Investigation of Energy Efficiency and Network Lifetime of Routing Protocols in Wireless Sensor Network

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Abstract— As the use of wireless sensor networks is increasing day by day at the same time they are facing the problem of energy constraint in terms of limited battery life time. Network lifetime of system is directly related to energy dissipation in sensor nodes. Hence more energy dissipation results in decreasing network lifetime of sensor network. This paper concerns with investigation of energy efficiency and network lifetime of three routing protocols: LEACH, PEGASIS and Multi-chain PEGASIS; in wireless sensor network. This paper also concentrates on finding the most energy efficient protocol so that energy efficient protocol that have high network lifetime can be utilized in wireless sensor network.

Key words: LEACH, PEGASIS, TDMA

I. INTRODUCTION

Wireless sensor networks were motivated by military application such as battlefield surveillance. Wireless sensor network consisting of large no. of small sensor nodes monitor physical and environmental conditions such as sound, pressure, temperature etc. and passes this acquired data to central node (Base Station or Sink node). Wireless sensor network consist of number of low cost wireless sensor nodes forming a sensor field and Base station, transmit the data in wireless mode and have the capabilities of processing, sensing and storing [1]. The various characteristics of wireless sensor network are Lifetime, Flexibility, Scalability, Responsiveness (and Latency), Maintenance, Data Collection [4]. Size of sensor node is variable. Topology of Wireless sensor network can be varied from star network to multi-hop wireless mesh network.

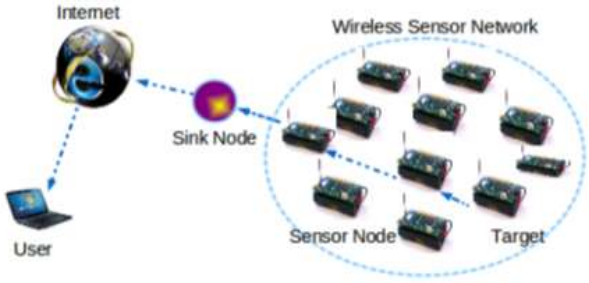

Fig. 1: Architecture of Wireless Sensor Network [2]

Wireless sensor networks play very important role in our life. They are used in many areas like industries, health care, military, environment [1]. Due to their unique features, their use is increasing day by day and they are facing the problem of energy constraint in terms of limited battery life time. Communicating with other nodes or sensing activities consumes a lot of energy in processing data and transmitting the collected data to Base Station. All the nodes are not rechargeable and it is not possible to replace the batteries in nodes that are depleted. As each node depend on energy for its activities this has become a major issue in wireless sensor network[3]. Hence, Energy efficiency is one of the main challenge in sensor networks. This paper work concentrates on investigation of energy efficiency in wireless sensor network for three routing protocols. Life of all nodes depend on what amount of energy they have. So only source of life in nodes is battery It also concentrates on network lifetime of routing protocols: LEACH,PEGASIS and Multi-chain PEGASIS; as network lifetime is directly related to energy consumption.

II. RELATED WORK

A. Factors Which Results In More Energy Dissipation:

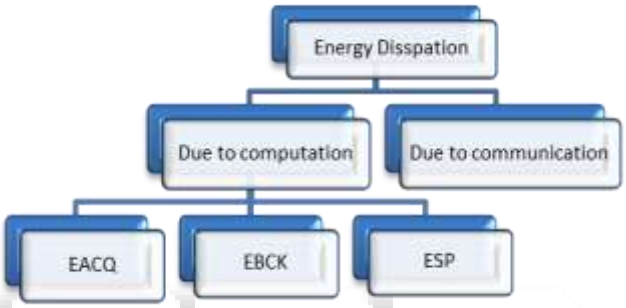

Fig. 2: Factors due to which Energy Dissipates

EACQ = Data Acquisition Energy Dissipation, EBCK = Background Energy Dissipation, ESP = Energy Dissipation during Processing. After realizing the reasons of energy dissipation it is concluded that following steps can be taken in order to minimize the energy dissipation. 1)To schedule state of nodes. 2)By changing transmission range between sensing nodes. 3)Using efficient routing and data collection methods[3].

B. Energy Consumption Calculation Can Be Done As Follows:

If the distance between sender and receiver is less than threshold distance(d0=Efs/Emp), Transmit Amplifier assumes free space model. If the distance between sender and receiver is greater than threshold distance(d0), Transmit Amplifier assumes multipath model. The formula for energy consumption (ETx) during transmitting data and energy consumption (ERx) during receiving data is written below.

$$E_{Tx}(L,d) = \begin{cases} LE_{elec} + L\varepsilon_{fs}d^2, d \le d_0 \\ LE_{elec} + L\varepsilon_{mp}d^4, d > d_0 \end{cases}$$

$$E_{Rx}(L) = LE_{elec} \quad (1)$$

Energy dissipation during Tx and Rx shown by eq. (1) [5].

In the above equation Efs denotes free space energy which is Amplification Coefficient for free space model and Emp denotes multipath energy which is Amplification Coefficient for multipath model. L is length of data to be transmitted [5]. Now we will discuss some

routing protocols which have minimized the energy dissipation by using above steps. So that network lifetime increases.

III. ROUTING PROTOCOLS

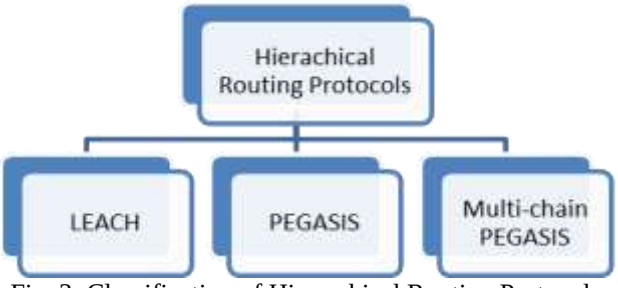

Fig. 3: Classification of Hierarchical Routing Protocols

A. LEACH: Low Energy Adaptive Clustering Hierarchy Protocol

It is a self-organizing, TDMA based adaptive clustering protocol that utilize the randomized rotation of cluster head (local base station) to evenly distribute the energy load among all nodes in network. Its Goal is to minimize the energy dissipation in network.

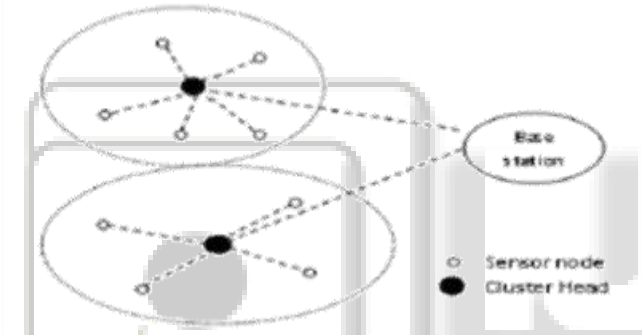

Fig. 4: Clustering in LEACH Protocol [7]

Operation of LEACH:- Operation of LEACH is broken down into different rounds where each round starts with Cluster Set Up Phase followed by Steady State Phase.

1) Cluster Set up phase – It consist of 4 steps. In this phase Cluster Formation takes place.

1) Cluster Head Selection Step- In The Network Architecture When Clusters Are Being Formed Each Node Decides Whether To Become Or Not To Become The Cluster Head For The Current Round. Each Node Takes This Decision Based On Required Percentage Of Cluster Heads In The Network And Number Of Times The Node Has Become Cluster Heads In Preceding Rounds.

After taking the decision of becoming Cluster Head, node select a random number between 0 & 1 and compare the selected number with some threshold value T(n) [7] given by the equation written below.

$$T(n) = \begin{cases} P/(1 - P\,(r * \bmod (1/p))), & n \epsilon G \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

If the random number is less than T(n) node will become CH for current round otherwise not. In the equation (2) P is probability of node to become the Cluster Head, r is current round, p represents desired percentage of CHs in the network and G is set of nodes that have not become Cluster Head(CH) in last 1/P rounds .

Using this threshold value (T(n)) all the nodes will be CH in every 1/P rounds. The node as a CH in round 0 can not be CH for the next 1/P rounds. Due to this, the probability of remaining nodes to become CH increases thus reducing burden on single node and not draining battery of that node resulting in increase in energy efficiency of network. After 1/P-1 rounds all node which have not been Cluster Head will be selected as Cluster head with probability 1. When 1/P rounds finished all the nodes returns to same line. After every 1/P rounds all nodes will be eligible to become the Cluster Heads again[6].

1) Advertisement Step- Using Carrier Sense Multiple Access Protocol, node after becoming Cluster Head broadcast the advertisement containing its status, to all the ordinary nodes. During this step the non CH must keep their receiver on in order to hear advertisement sent by all Cluster Heads.
2) Cluster Joining Step- Based on received signal strength of advertisement and CH which require minimum communication energy each ordinary node decided to which cluster it wants to belong for current round. Using CSMA MAC protocol, each node send the message to CH for obtaining its membership. CHs must keep their receiver on during this step.
3) Schedule Creation Step- After cluster joining step each CH in its cluster creates Time Division Multiple Access (TDMA) schedule for all the sensor nodes. TDMA schedule permit radio component of all sensor node to be switched off all time excluding their transmit time. Thus less energy dissipation takes place in individual sensor nodes [7].

2) Steady State Phase-

1) First Step- Ordinary nodes are able to know at what time they can transfer the data. So all nodes in cluster send data to Cluster Head.
2) Second Step- After receiving data from all sensor nodes each Cluster Head in its cluster compress data and send aggregated data to global Base Station[7].

3) Advantages:-

Data fusion helps to reduce the amount of data transmitted to BS resulting in less Energy Dissipation compared to previous protocols.

4) Disadvantages:-

1) LEACH have long transmit distance between sender and receiver. As the Energy consumption is directly proportional to distance hence more energy dissipation takes place.
2) There is burden on Cluster Head to acquire data of all nodes in clusters. Thus results in energy dissipation of one CH. Whole network depend only on CH whenever it dies whole network get failed.
3) LEACH uses single-hop routing where each node transmit data directly to the CH and CH send aggregated data to the Base Station. Therefore, it is not applicable to networks deployed in large regions[8].
4) The idea of dynamic clustering brings extra overhead, e.g. head changes, advertisements etc., which may decrease the gain in energy consumption [8].
5) Random election of CH, hence there is Possibility that all CHs will be concentrated in same area [8].
6) The protocol assumes that all nodes begin with the same amount of energy capacity in each election round, assuming that being a CH consumes approximately the same amount of energy for each node[8].

7) LEACH assumes that all nodes have data to send and so assign a time slot for a node even though some nodes might not have data to transmit [13].
8) LEACH requires that all nodes are continuously listening (this is not realistic in a random distribution of the sensor nodes, for example, where cluster-heads would be located at the sedge of the network) [13].

B. PEGASIS: Power Efficient Gathering in Sensor Information System

PEGASIS is extension of LEACH protocol. In this protocol the concept of chaining comes into picture. The sensor nodes which are closest to each other will be considered to form the chain and this chain is responsible for communicating with the base station. Only one node (leader node) will be considered from this chain to transmit data to the base station instead of multiple nodes [14].

Greedy approach is used in forming the chain. In PEGASIS, signal strength is considered to measure the distance to all the neighboring nodes. This signal strength is adjusted so that only one node can be heard. After formation of chain each node fuse its own information with the information of the neighboring node and this will form a single packet. This single packet will be of the same length and transmit the fused information to the next sensor node. In this way data reaches to Base Station. The problem with the chaining approach of PEGASIS protocol is that whenever a single node dies the whole chain has to be constructed as it becomes non-functional [15].

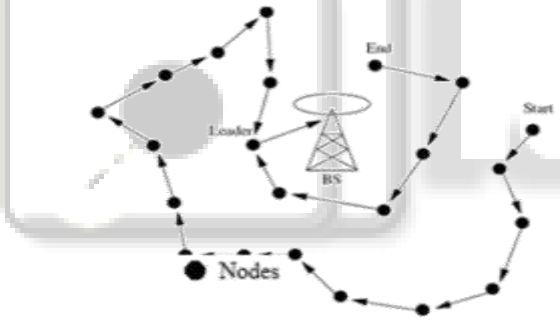

Fig. 5: Illustration of PEGASIS Protocol

1) Advantages:

Short transmit distance due to which Energy dissipation (Energy dissipation is directly proportional to square of distance) is less compared to LEACH protocol. Less overhead results in less energy consumption. As Energy dissipation is less as compared to LEACH, PEGASIS is more Energy efficient protocol. PEGASIS achieves energy conservation in two ways: 1) The number of data messages received by the leader node is at most two. 2) The distance over which the data are transmitted to one-hop neighbor is much less So, PEGASIS conserves energy by reducing the number of data messages gathering at head node [8].

PEGASIS improves on LEACH by saving energy at following stages. First, in the local gathering, the distance that most of the nodes transmits is much less as compares to CH distance in LEACH. Second, the leader receives at most only two messages from the neighbors which is not in the case of LEACH. Finally, one node transmits the message to the BS in each round of communication [9].

2) Disadvantages:

The main drawback of PEGASIS is that chain has to be reconstructed again as it does not perform its functions whenever any leader node in chain dies. It takes long time to reconstruct a long link chain due to which delay occur in data transmission and unnecessary energy dissipation occur in forming chain again. Delay in data transmission thorough long link chain decrease performance of PEGASIS. PEGASIS assumes that each sensor node is able to communicate with the BS directly. In practical cases, sensor nodes use multi-hop communication to reach the BS [8]. PEGASIS assumes that all sensor nodes have the same level of energy and are likely to die at the same time [8]. PEGASIS introduces excessive delay for distant nodes on the chain [8]. The single leader can become a bottleneck [8]. Though PEGASIS protocol has its advantages over LEACH protocol, it still had certain deficiencies.

C. Multi-Chain PEGASIS

In Multi chain PEGASIS 4 chains are formed in 4 regions in the similar way as in PEGASIS. In this mobile Base Station is employed. It uses token passing approach in data transmission. Chain formation Procedure: Base Station find the far node by comparing the distances of all nodes from itself in first region. Base Station send the hello packet to all nodes in order to get the information regarding all nodes. The chain construction is start from end node which is far away from the Base Station. End node find the closest neighboring node and make the chain between End node and closest neighboring node [16]. In similar way each node find the distance between itself and the nearest node not connected in chain and connect it with the same method which mention above. The same procedure of chain formation is apply in all four region.

1) Data Transmission:

First Chain leader transmit token to End node then End node after sending its data to next node pass token to next node.

In the same way all nodes after sending its data pass token to next node and at last data is transmitted to leader node which transmit all the data to base station. Each node receives the data of its child node and compress it using DCT. Each combine its data with received one by compressive sampling. As each node is compressing and sending aggregate data to next node in each and every chain, Energy dissipation evenly distributes among all nodes.

2) Advantages:

Mobile Base Station and multiple chain lead to increase in energy efficiency of network and thus increasing network lifetime. There is less overhead and minimum delay in data transmission . As less amount of data is transmitted by Each chain so very less Energy dissipates. It is more Energy efficient as compared to PEGASIS [17].

IV. SIMULATED RESULT AND DISCUSSIONS

Input parameters	Values
Number of Nodes	100
Initial Energy of each Node	0.2 Joules
Transmitting Energy	50*10^(-9) Joules
Receiving Energy	50*10^(-9) Joules
Free Space Energy	10*10^(-12) Joules
Multipath Energy	0.0013*10^(-12) Joules

Data Aggregation Energy	5*10^(-9) Joules

Table 1:

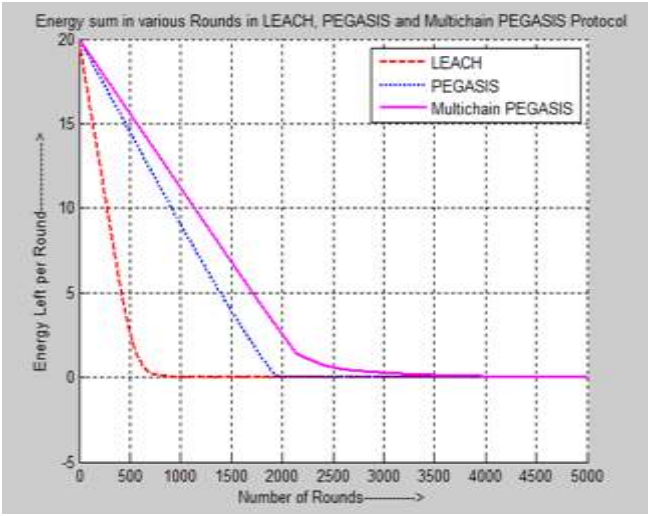

Fig. 6: Simulated graph showing comparison of LEACH, PEGASIS and Multi-chain PEGASIS based on energy consumption/dissipation in various rounds.

Energy of Routing Protocols	**15 J**	**10 J**	**5J**	**Energy reaches to zero**
LEACH	180 round	280 round	420 round	950 round
PEGASIS	400 round	900 round	1380 round	1990 round
Multi Chain PEGASIS	600 round	1200 round	1700 round	4900 round

Table 2: Comparison Of Leach, Pegasis And Multi-Chain Pegasis Based On Energy Consumption In Various Rounds

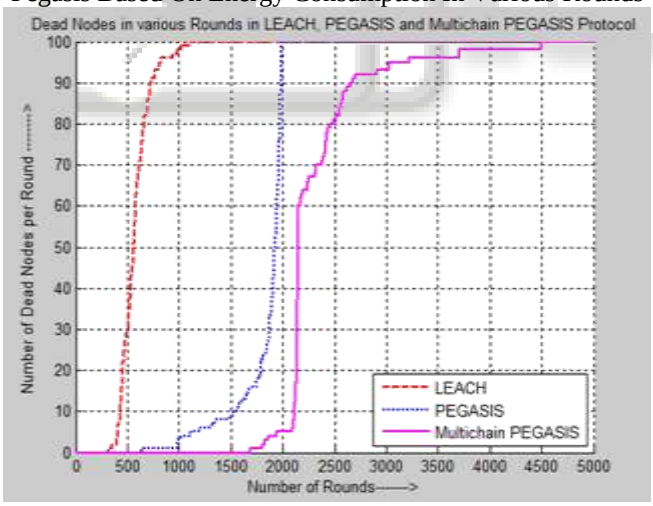

Fig. 7: Above results represents the number of dead nodes during the network duration of different routing protocols.

Routing Protocols	**First Node dead**	**Fifty nodes Dead**	**All nodes dead**
LEACH	At 350 rounds	In 560 rounds	In 950 rounds
PEGASIS	At 520 rounds	In 1900 rounds	In 1990 rounds
Multi-chain PEGASIS	At 1900 round	In 2250 rounds	In 4900 rounds

Table 3: Comparision Of Leach, Pegasis And Multi-Chain Pegasis Based On Dead Nodes

All the simulations have been done using MATlab. Simulation results shows that PEGASIS is 100% to 200% more energy efficient than LEACH. Multi-chain PEGASIS has minimum delay in data transmission and 30 to 100% more energy efficient than PEGASIS. As compared to LEACH, Multi-chain PEGASIS is 200 to 500% more energy efficient. Multi-chain PEGASIS is most energy efficient routing protocol. From simulation results based on dead nodes we have find out network lifetime of all Routing Protocols. Network lifetime of LEACH is 950 rounds. Network lifetime of PEGASIS is 1990 rounds and that of Multi-chain PEGASIS is 4900 rounds.

V. Conclusion and Future Work

After investigating energy efficiency and network lifetime of different routing protocols in wireless sensor network. We have reached to the conclusion Multi chain PEGASIS is most suitable routing protocol for wireless sensor network. Multi-chain PEGASIS dissipates least energy and maximize network lifetime with the induction of Base Station mobility. It also diminishes the delay in data delivery due to short chains and decrease load on leader node. In future its performance can be made better by periodically changing the chain leader of chain in wireless sensor network. Other future works can involve different routing protocols and different optimizing algorithms.

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