Energy Efficient Routing in Multi-Level LEACH for WSNs

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Abstract—**Energy efficient routing is the paramount point of significance in any wireless sensor network (WSN) so that the network sustains without any human intervention. Various energy efficient protocols have been proposed, multi-level Low Energy Adaptive Clustering Hierarchy (LEACH) being one among these. The multi-level LEACH protocol involves election of cluster heads at various hierarchical levels. If the area of deployment is large, the farther cluster heads cannot reach the base station directly. In such cases, it is needed to make use of an energy efficient routing technique for communication among cluster heads and forward the data towards the base station. Energy consumption is reduced by adopting routing mechanisms based on *multi-hop* and *inverted tree* in this multi-level LEACH protocol. This work deals with multi-level LEACH comprising of 1L-LEACH and 2L-LEACH. Directed diffusion carried out in 1L-LEACH and flat topology are compared with flooding. In directed diffusion, routing is done between a source and a sink optimizing the path taken. NS-3 simulation platform has been used and the results are presented.**

Keywords:- WSN, LEACH, inverted tree, directed-diffusion

I. Introduction

Wireless Sensor Networks (WSNs) find their applications in various diversified fields such as environmental, military, forest fire detection, intelligent homes and so on [1]. In these WSN applications, the nodes that are spread out can be either random or structured and in certain applications the nodes may not be accessible physically. The WSN must be able to exist on its own and last longer, hence energy optimization becomes crucial. Each WSN node contains a small battery, micro-controller (generally $8-$ bit), DC-DC converter, sensors, analog to digital converter (ADC) and radio (transmitter and receiver) electronics [2]. The major component of energy savings is radio electronics, where data transmission and reception take place. Energy consumption is proportional to square of distance transmitted and message length, whereas reception depends on message length [3]. Hence, wise routing mechanisms must be made use of.

Various data transfer mechanisms were proposed. Direct transmission and Minimum Transmission Energy (MTE) are two basic protocols [4]. In direct transmission, each node directly communicates to the base station (BS). Consequently, the nodes far away may die first. In MTE, each node forwards the data to the neighboring nodes until the BS is reached. The nodes proximate to the BS die first. Low Energy Adaptive Clustering Hierarchy (LEACH) is one of the energy efficient protocols [5] aimed at uniform energy distribution and prolonging the network lifetime. In LEACH, many clusters are formed in the network. Each member selects a CH based on the distance and number of members in that cluster. Cluster Heads (CH) are decided based on various election algorithms and the balance energy in those particular nodes [6]. They are elected in such a way that energy distribution remains uniform among all the nodes in the long run. Hence the rotation of CHs takes place in each round and every time a different node as a CH is elected. The cluster members transmit the data to the CH based on their allotted time slots. Each CH must now directly transmit its data to the BS.

In LEACH, if the network is spread over large areas, in the range of kilo meters, direct transmission from the CHs to the BS is infeasible. In such cases, routing must be done among the CHs so as to forward the data with the CHs to the BS. This paper discusses two routing techniques based on multi-hop and inverted tree models and the same have been simulated using NS-3 simulation platform. In multi-hop, the data is forwarded using the neighboring nodes in the direction of the BS and whereas, in inverted tree technique, a tree shaped structure is created such that the node nearest to the BS acts as the root node. In inverted tree method, each node maintains a routing table of all eligible parent nodes for transmission. It is assured that there always exists a path between each CH and the BS. In certain cases, where the BS or a node needs information about an event in the network, a query will be diffused into the network from the BS or node. The specific node then needs to transmit the data to the BS. This paper also discusses and compares the flooding and directed-diffusion approaches in flat topology and 1L-LEACH. The rest of the paper is organized as follows: section II discusses LEACH protocol, section III presents 2L-LEACH. The proposed protocols are given in section IV and the simulation results are discussed in section V and the final section concludes the work.

II. LEACH protocol

Low Energy Adaptive Clustering Hierarchy (LEACH) is based on cluster formation, which forms different hierarchical levels among the nodes by selecting few of these as CHs [5]. The main advantage LEACH has over the other protocols is the data aggregation from a group of nodes and the active sleep states that each node goes into during each round. First, clusters or groups of nodes are formed in the network,

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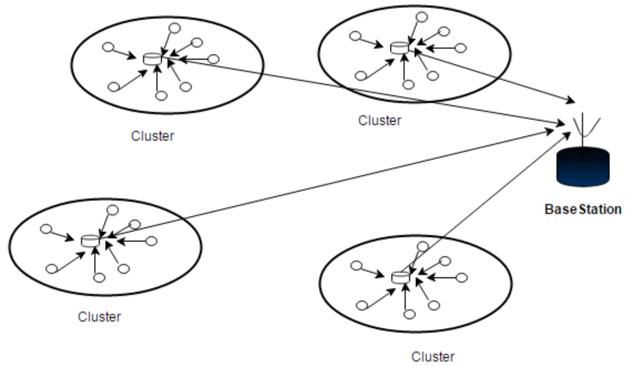

Fig. 1: LEACH schematic

which are almost of the same size and are nearby. The cluster members collect the data from physical environment and forward it to their respective CH using TDMA [7].

Fig. 1 shows a WSN using LEACH. Each CH sends the aggregated data collected from all of its cluster members directly to the BS using CDMA/FDMA. Hence, the CHs drain relatively large amounts of energy than their members. The role of a node being a CH need to be rotated after each round in order to maintain uniform energy distribution in the network. The operation of LEACH protocol comprises of two phases:

1) *Setup phase*, during which various clusters are formed.
2) *Steady state phase*, during which actual data transfer takes place.

A. Setup phase

In this phase, various clusters are formed. Each node generates a random number between 0 to 1 and if the number generated is less than the threshold value, evaluated by using equation (1) [8], the node assumes the role of a CH.

$$T(n) = \begin{cases} \frac{cp}{1-cp\times[r\times mod(1/cp)]} & n \in N, \\ 0 & elsewhere \end{cases} \quad (1)$$

where

cp is the percentage of CHs present in the network,
r is the round number,
N is the set consisting of all the nodes other than the CHs in the present round.

The CHs, which are selected by following the above process then broadcast an *advertisement* message indicating that they are CHs. This is similar to inviting the other nodes to join the cluster as members. The non-CH nodes may be able to receive more than one advertisement message. The non-CH nodes then decide which cluster to join based on the distance of the CH or the signal strength of the advertisement broadcast message. In reply, they send an *acknowledgment* message to the respective CHs indicating their association with a CH.

B. Steady state phase

After the formation of clusters, the data transfer begins. The nodes including CHs start collecting data. Each node present in the cluster starts transmitting data to the CH using TDMA based on the time slots allocated by the CH to its members. Each CH then aggregates the data of all its members and forwards the aggregated data combined with its own data to the BS. In order to reduce the amount of data to be forwarded to the BS the CH can calculate the average of all the values collected by its members and then forward it. Each CH similarly forwards its data to the BS based on CDMA/FDMA. The round then concludes and again new round starts by a setup phase again changing the CH each time. The radio-energy model taken for simulation follows the two equations taken from [9].

$$E_{transmit}(n,d) = E_{elec} * n + \epsilon_{amp} * n * d^2, \quad (2)$$

$$E_{receive}(n) = E_{elec} * n \quad (3)$$

where

E_{elec} - the energy require for transmission or reception circuitry,
ϵ_{amp} - transmit amplifier energy consumption,
n - length of the message in bits,
d - distance to be transmitted in meters

When a cluster member is transmitting the data to its CH, the remaining cluster members enter into sleep state by turning off the transmitter electronics thus saving their energy. They turn into active state again during their respective allotted time slots. This transition of each cluster members between active and sleep states is one of the main reasons for energy saving in LEACH.

The proposed protocol uses 1L-LEACH and 2L-LEACH. The 2L-LEACH is similar to LEACH with an additional hierarchical level. The CHs formed in LEACH again congregate to form second level clusters electing a *super* CH among them [9]. The data transfer takes place from the level -1 cluster members to the CH and data aggregated from the CHs to level -2 CHs. Level -2 CHs transmit data to the BS directly. In this work, two different routing mechanisms multi-hop and inverted tree have been implemented among the CHs. It is assumed that the nodes are deployed over a large area randomly. Consequently, the CHs cannot reach the BS directly and the need to route through the neighbours arises.

In LEACH, as the area of deployment increases, it is practically infeasible for the CHs to reach the BS directly. To reduce the number of CHs transmitting to the BS, additional hierarchical levels can be implemented as proposed in [9]. This work uses hierarchical levels and proposes the routing through two protocols so as to enhance the energy saving in the WSN. Also, the communication about occurrence of an event in the network, directed-diffusion, flooding in flat topology and directed-diffusion in 1L-LEACH have been compared.

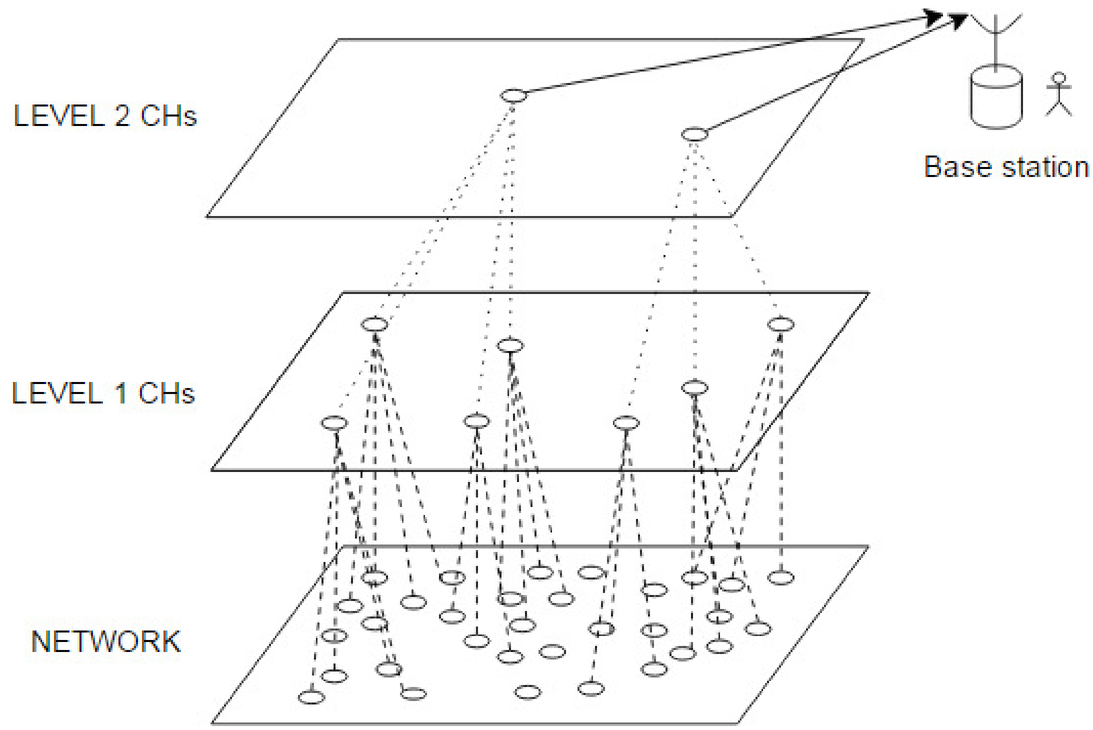

Fig. 2: LEACH levels: level one and level two formation [9]

III. Two level LEACH

Two-level LEACH (2L-LEACH) is an extension of LEACH protocol, where LEACH is again implemented on the level -1 CHs in order to get an additional level -2 CHs in the network. The level -2 CHs are elected among the level -1 CHs. The level -2 CHs collect the data from level -1 CHs, which in turn collect the data from its members, that is the original flat network. The level -2 CHs now transfer the data to the BS. Similar to the LEACH there are two phases even in the 2L-LEACH.

1) *Setup phase* (Formation of level -1 and level -2 CHs)
2) *Steady state phase* (Data transfer from level -1 CHs to level -2 CHs and level -2 CHs to the BS)

A. Setup phase

In this phase, similar to LEACH, first, level -1 CHs are formed by each node generating a random number between 0 to 1 and comparing with threshold computed by using equation (1) or other algorithms as described in [8]. The level -1 CHs then broadcast the advertisement message indicating they are CHs. The remaining nodes choose a CH based on distance or strength of the broadcast signal received. The nodes send an acknowledgment to the CH chosen. Now level -2 structure is formed. Among the level -1 CHs, based on the energy present in the nodes, certain level -1 CHs are chosen as level -2 CHs. The level -2 CHs again send a broadcast message to which only level -1 CHs respond. The level -1 CHs then choose appropriate level -2 CHs and send an acknowledgment containing information about its cluster members.

B. Steady state phase

First a node forwards the data available with it to its CH using the allocated TDMA schedule. Each level -1 CH aggregates the data collected from its cluster members, sends its own data along with aggregate computed to its level -2 CH again based on the allocated time slot. Subsequently, the level -2 CH forwards the collected data and its data to the BS directly.

When a node is transmitting to its higher level CH, all the other nodes in its cluster can go into sleep state and wait until their allotted time slot. In the case of 2L-LEACH, the ground nodes switch between sleep and active states when transmitting to level -1 and similarly, level -1 CHs switch between sleep and active states when transmitting to level -2 CHs. In 2L-LEACH, the number of nodes transmitting directly to the BS is considerably less when compared to the LEACH or 1L-LEACH and hence greater energy savings when compared to 1L-LEACH.

IV. Proposed protocols

A. Multihop in 1L-LEACH and 2L-LEACH

The setup phase is similar to that of LEACH protocol, where level -1 CHs are formed and in 2L-LEACH protocol, where level -1 and level -2 CHs are formed [10]. During the steady state phase, the collection of data starts and when the data reaches the top most level where it needs to be sent to the BS. Instead of direct transmission, the multi-hop routing mechanism is made use of. In the case of 1L-LEACH it is implemented among the level -1 CHs and whereas in 2L-LEACH it is implemented among the level -2 CHs. The level -1 CHs and level -2 CHs in 1L-LEACH and 2L-LEACH are assumed to be forwarding the data towards the BS using multi-hop connectivity links at their respective levels.

Fig. 3 illustrates the data flow in multi-hop based 2L-LEACH WSN. In this routing technique, each CH forwards the packet to all the neighboring CHs. The packet contains the information of the sender's hop count, its address. The neighboring nodes which receive the packets decide whether to transmit or not depending on its hop count and the hop count in the received message. If it is less, it transmits; otherwise it discards the message. Similarly all the nodes try to reach the BS over multiple hops instead of direct transmission thus saving a considerable amount of energy. Even multiple paths exist in this technique from each node to the BS. Even if a particular path fails, the messages reach the BS through alternate path(s) and hence data delivery to the BS is guaranteed.

B. Inverted tree in 1L-LEACH and 2L-LEACH

This routing is initiated by a tree formation involving all the nodes with the root node which is the node closest to the BS. This protocol ensures that connectivity is maintained from each node to the BS all the time. The root node sends a beacon packet and all the nodes which receive it send an acknowledgment. A connection is established between the nodes and the root. Both the root node and the children update their routing tables regarding the number of children and the number of parents each node establishes connection with. Now the children of the root node again go through the process by sending a beacon packet and in turn finding their children. Thus a tree structure is established in the network. Data transfer takes place with each node communicating with its parent and the parent node in turn communicating with its parent and so on using TDMA [11]. The whole process can be explained involving LEACH in three phases:

1) Set up phase
2) Tree Construction and
3) Data transfer

1) Setup phase: This phase is similar to the setup phase of 1L-LEACH and 2L-LEACH as discussed in the previous sections. Where clusters are formed and CHs are elected. In case of a 2L-LEACH, additional level of CHs are elected.

2) Tree Construction: Tree construction takes place among the CHs in 1L-LEACH and among the level -2 CHs in 2L-LEACH. First the node closest to the BS sends a beacon packet inviting for nodes to form its children. The nodes which receive this message send a connection request to the root node and the root node again sends an acknowledgment message to each connected node completing the connection establishment

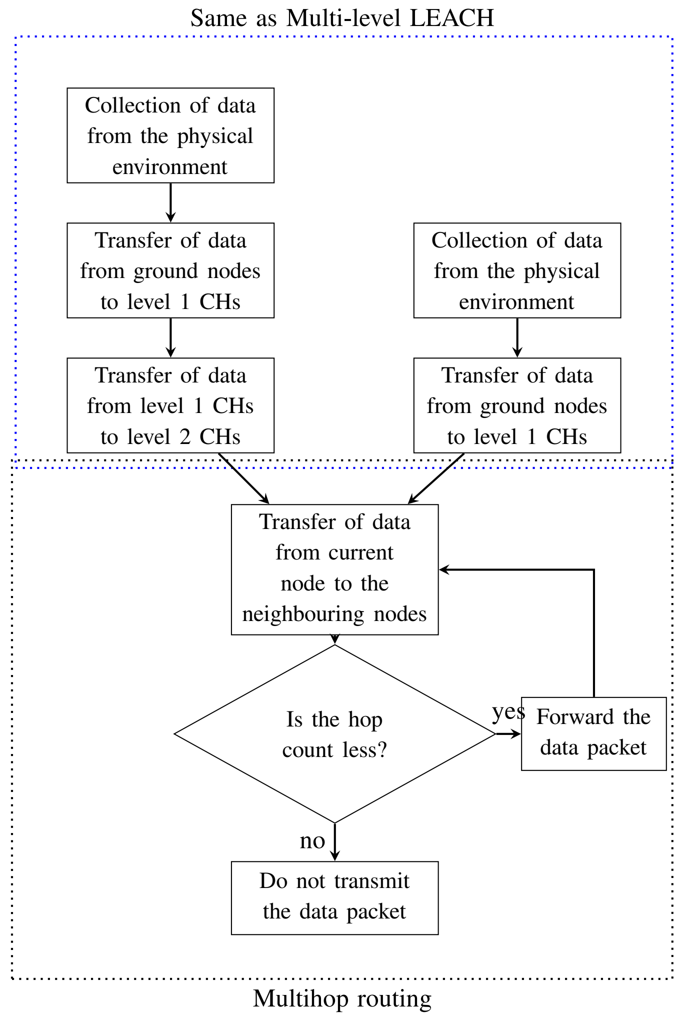

Fig. 3: Flow diagram: Data flow in multi-hop 2L-LEACH

by three way handshaking [11]. Now the children of the root node go through the same process in turn finding its children and so on.

Each node maintains two routing tables. A parent routing table, which contains the addresses of its parents in a sorted order. The sorting can be done based on parent nodes distance from the BS. This table is updated after the three way handshaking is done. A child routing table is also updated depending on the connection request received. Each child node is allocated a TDMA slot by its parent in the order of the connection requests received. A tree is formed till it covers the whole network.

3) Data Transfer: Each node collects the data from its environment and sends it to the CHs which must forward towards the BS. In case of 2L-LEACH, each CH in turn forwards it to the level -2 CHs which must direct the information to the BS. Now data transfer from the CHs to the BS takes place making use of inverted tree mechanism.

First, each CH checks its routing table for the parent and transmits information to the parent. Here, it must be noted that both the child and its parent are CHs and both are at the same hierarchical level. If a data packet is received by a parent, it sends an acknowledgment to the child. If the link between a parent and a child is broken, the acknowledgment is not received. The child forwards the packet to the next parent from its routing table. The data transfer is done based on the allocated time slot. Thus a connection is always maintained. The data transfer is carried out by each CH communicating its parent CH until the data reaches the BS through the root node. Once a child node forwards the data to its parent successfully, it can go into sleep state, thus saving a lot of energy. The tree formation takes place for each round of LEACH and the routing tables are updated accordingly.

C. Directed diffusion in LEACH

Directed diffusion is carried out generally when information is required from a particular location in the network [12], [13]. The sink floods a query into the network which reaches the specific node [14]. The node chooses the best path to address the query using gradient based approach [13].

If the sink repeatedly queries a particular location or data is needed over prolonged duration, nodes in the path taken are repeatedly loaded and energy in the nodes is depleted. To offset this energy depletion problem, LEACH can be used where the path establishment takes place through CHs and at that particular location, data can be collected from the cluster members by that CH. The CH aggregates the data on receiving and sends it to the next CH. Next time the query is sent, different path can be taken as different CHs are chosen. In networks where nodes are equipped with self rejuvenating mechanism like in [15], where the network is solar powered, propagation through LEACH is very helpful. But at still higher levels it may not be advantageous when implemented in LEACH because the distances between CHs increases further.

V. SIMULATION RESULTS

Simulation analysis is carried out using NS-3 simulation platform and a comparison of the flooding and directed diffusion in LEACH and flat topology is made. Table -I provides the parameters considered for simulation. The first part of the simulations compares the performances of multi-hop LEACH and inverted tree LEACH at level -1 and level -2 hierarchies. The second part compares directed diffusion in LEACH and in flat topology along with flooding.

A. Performance Comparison of multi-hop and inverted tree routing schemes in 1L-LEACH and 2L-LEACH

A comparison between multi-hop and inverted tree routing approaches among the level -1 LEACH CHs is shown in Fig. 4. Similarly, multi-hop and inverted tree based routing schemes among level -2 CHs have been compared using Fig. 5. It may be observed from both of these plots that the WSN inverted tree based routing scheme lasts longer when compared to multi-hop routing. This is due to selection efficient path with reduced hop count which is the case with inverted tree approach. Whereas in 2L-LEACH, inverted tree routing fares slightly better than multi-hop scheme. The number of level -1 CHs is higher than that of level -2 CHs resulting in more alternate paths. In inverted tree scheme, a level -2 CH can go to sleep state after forwarding the data to its parent level -2 CH. Also in inverted tree the CHs present at the top most level can also go into sleep states after transmitting energy to the parent CH.

By comparing both the plots as given by Fig. 4 and Fig. 5, it may be observed that 2L-LEACH multi-hop lasts additional 200 rounds approximately when compared with that of 1L-LEACH multi-hop scheme. In the case inverted tree based

TABLE I: Parameters considered for Simulation

Parameter	**Value**
Routing	LEACH, hierarchy with multi-hop, inverted tree, flooding, directed diffusion
Deployment of nodes	Random
Area of network	10 Km $\times$ 10 Km
Number of nodes	20000 and 40000
Packet size	25 $bytes$
Initial Battery level in nodes	0.75 $Joules$
Cluster percentage	5 $percent$
CH selection	Random Residual energy consideration
Energy to run Tx,Rx electronics	50 nJ/bit
Transmit amplifier	120 $nJ/bit/m^2$
BS Location	Outside the WSN deployment area

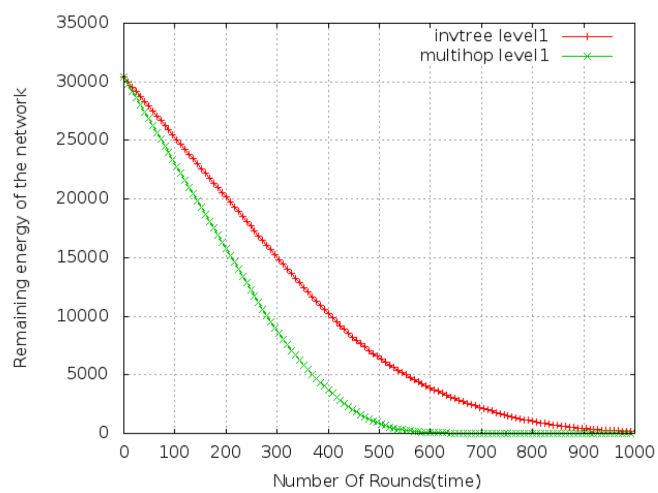

Fig. 4: Comparison of 1L-LEACH for multi-hop and inverted tree routing

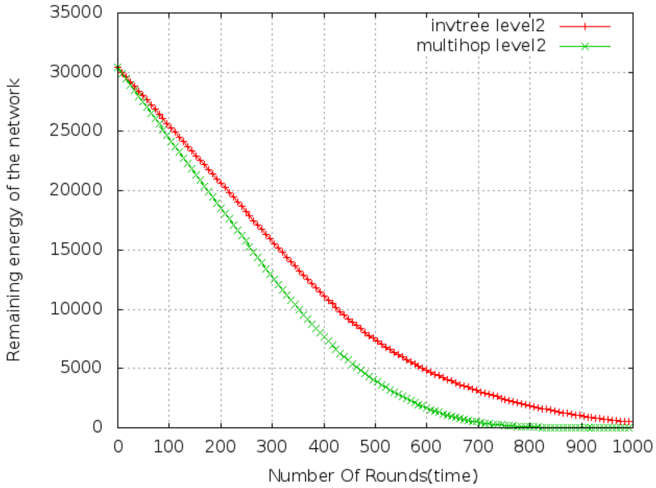

Fig. 5: Comparison of 2L-LEACH for multi-hop and inverted tree routing

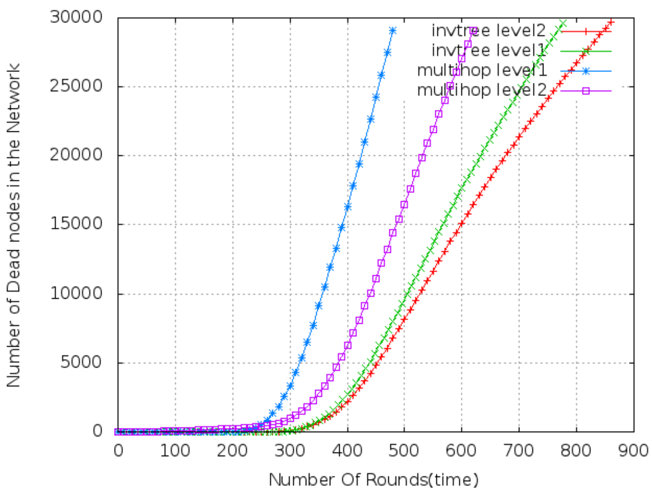

Fig. 6: Graph showing dead nodes vs number of rounds in 1L-LEACH and 2L-LEACH

scheme the additional number of rounds is about 100.

Fig. 6 illustrates that for the initial 200 rounds in all the cases, the number of dead nodes is negligible due to the rotation of CHs resulting in uniform energy distribution.

It can be observed from Fig. 6 that level -2 of multi-hop and inverted tree surviving greater rounds that level one of inverted tree and multi-hop respectively. As the hierarchy increases, the lifetime of the network increases this is due to lesser number of nodes need to transmit to the BS which is present at a larger distance and the nodes present in the penultimate level can get into sleep active transitions. But one drawback in both cases is the latencies associated. A node far away from the BS must pass through a number of intermediate nodes whereas in basic LEACH, a CH can transmit directly to the BS.

B. Directed diffusion in LEACH and Directed diffusion with flat topololgy and flooding

Next comparison is done between flooding and directed diffusion. Towards this. it is assumed that event information is needed from a single source, which is far away from the BS and the same is requested by the five sink nodes that are positioned near to the BS. In flooding, each node starting from the source transmits to all of its neighboring nodes, till it reaches the sink. The remaining nodes other than the nodes along the path between source and the sink transmit data to the BS.

Fig. 7 and Fig. 8 show the paths taken by the message in two different cases. Only CH nodes are shown in both these figures.

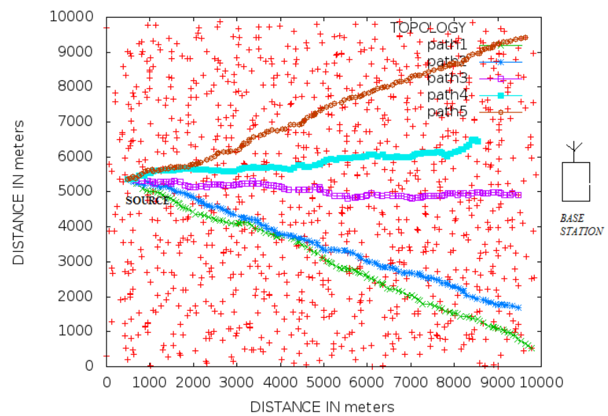

Fig. 7: Paths taken by messages in directed diffusion in flat topology

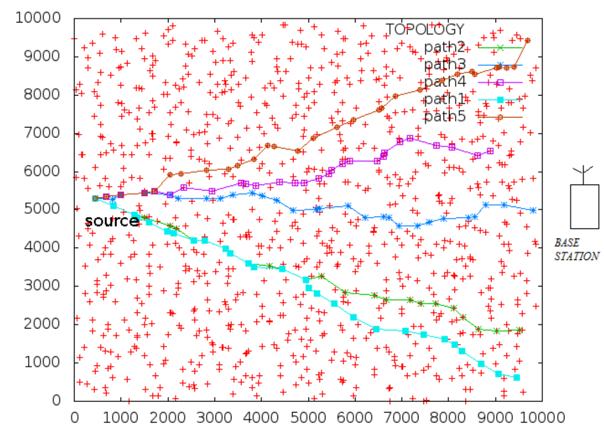

Fig. 8: Paths taken by messages in directed diffusion using LEACH

The LEACH is more efficient as the number of hops is less and CH role is rotated among the cluster members. In flat topology alternate path is not chosen till all the nodes in current path exhaust their energy. But in higher levels of LEACH it may not be efficient because it has to transmit longer distances to reach the next CH. Fig. 9 shows the energy

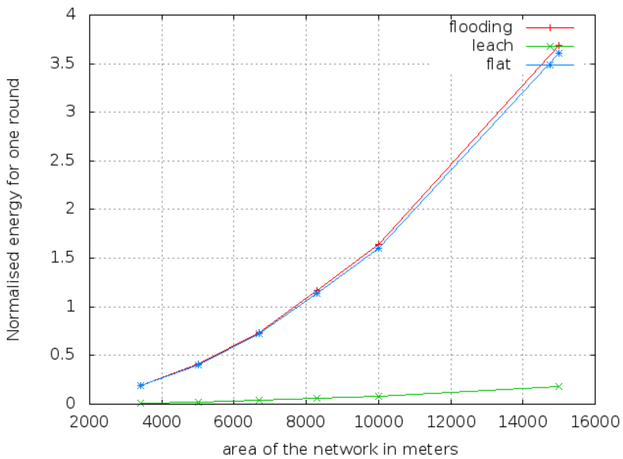

Fig. 9: Comparison of flooding with directed diffusion in LEACH and flat network

model providing the graph for the total energy consumed by the network using various protocols as the area of the network is altered.

VI. Conclusion

The models for basic LEACH and a higher level LEACH, 2L-LEACH using multi-hop and inverted tree routing techniques, have been created and simulation analysis and comparison of the same has been carried out using NS-3. Directed diffusion in LEACH and flat topologies are compared with flooding and the results are provided. Based on the results, it may be concluded that inverted tree is a better routing technique than multi-hop routing in terms of energy consumption and when combined with LEACH and hierarchical LEACH, it becomes even more energy efficient. However, latency is going to be more in inverted tree approach due to the TDMA schedules and active sleep state transitions. In the case of directed diffusion, it is efficient to be carried out in LEACH compared to flat topology. Also it can be concluded that hierarchical LEACH performs better than basic LEACH.

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