Multi-level LEACH Protocol model using NS-3

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***Abstract*—A Wireless Sensor Network (WSN) consists of a large number of tiny devices called sensor nodes, which are usually deployed randomly over a wide area in order to sense and monitor various physical phenomena related parameters including environmental conditions at various locations. The WSN nodes communicate with each other. WSN devices have various resource constraints such as less memory, low clock speed, finite battery energy, and limited computational power. It may not be feasible to replace the batteries in the WSN nodes. As all the nodes are battery operated it is necessary to conserve the limited battery energy so that the lifetime of the network can be extended. Network lifetime, energy efficiency, load balancing and more over scalability are some key requirements of WSN applications. This work presents a multi level hierarchical routing protocol, which is based on the LEACH protocol. This protocol improves both the energy efficiency and the lifetime of the network. Two-level LEACH (TL-LEACH), Three-level LEACH (3L-LEACH) and Four-level LEACH (4L-LEACH) have been presented. NS-3 simulation platform has been used to carry out performance analysis of these hierarchical routing protocols. The performance analysis shows that the hierarchical routing protocols, TL-LEACH, 3L-LEACH and 4L-LEACH fare better than the LEACH protocol.**

Keywords : WSN, LEACH, network lifetime, energy efficiency.

I. INTRODUCTION

A Wireless Sensor Network (WSN) consists of a many spatially distributed sensor nodes [1], which are used to monitor various kinds of climatic conditions such as temperature, humidity, sound, moisture, etc. WSN's find their applications in various fields such as military, medical, agriculture, disaster management, green house monitoring and industrial monitoring, etc. [2]. A WSN node or a mote has a radio transceiver, a micro-controller and memory, sensors and batteries. A mote is capable of gathering the sensed data, perform some processing related to the data, and communicate with other neighbouring nodes. Free radio, spectrum allocation and moreover global availability can be obtained by sensor node by making use of ISM band. Usually sensors are small in size and less expensive. These sensor devices have the capability to communicate with the Base Station (BS) directly and also among themselves. Usually the nodes are deployed in the field, where we need to monitor certain physical phenomena related parameters. The communication among the nodes need to be coordinated so as to transfer the sensed parameter related data towards the BS using multi-hop wireless communication links formed by the nodes. Certain WSN applications have security as an additional requirement [3].

Energy plays a major role in a WSN [4], as all the nodes are battery operated. It is necessary to conserve the energy so as to extend the networks lifetime. Consequently, many protocols have been proposed in order to reduce the energy consumption in the nodes.

Among the existing routing protocols, Low Energy Adaptive Clustering Hierarchical (LEACH) [5] protocol has been considered as it is an energy efficient routing protocol that creates many groups or clusters of nodes in the WSN and aggregate the data within a group and the aggregated information is sent towards the BS instead of sending each and every data item from every node and thereby improving the energy efficiency of the WSN. In this, the cluster heads(CHs) are elected among the nodes for every round and the same CH role is rotated such that the load is distributed equally within the cluster. By creating the clusters [4] of the nodes the sensed data from a node is sent to its CH, instead of transmitting it directly to the BS. The performance of the LEACH protocol in terms of energy efficiency and network lifetime is more compared with that of direct simulation. As area of network increases the cluster heads which are far away from the BS will drain soon, as a result number of nodes will be dead within few number of rounds. By adopting Hierarchical routing protocol the energy efficiency can be improved drastically. Hierarchical routing protocol performs well then LEACH due to improved clustering formation in the hierarchical routing protocol.

One of the predominant applications of WSN is in Earth monitoring. And many applications related to earth science research such as ocean monitoring, volcanoes, forests and agriculture etc. have been reported. As we know that ocean covers almost 71 % of the earth's surface. By monitoring the ocean we can detect the submarine volcanoes, glaciers, water levels and ocean related hazards. So there is a need to monitor water levels, currents and harsh environment in the ocean and WSN's can be used to monitor. In forest fire detection applications our sensor nodes are generally equipped with some fire sensing elements, it detects smoke and fire. And in the area of agriculture, WSN's plays an important role. The use of WSN in precision agriculture provides the real time analysis of different crops. As sensors are very small and less expensive more farmers have been using WSN's for the crop management. As WSN is cost effective, it is possible to monitor a large crop area. This type of approach in precision agriculture is easily scalable.

Early detection of an event is important so that related

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remedial measures can be undertaken sooner. Thus, a WSN can be used in monitoring, analysing and protecting various natural resources. In these applications, the area to be monitored is very large. In order to cover such large areas Hierarchical routing protocol needs to be used.

The rest of the paper is organized as follows: Section II discusses the LEACH protocol and its operation and section III presents ns-3 simulator related aspects. The proposed protocol is discussed in section IV. The simulation results are presented in section V and finally section VI concludes the work.

II. LEACH PROTOCOL

Low Energy Adaptive Clustering Hierarchy(LEACH) is a hierarchical cluster based routing protocol [6] used in WSN applications. It divides the network nodes into clusters. By clustering the nodes organize themselves into a hierarchical structure. In each cluster, a cluster head(CH) is elected that takes responsibility of TDMA schedule handling [7] among its members and send the aggregated data towards the BS. LEACH assumes that each node has sufficient RF transmit power so as to reach the BS or the nearest CH and send the data either directly to the BS or to its CH. The nodes elect their respective CH's after the deployment and forward the data to the respective CH as shown in Figure 1. With this approach each node can conserve its limited battery energy. However, the additional responsibility of being a CH results in further energy drain in the nodes acting as CH's. LEACH, addresses this problem by randomized rotation of CH among the nodes in a group. LEACH uses TDMA/CDMA techniques in order to reduce any cluster collisions.

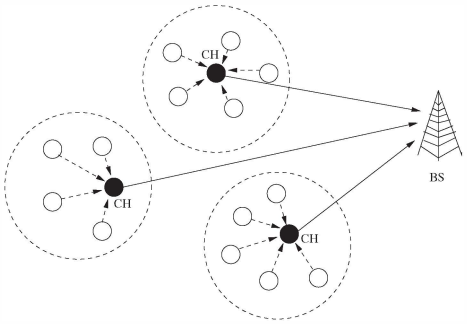

Fig. 1. LEACH clustering model

The functioning of the LEACH involves many rounds. Each of the LEACH rounds consists of the following two phases:

A) Set up phase *B*) Steady state phase

1) Set up phase: The CH's are chosen randomly among the nodes during the set up phase and several clusters [8] are formed dynamically. Initially, each node generates a random number in the range from 0 to 1. If it is less than a threshold, $T(n)$, that node is elected as a CH for the current round. This decision also involves the past history of the node being CH [9]. The T(n) is given in equation (1) [10].

$$T(n) = \begin{cases} \dfrac{CP}{1 - CP[r * mod(\frac{1}{CP})]} & n \in G, \\ 0 & \text{elsewhere} \end{cases} \quad (1)$$

where CP is the percentage of the number of clusters in the network, r is the number of election rounds, ($r \mod \frac{1}{CP}$) is the number of nodes which have been elected as cluster heads in the round r, and G is the set of nodes that have not been elected as cluster heads in round r.

Once the CHs are elected, they broadcast advertisement messages. Based on the received signal strength, each non-cluster head node chooses its CH, in case it is able to hear more than one broadcast message, for that round. Each non-cluster head transmits a join request message containing its ID back to its chosen CH using a CSMA. After the set up phase, each CH knows its members and their respective ID's.

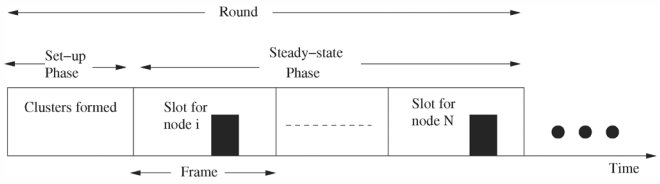

Fig. 2. Time-line operation of LEACH [5]

2) Steady state phase: Once the clusters are formed, the CH allocates its TDMA schedule to its member nodes. Based on the schedule each member node transmits the sensed data to its CH. Once CH collects all the data from its members, it transmits the aggregated data [11] along with its own data to the BS. The duration of steady state phase is longer than the set up phase. After certain time, the network again enters into set up phase of another round. After each round the CHs are re-elected to form new clusters. Thus the lifetime of the network can be estimated based on the number of rounds. Figure 2 shows the time line operation consisting of set up and steady state phases of the LEACH protocol.

A. Energy Radio Model

Different characteristics of radio provide different energy dissipations in transmit and receive modes. In this work, we use simple characteristics of radio that dissipate transmit electronics E_{elec} at a rate of 50nJ/bit. This is the minimum requirement for the transmitter to run or the receiver circuitry and the transmit amplifier. ϵ_{amp} = 120 $pJ/bit/m^2$ in order to achieve an acceptable range of SNR.

In order to transmit n- message bits at a distance of d meters the energy requirement for transmit [12] is given by equation (2) and to receive the message is given by (3).

$$\begin{aligned} E_{Tx}(n,d) &= E_{Tx-elec}(n) + E_{Tx-amp}(n,d) \\ &= E_{elec} * n + \epsilon_{amp} * n * d^2, \end{aligned} \quad (2)$$

$$\begin{aligned} E_{Rx}(n) &= E_{Rx-elec}(n) \\ &= E_{elec} * n, \end{aligned} \quad (3)$$

where

E_{elec} = Minimum electronics energy required to run Tx or Rx circuitry,
$E_{Tx-elec}$ = Energy consumed due to transmit electronics
$E_{Rx-elec}$ = Energy consumed due to receive electronics
ϵ_{amp} = Transmit Amplifier Energy consumption
n - number of message bits
d - distance in meters
E_{Tx} = Total Transmit energy consumed
E_{Rx} = Total Receive energy consumed

B. Limitations of LEACH protocol

Although LEACH protocol conserves energy in the nodes and prolongs the lifetime of the WSN application, it still has the following problems:

- Randomized rotation of the CH without considering the residual energy in the nodes.
- As the network size increases the CH's which are far away from the BS drain their energy sooner.
  If the deployment area is less, the LEACH protocol works well.

Since the LEACH protocol cannot be used over large areas, a Hierarchical routing protocol based on the LEACH is given in [13].

III. NS3 SIMULATOR

As of now there are few simulator like OmNET++, NS-2, Java based JiST in order to model WSN's [14]. NS-3 is relatively a new simulator where different WSNs cam be modelled. NS-3 can be used to model a network by specifying its characteristics and also those of various types of communication channels. NS-3 has been gaining attention due its unique features.

NS-2 lacks software maintenance and realism of the models. On the other hand in order to carry out a large scale network in an efficient way we can make use of NS-3. The unique characteristics of NS-3 are: network scalability and realism to the actual models implemented with different network characteristics. There are not many modules for NS-3. When compared to other simulators, NS-3 is better in terms of performance and memory usage. In this paper, we have made use of the energy module related to Hierarchical routing protocol. And we have created a large WSN simulation model consisting of 10,000 sensor nodes and evaluated the performance of hierarchical routing protocol which is LEACH protocol based.

IV. PROPOSED PROTOCOL

Few routing protocols for WSNs which are energy efficient have been given in [15], [16]. In LEACH protocol each CH directly communicates with the BS by increasing the transmit power appropriately [17]. In a WSN application where the nodes are deployed over a large area the LEACH cannot be relied upon. In order to overcome this problem an extension of LEACH, a Hierarchical routing protocol as given in [13], in which the CHs are divided into various levels so that each CH at a level i transmits the data to its higher level, $(i+1)$-level CH, instead of transmitting the data to the BS directly. In this work, the following Hierarchical routing protocols are considered:

A) Two-level LEACH (TL-LEACH) *B*) Three-level LEACH (3L-LEACH)

A. TL-LEACH

In this, we have a two- level structure consisting of leaf nodes, level-1 CH's, level-2 CH's. One of the level-1 CH's is chosen as level-2 CH as shown in figure 3. After collecting the data, a level-1 CH forwards the same to its level-2 CH. This level-2 CH aggregates the data received from its level-1 CH's and the same aggregated data is forwarded to the BS resulting in energy savings.

The operation TL-LEACH can be divided into the following 3 phases, namely:

1) Selection of level-1 and level-2 CH's
2) Set up phase
3) Steady state phase

1) Selection of level-1 and level-2 CH's: In this the level-1 CH is elected as given in the LEACH protocol. After the election of level-1 CHs, the level-2 CH election is initiated. Among level- 1 CHs, the CH with maximum residual energy and proximate to the BS is elected as the level-2 CH as shown figure 3. In addition to its current role as level-1 CH, the node also act as level-2 CH as well.

2) Set-up Phase: After the election of level-1 CHs, each CH broadcasts an advertisement message to all its leaf nodes. Each leaf node based on received signal strength from all the CHs, it decides which CH join. Then each leaf node transmits an acknowledgement message to its chosen CH along with its node ID. Each level-1 CH records the node IDs of its member nodes.

The set up phase for level-2 CH is also similar. In this case, level-1 CHs are treated as the leaf nodes. Each level-1 CHs sends a message containing the number of its member and its own node ID to the elected level-2 CH. Thus, a level-2 CH has information regarding its level-1 CHs and their associated leaf nodes. So based on this information a level-2 CH creates a TDMA schedule to its members and broadcasts a message.

3) Steady state phase: In the steady state phase transmission of the data takes place. Each leaf node sends the sensed data to its respective CH within its allocated time slot. Until their allocated time slot the leaf nodes can turn off their radio so that energy can be saved. All the leaf nodes transmit their data to its respective level-1 CH. And the level-1 CHs aggregate all the sensed data. The aggregated data received by the level-1 CH is forwarded to their level-2 CH based on its allocated time slot. Thus the data collected by the level-2 CH is sent to the BS. Thus the data from a leaf node to the BS is transmitted using level-1 CH and then level-2 CH. Considerable energy in the WSN application can be saved with this type of hierarchical routing.

B. 3L-LEACH

As the network size increases because of the area of the WSN application, we can extend the LEACH from 2-level to

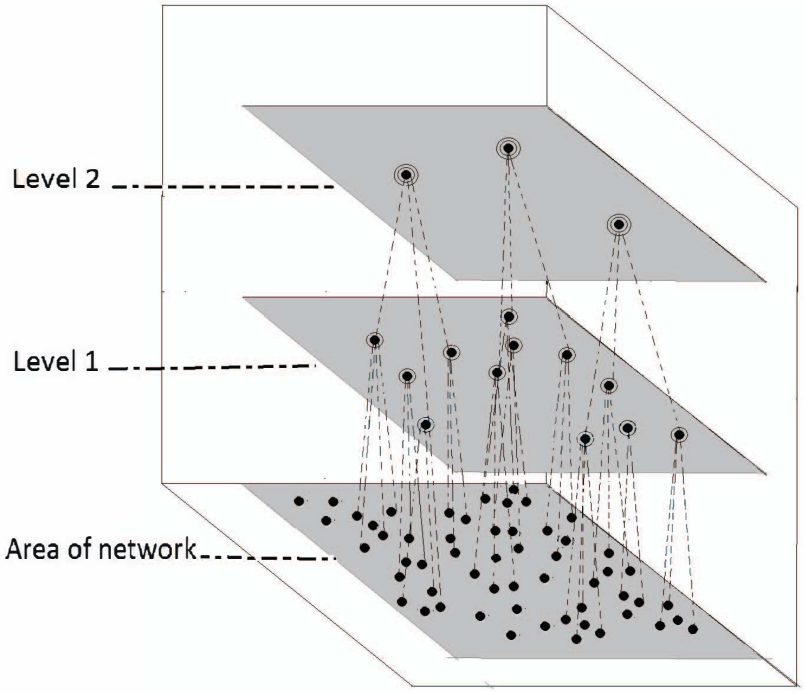

Fig. 3. Two level LEACH hierarchical structure

3- level LEACH further. The operation of 3- level LEACH is similar to that of Two- level LEACH [13]. The operation of 3L-LEACH can be broken into 3 phases in the similar manner as in TL-LEACH.

1) Selection of CH's: The level-1 and level-2 CH's are selected similar to that of TL-LEACH. From the level-2 CH's based on residual energy left among the level-2 CHs and the one which is nearer to BS is elected as level- 3 CH.

2) Set up phase: This is also similar to that of Two level cluster set-up phase. For level-3 CH the level-2 CH's form the group members. Each of the level-2 CH's sends a message containing its group members and the respective ID's to the level-3 CH. Thus level-3 CHs record a total number of level-2 CH's supported by it and all leaf nodes belonging to corresponding level-2 CH's. Level-3 CHs allocate a TDMA schedule to their respective level-2 CH's.

3) Steady state phase: Once the level-3 CH's are formed, the leaf nodes transmit the data to the level-1 CH's. Then, the level-1 CHs send the aggregated data to the respective level-2 CHs during the allocated time slots. The level-2 CH's collect the data and forward it to the level-3 CH. The level-3 CHs aggregate the data and the same is forwarded to the BS. Similarly we can have a 4L-LEACH in which 4- levels of CH's are elected and the data is forwarded to BS using these levels of CHs so that more energy can be conserved.

V. Simulation Results

A performance comparison of LEACH and the Hierarchical routing protocols, TL-LEACH, 3L-LEACH, 4L-LEACH using NS-3 is given. In this the nodes are randomly deployed in the area and the BS location is assumed to outside the WSN node deployment area. The parameters used for the purpose of simulation are given in Table I.

TABLE I
Simulation parameters

Parameter	**Value**
Routing Protocols	LEACH Hierarchical routing
Deployment area	10000 * 10000 m^2
Number of Nodes	5000, 10000
Data message	500 bytes
Packet size	25 bytes
Traffic type	Constant Bit Rate
% of Clustering	20 to 50
Initial battery power	1J
Energy Dissipated in Tx , Rx	50 nJ/bit
Transmit Amplifier	120 pJ/bit/m^2
Nodes Deployment	Random
BS location	Outside the WSN area

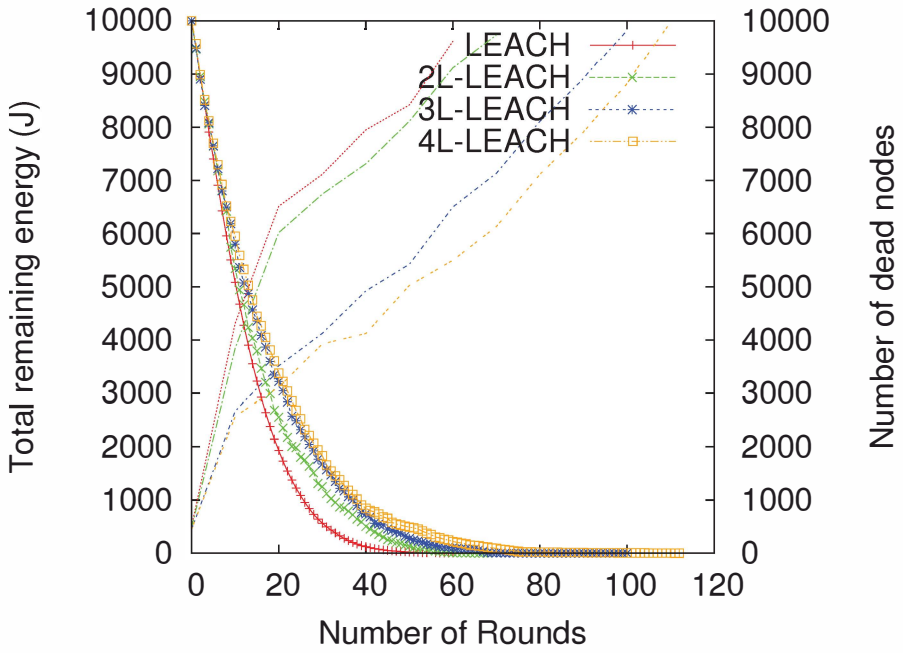

Fig. 4. Graph showing the total remaining energy and number of dead nodes vs. number of rounds

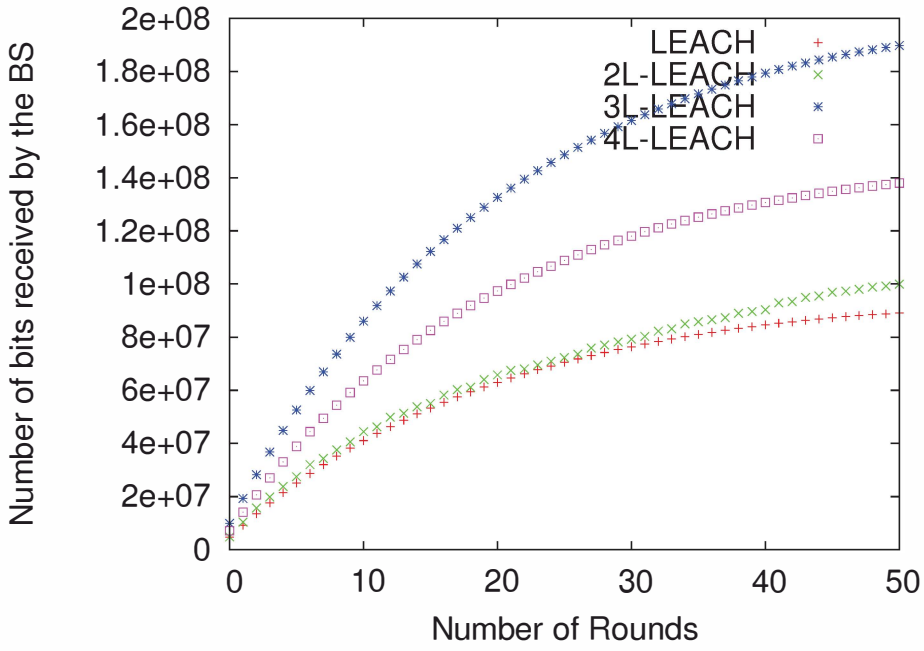

Fig. 5. Graph showing number of rounds vs number of bits received by BS

It can be observed from the simulation results as given in figure 4 that higher energy efficiency can be achieved by using Hierarchical routing protocol rather than the LEACH protocol alone. Generally in LEACH for a large coverage area, some of the CHs will be far away from the BS resulting in higher transmit power to send the data to the BS directly thereby draining the energy of the associated nodes and as a consequence they die very early. By using 2L-LEACH it can be noticed from figure 4 that an improvement in the energy efficiency when compared with LEACH. In this the data is sent to the BS using level-2 CH's resulting in the energy savings. The lifetime of network is less as the level-2 CHs need more energy to transmit the data to BS due to the longer distances In 3L-LEACH and 4L-LEACH, the CH's communicate with ith level CH's and $(i+1)$th level resulting in even distribution of the load among the nodes leading to longer lifetime of the network.

From figure 4, it can be observed that 4L- LEACH is able to last for higher number of rounds when compared to the LEACH protocol. Hence the lifetime of the network increases by using hierarchical routing protocol than the LEACH even for large coverage areas. It can be noticed from figure 4 that the percentage of dead nodes in a WSN using Hierarchical routing protocol is less when compared to that of the LEACH. In LEACH, the nodes die sooner resulting in lesser number of simulation rounds.

When the number of nodes deployed is increased to 20,000 in the given area, the number of simulation rounds for LEACH and Hierarchical routing protocol increases. Instead if the deployment area of network is increased for a given number of nodes the simulation rounds for the above protocols gets reduced.

Figure 5 shows the overall bits received by the BS over the duration lasting 50 rounds. It can be observed that higher amount of information is received by the BS using Hierarchical routing protocol when compared to the LEACH.

As the deployment area is extended, the number of nodes deployed and the total number of clusters increase. As a result the energy consumption also increases with the increased distances in LEACH and shortens the lifetime of the network. As the energy consumption is less in the Hierarchical routing protocols it prolongs the lifetime of the network relatively longer. Thus, the protocol performance discussed in this paper has a promising potential in terms of energy efficiency and network lifetime. Moreover, the hierarchical routing protocols are scalable meeting an important requirement of WSN's.

VI. Conclusion

In this work a simulation model using ns-3 tool for the LEACH protocol has been created. Various simulation models for the extensions of LEACH using three different Hierarchical routing protocols have been created. A performance analysis for the same has also been carried out. From the simulation results, it can be concluded that the multi-level Hierarchical routing protocol is more energy efficient when compared to the LEACH. The lifetime of the network also gets extended. As the deployment area of WSN increases, the 3L-LEACH and 4L-LEACH perform well when compared to the 2L-LEACH.

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