [3, 11, 13].

8) LEACH-L (Energy Balanced Low Energy Adaptive Clustering Hierarchy):
LEACH-L is an advanced multi-hop routing protocol. It is suitable for large area covered WSNs. In this, the cluster heads can able to communicate directly to the sink node when these sensor nodes are located close to the sink. When sensor nodes are located too far from the sink, they can communicate to the process of multi-hop way. In LEACH-L, the sensor nodes are allowed to use different frequencies and also different frequency gaps to communicate to the sink node. The clusters would re- establish in every round of transmission of information in the network which consists of both setup phase and steady state phase. In every round new CHs would elect for every cluster and the network load would be distributed among every node and thus balanced among the nodes would remain perfect in the network [9, 11].

9) LEACH-M (Mobile Low Energy Adaptive Clustering Hierarchy):
LEACH-M is been proposed to overcome from the mobility issue which is an important issue in LEACH protocol. During the setup and steady state phase, LEACH-M provides mobility to the non-CH nodes along with CH. In LEACH-M the nodes' location assumed to be gain by the GPS process along with the characteristics of the nodes to be assumed to be homogeneous. The CHs are being chooses on the basis of minimum mobility of the node and lowest attenuation mode of the node. After this process the status of the CHs are being broadcasted within its transmission range [9, 10, 11].

10) LEACH-S (Solar aware Centralized and Distributed Low Energy Adaptive Clustering Hierarchy):
In Centralized LEACH-S, the sink node would select the CHs with the help of improved central control algorithm. In Leach-S, the solar status along with the energy of the sensor nodes is being transmitted to the sink and the nodes with having the higher energy are selected as the CHs. When the number of solar-aware nodes is getting increased, the performance of sensor network is also get increased and by this the lifetime of the network also get increased. In Distributed LEACH-S, the solar driven nodes are given more preference than the battery driven nodes for choosing CHs [9, 10, 11].

11) Q-LEACH:
Q-LEACH divides the cluster into four quadrants geographically. According to this approach sensor nodes are deployed in the territory. In order to acquire better clustering the network is partitioned into four quadrants. Doing such sort of partitioning better coverage of the whole network is achieved. Additionally, exact distribution of nodes in field is also well defined [12][13].

12) TL-LEACH (Two level Low Energy Adaptive Clustering Hierarchy):

Clusterig Routing Protocol	**Mobility**	**Scalability**	**Self-Organization**	**Distributed**	**Hop Count**	**Energy Efficiency**	**Homogeneous**	**Use of location Information**	**Data Aggregation**
LEACH	Fixed BS	Limited	Yes	Yes	Single Hop	High	Yes	No	Yes
A-LEACH	Fixed BS	Good	Yes	Yes	Single Hop	Very High	Yes	Yes	Yes
LEACH-A	Fixed BS	Good	Yes	Yes	Single Hop	Very High	No	No	Yes
LEACH-B	Fixed BS	Good	Yes	Yes	Single Hop	Very High	Yes	Yes	Yes
LEACH-C	Fixed BS	Very Good	Yes	No	Single Hop	Very High	Yes	Yes	Yes
C-LEACH	Fixed BS	Very Good	Yes	Yes	Single Hop	Very High	Yes	Yes	Yes
LEACH-E	Fixed BS	Very Good	Yes	Yes	Single Hop	Very High	No	Yes	Yes
E-	Fixed	Good	Yes	Yes	Single	Very	Yes	Yes	Yes

LEACH	BS				Hop	High			
LEACH-F	Fixed BS	Limited	Yes	No	Single Hop	Very High	Yes	Yes	Yes
I-LEACH	Fixed BS	Very Good	Yes	Yes	Single Hop	Very High	Yes	Yes	Yes
LEACH-L	Fixed BS	Good	Yes	Yes	Multi Hop	Very High	Yes	Yes	Yes
LEACH-M	Mobile BS and Nodes	Good	Yes	Yes	Single Hop	Very High	Yes	Yes	Yes
M-LEACH	Fixed BS	Very Good	Yes	Yes	Multi Hop	Very High	Yes	Yes	Yes
LEACH-S	Fixed BS	Very Good	Yes	Yes	Single Hop	Very High	Yes	No	Yes
TL-LEACH	Fixed BS	Very Good	Yes	Yes	Single Hop	Very High	Yes	Yes	Yes
V-LEACH	Fixed BS	Very Good	Yes	Yes	Single Hop	Very High	Yes	Yes	Yes

In LEACH protocol, the CH sends the aggregated data to the sink directly. Due to this process CHs would die very early compared to the other sensor nodes due to energy loss for transmission of information to the sink because sink node may be located too far away from the CHs might be located far away from the BS. To overcome from this TL-LEACH was been proposed. In this CH collects information as LEACH protocol, but for transmission to the sink it uses one of the CHs that lies between the CH and the sink as a relay station [8, 11, 12].

13) LEACH-F:

In this, it is proposed that, the number of clusters throughout the network is fixed. Cluster Head nodes can rotated within clusters of the same network. Here, data transmission phase is same as that of LEACH. The energy consumption minimization is not fixed in this proposed protocol. It also violates the flexibility to mobility of sensor nodes and scalability of network [10].

14) Multihop LEACH:

It is observed that when the network diameter increases, the distance between cluster head and base station will increase enourmously. This is not suitable for the efficient communication. So, multihop communication will be carried out in order to decrease the energy consumption of the network [11].

15) Energy-LEACH:

It makes the cluster head selection method efficient by making the residual energy of the cluster head nodes as vital factor. It will decide whether these cluster nodes turn into the cluster head or not in the next round. E-LEACH will make better election process of cluster head nodes. This will result in longer lifetime and energy saving compared to LEACH protocol[11].

V. CONCLUSION

In this paper, wireless sensor networks are elaborated with their applications and network issues, characteristics. Routing is very vital in WSN. Moreover, WSN is works using energy of the sensor node. Therefore, energy efficiency of any routing protocol is important parameter for prolonging the network lifetime. LEACH consumes less energy comparatively. More research has been and is being done in this field to minimize the energy consumption of network. Various variants of LEACH are described in this paper.

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