Energy Efficient Protocol with Low Latency for Wireless Sensor Networks

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***Abstract*—a wireless sensor network is composed of tiny sensor nodes. Each sensor node is battery operated and has limited capacity for specific number of transmission rounds. In some applications of sensor nodes, replacement of batteries is not possible; this limitation cause energy constrain for wireless sensor networks. Due to this restriction, energy efficient routing protocols have gained vital importance. Many routing protocols have been developed to improve the lifetime of wireless sensor networks. In this paper one of the routing protocols, power-efficient gathering in sensor information systems (PEGASIS) is modified as PEGASIS Improved Chain Formation (PICF) by overcoming drawbacks in the existing protocol such as technique of chain construction, selection of lead node and deletion of dead nodes from the new chain formation. Simulation results of the proposed protocol are compared with PEGASIS and one of its variant PEGASIS Double Cluster Head (PDCH) to demonstrate its outperformance.**

***Keywords*— WSNs, PEGASIS, PDCH, PICF.**

I. INTRODUCTION

Wireless sensor network comes with tiny sensor nodes; each node is capable to sense, monitor data, and carry out communication among them to send the sensed data to the base station[1][2]. These sensor nodes are placed in a vast sensing area from where parameters of interest are sensed and communicated to the designated station. Each sensor node acts as a data originator as well as data router. Practically each node is active throughout its life time and relays sensed parameters to the base station. As these sensor nodes are powered with battery so each node dies after specific number of transmissions. This leads to significant topological changes in the sensor network. The node once declared as dead node is deleted from the network topology and it would be essential for wireless sensor network to reorganize itself. Typically each sensor node consists of several parts such as a battery unit, data sensing unit, data processing unit and the most important transmitter-receiver unit [3]. As sensor node is very small in size, therefore above mentioned components are very small. Due to the size limitation, the processing capacity of these components is also limited.

Wireless sensor networks provide endless applications in environmental monitoring, surveillance, war fare, medical applications, (e.g., micro surgery), agriculture and education. Because of the placement of sensor nodes in diverse fields, performing maintenance activities, such as replacing batteries of dead sensor nodes, may not be practical. As energy is a meager and non-renewable resource, it poses alarming challenge to extend the life time of wireless sensor network [4]. The sensor node's power unit design has emerged as a critical issue in most of applications to prolong nodes' lifetime. Due to limited energy, efficient routing protocols are indispensable. Routing protocols optimize the routing path to improve life time of wireless sensor networks. Many routing protocols for wireless sensor networks have been developed based on different techniques. PEGASIS is one of the hierarchal routing technique which is efficient than other hierarchical routing techniques considering lifetime of the network. PEGASIS Double Cluster Head (PDCH) is modification in PEGASIS protocol and it is more efficient than PEGASIS. PDCH has improved the lifetime of the wireless sensor networks by avoiding long chain construction and using the concept of double cluster head in hierarchal routing. In this paper, PEGASIS is modified as PEGASIS Improved Chain (PICF) formation by overcoming drawbacks in existing PEGASIS protocol such as way of chain construction, selection of lead node and deletion of dead nodes from the new chain formation.

The rest of the paper is divided into following sections: Section-II describes PEGASIS and PDCH; Section-III is about the proposed protocol; Section-IV presents the implementation of the proposed protocol; Section-V compares the results of the three protocols and Section-VI concludes the paper.

II. PEGASIS AND PDCH

A. PEGASIS

LEACH is a pioneer energy efficient protocol in wireless sensor networks. Many extensions in LEACH routing protocol [5] have been proposed. Power efficient gathering in sensor information system (PEGASIS) [6] is one of these extensions. PEGASIS is based on chain algorithm. Nodes communicate after establishing a chain. They must communicate with their nearest node. Data gathering from the field is prime target of a wireless sensor network. After formation of chain, data is transmitted to the base station by one node, which is considered as a lead node. Usually, the base stations are far away, hence, energy of nodes is depleted quickly with direct communication to the base station. Therefore, it is desired that least number of nodes come in direct communication with base station. To minimize this direct communication to base station for conservation of energy, PEGASIS algorithm was proposed, which follows these assumptions:

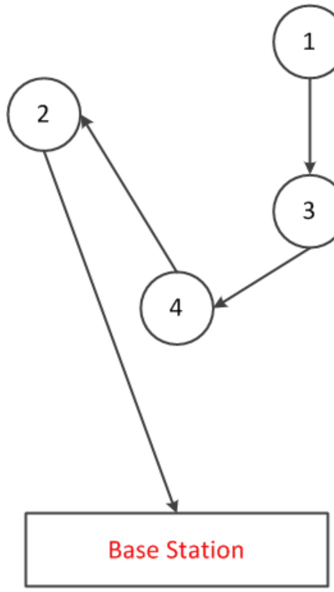

Fig. 1: PEGASIS chain formation

- Base station is situated at a remote end.
- Initially, all of the sensor nodes carry same characteristics and uniform energy.
- Nodes are static and they do not move after deployment.

PEGASIS is based on greedy algorithm with functions of chain construction and data fusion. In PEGASIS, each node has global knowledge about the entire sensor network and complete information about the location of other nodes in network. The chain formation is initiated by a node at furthest distance from the base station, after decision of furthest node the next node is connected in chain with its nearest and closest neighbor node. Once a node is connected in chain its radio can be turned off for remaining process of chain formation as it would not be revisited now. Since PEGASIS perform data fusion as well, so a node which is connected in chain, defuses its data with its neighbor node received data and sends it to next node as a single packet of data. The data fusion process is continued during chain formation until the last node, leader of the chain, is reached.

Once the global information is carried out by all the sensor nodes, it assumed that the sensor nodes have capability to vary its radio signal strength. By varying the signal strength the energy dissipation can be reduced to enhance the lifetime of the network. Sensor nodes adjust their signal strength to such a low level that these can only hear nearest neighbor node.

Figure 1 illustrates this chain formation. For example, if node 1 takes charge to initiate operation of chain formation, it is selected as far away node by considering base station as reference. After its nomination for chain starter, node 1 broadcasts a signal for all the nodes present in network. The main purpose for this broadcasting is to select the nearest neighbor. Node 3, being the nearest neighbor, the next downstream for chain formation, it is added in the chain. Applying the same procedure, node 3 selects next nearest node which is node 4 in this case. Node 3 diffuses its own sensed information with the node 1 received information and this diffused data is transmitted to node 4. With same repetition of operations, node 4 comes across with node 2 as being nearest to node 4 and sends the diffused data (data packet contain the whole data of all the nodes in chain). Now, node 2 is elected as lead node being nearest node to the base station, all the data is sent out to the base station by the lead node. Reformation of the chain takes place, if any sensor node dies, to exclude the dead node.

Although PEGASIS is extension of LEACH algorithm, but PEGASIS is more energy efficient than LEACH in term of network lifetime. Cluster formation caused overhead problem in LEACH, which is eliminated in PEGASIS. The energy is conserved by transmitting aggregated, instead of bulk data transmission to the remote base station. However, high latency is associated with PEGASIS due to long chain formation. Many modifications in PEGASIS have been proposed. Hayoung Oh and Kijoon Chae [7] present a novel energy-efficient protocol, namely Energy-Efficient Sensor Routing (EESR) which utilizes relative direction scheme. This paper [8] employs ant colony algorithm for constructing the chain beside the greedy algorithm to improve PEGASIS. Y. H. Lee et. al., [9] propose an amalgam of LEACH and PEGASIS to achieve network lifetime longevity. An improved energy-efficient PEGASIS-based protocol (IEEPB) [10] is presented in this paper, which utilizes weights to select lead nodes. These weights are based on the residual energy and distance from the base station. A. Norouzi et. al., [11] provide a comparison of different protocols, namely, LEACH, Director Diffusion, Gossiping, PEGASIS, and EESR. This comparison is based on data aggregation, clustering, routing, node role assignments and data-center methods. Krishna B B and A.S Raghuvanshi [12] propose Centralized Border Node based Cluster Balancing (CBCB) protocol, which equally distributes the load among the clusters to increase network lifetime. CBCB is compared with other cluster-based protocols.

B. PDCH

PEGASIS Double Cluster Head (PDCH) [13] is extension in PEGASIS. It is a combination of both PEGASIS and LEACH. PDCH was proposed to overcome the long chain formation. In PDCH, each region has its own cluster and each cluster has two cluster heads; one is primary and the other one is secondary. PDCH is hierarchal routing protocol which forms two chains; main chain and branch chain. The nodes elected for main chain are related to main cluster head and the nodes related to branch chain belong to secondary cluster head as shown in Figure 2. PDCH is designed as an energy efficient protocol with load balancing technique.

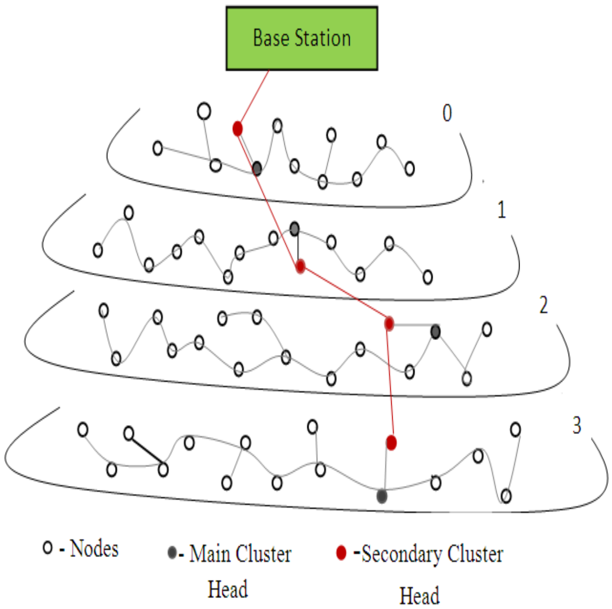

Fig. 2: PEGASIS Double Cluster Head [13]

III. PROPOSED PROTOCOL

PEGASIS is a chain based protocol in which one node is responsible for transmission of data to destination at remote base station and only single chain is gathering and aggregating the data. PEGASIS was extension of LEACH routing protocol and it is found reasonably energy efficient routing protocol but it carries the disadvantage of excessive time delay. The formation of a single long chain in PEGASIS is based on greedy algorithm. In chain formation, each node follows the greedy phenomenon that each node looks only for its closest node irrespective of the base station location. Although PEGASIS is energy efficient routing protocol, but in its chain formation it might be possible that the lead node that has to send information to the far end base station is not close to lead node.

As most proportion of energy consumption is dependent on distance of transmission, so more energy is required for long distance. The energy consumption can be minimized by decreasing the distance for transmission of data to other end. To reduce this distance and enhance the life time of sensor network, more efficient chain formation is proposed. PEGASIS improve chain formation (PICF) is extension of PEGASIS, in which, during chain formation the shortest distance is adopted to reach the base station. The key idea is that nodes located at minimum distance from base station are responsible for transmission of data message to the designated station. The node-to-base station distance is greater as compared to node-to-node distance and therefore a larger amount of power is consumed for communication between lead node and base station as compared to transmission of data between nodes. The other drawback of PEGASIS in addition to high latency is that a single lead node can result in a bottleneck. Since the delay is due to the single large chain, so if the chain length is shortened its time delay can be improved, and similarly if more than one lead node are selected, the bottleneck can be avoided. Complete field may not be covered due to all nodes not being included in the chain, i.e., when chain length is shortened. As a result of which the data from all areas of the field may not be possible to reach the base station. To avoid these shortcomings, PICF is proposed and the results are compared with PEGASIS and PDCH.

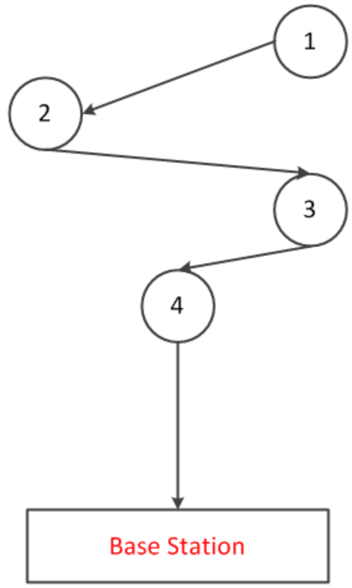

Fig. 3: PICF chain formation

In PICF, the nodes closest to the remote station are responsible for transmitting data to this station. This idea is illustrated in Figure 3 using the scenario of Figure 1. Based on node-to-node and node-to-base station distance the chain is formed. In PEGASIS, chain formation is based on selection of nearest node irrespective of base station distance from the lead node. However, in case of PICF, the neighbor is selected on the basis of the distance from the base station to ensure that the distance between base station and lead node is minimum. Node 4 is the preferred one to transmit data to base station. In the chain formation with PEGASIS, node 2 was selected as lead node as shown in Figure 1. But in PICF, node 4 is selected as lead node to ensure that distance between lead node and base station is shortest. So, node 1 sends data to node 2 which further transmits this message to node 3 and after that data is sent to node 4. Node 4 sends this data to the base station.

Secondly, PEGASIS is modified by constructing more chains in the same sensing field. Each chain is sending its data to the respective lead node in the region, which results in low latency. To implement this idea, the field where nodes are deployed is subdivided into different regions and each region is having its own chain. As the original chain constructed in PEGASIS is divided into a number of chains lying in different regions, hence, delay is decreased at the expense of number of dead nodes (for same number of transmission round). Thus, a tradeoff exists and a compromise must be made.

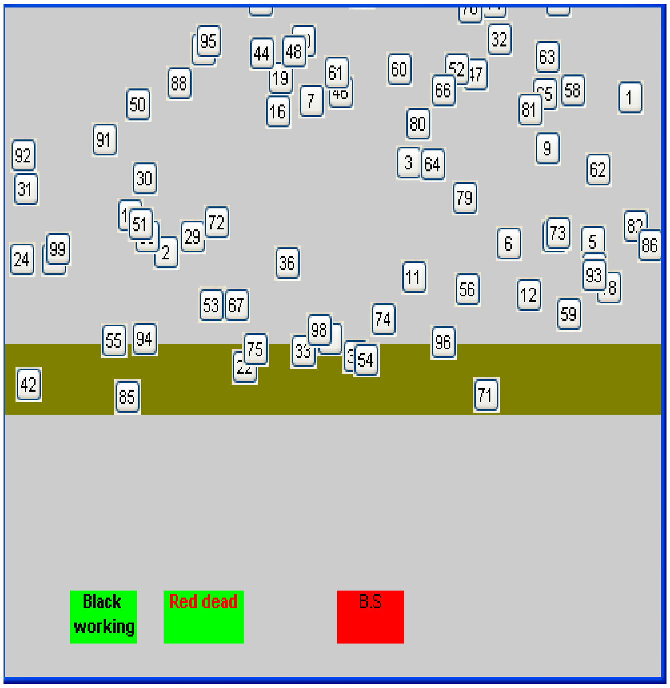

Fig. 4: Nodes deployment

IV. Implementation of the Proposed Protocol

Following are the key features of the proposed protocol:

- Fixed location for the base station.
- All of the nodes carry equal energy level initially.
- Location database is maintained by all nodes about network.
- Lead node must be closest to the base station.
- Entire sensing field is subdivided into different regions to achieve low latency.

Last two features are the modification in PEGASIS and are the key ideas of our design.

A. Nodes Deployment

The proposed protocol is implemented using MATLAB. The nodes are placed at random position in the field (where data is to be sensed) in random fashion; this target area is designated as "Sensing Field". As nodes are distributed randomly in most of WSN applications, so, uniform distribution is selected to keep the scenario simple. The field size is 100×100 m^2 field. Different numbers of nodes are deployed randomly, for example 50, 100, 200 and 300 nodes. After deployment, each node has information about its location as well as the position of other nodes in the sensor network. Sensing of data and its transmission to the designated end is the major task of each sensor node in WSNs. A fixed far end position is designated where base station is located, which is at distance of 200 m from the lead node. The nodes near the base station are considered as lead nodes and the routing protocol forces to select the node among these lead nodes for sensed data transmission to the target base station by these nodes. The energy level of each node is same initially and the nodes check their energy level before transmission so that they can

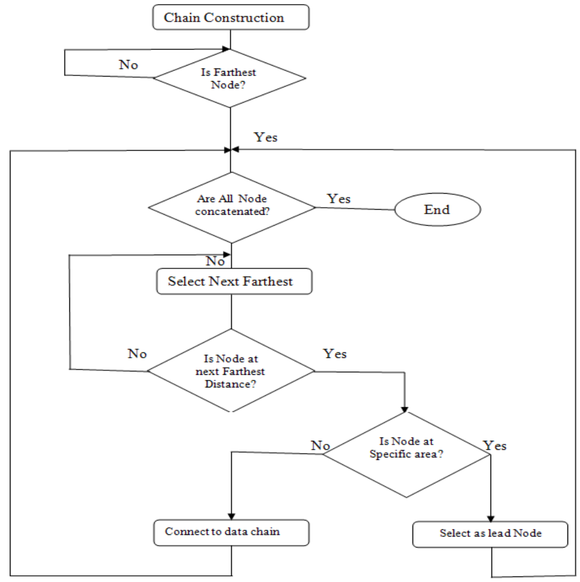

Fig. 5: Flow chart for chain construction

complete their operation. General view of sensor network topology is expressed by Figure 4, which shows the random placement of nodes in the area and the network top view. The green region indicates the area designated for lead nodes and as initially energy level of each node is same, therefore, no dead node (Red node) is present.

B. Radio Model

The radio transceiver used in all the routing protocols in the simulations are using same sensor nodes, in which, all sensor nodes have same radio model [14]. The equations for transmitter and receiver are given below. E_{elect}= 50 nJ/bit is dissipated for internal processing of the transmitter or receiver circuit during accumulation of data and similarly transmitter amplification requires E_{Amp} = 100 pJ/bit. The energy required for transmission is calculated by distance square-lose law in which energy dissipation is proportional to the square of distance [15].

Transmitting

$$E_{Tx}(k,d) = E_{Tx\ elect}(k) + E_{Tx\ Amp}(k,d)$$

$$E_{Tx}(k,d) = E_{elect} \times k + E_{Amp} \times k \times d^2$$

Receiving

$$E_{Rx}(k) = E_{Rx\ elect}(k)$$

$$E_{Rx}(k) = E_{elect} \times (k)$$

where k is packet length which is 2000 bits in the simulation and d is distance for transmission.

C. Chain construction

PEGASIS is a chain based routing protocol. As each node carries the knowledge about the location of all nodes in whole network, this information is utilized in constructing the chain. PICF modifies the chain construction operation of PEGASIS.

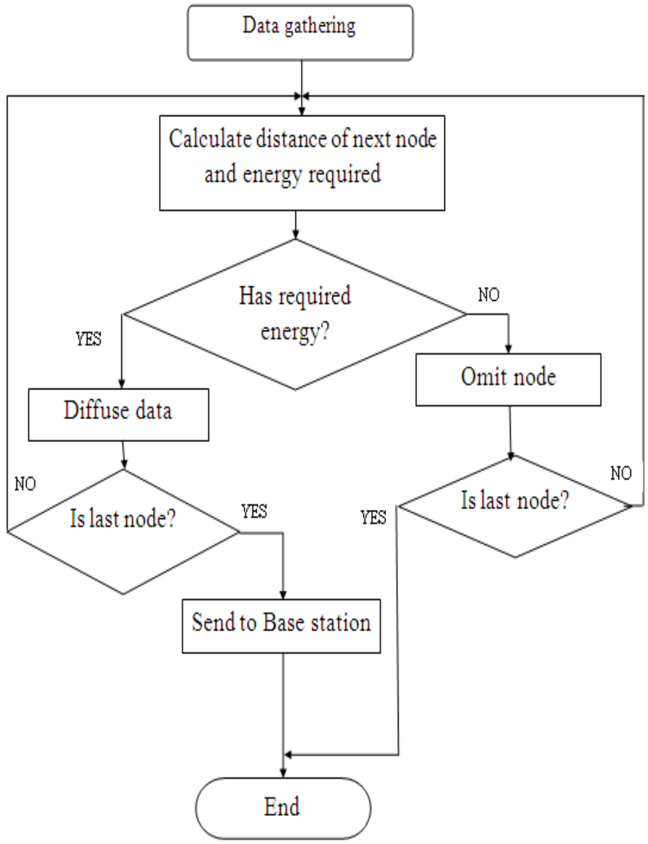

Fig. 6: Flow chart for data gathering

In PICF, a chain is constructed for data gathering and data is transmitted to base station by lead node. Initially the chain starts to form from a node, which is placed at farthest distance from the base station. The node which is selected for chain, or after becoming part of chain, searches for next node. The next node is selected in such fashion that this node is farthest among the remaining nodes those have not been a part of chain till now. It continues to concatenate the next node until it is not in the specific band of distance near the base station, which in our simulation is a 10 m (i.e. from 200 to 210) region. If node is in this region, the first chain formation skips this node and proceeds to the next node. This skipped node is designated as lead node and all the skipped nodes are concatenated in a chain. Only one lead node is selected at a time for transmission to the base station, and the same operation continues until all the nodes are included in any one of these chains. The chain construction operation is illustrated in Figure 5.

D.Data gathering and transmission

After the formation of chain in PICF, the node senses the data and sends it to next downstream node after some processing. The downstream node receives data and sends it to next node nominated in the chain with aggregation of its own data, such that it precedes to the last node of the chain. The lead node receives data from last node of chain, and the lead node transmits the diffused data packet to the base station. In fact, the dead node is omitted from the chain. Energy level of all

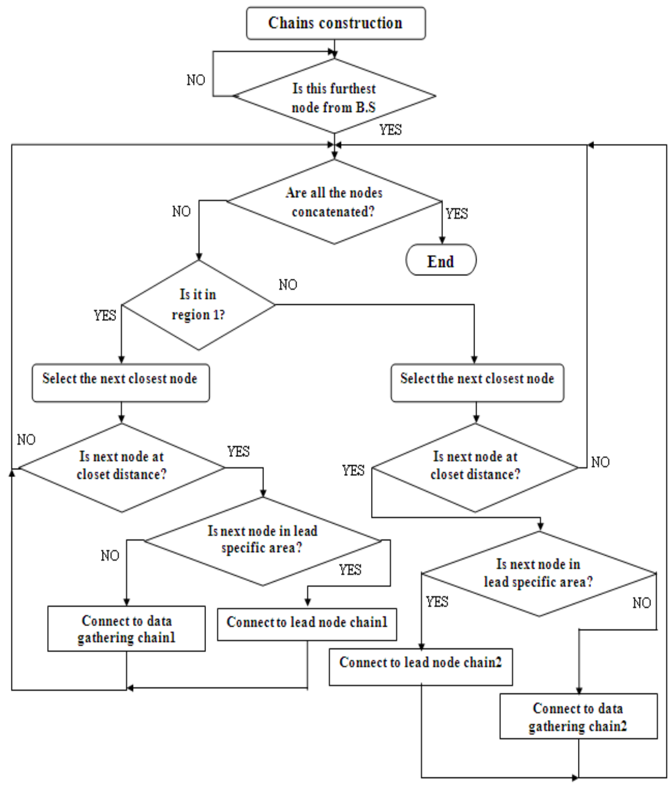

Fig. 7: Flow Chart for low latency

nodes is considered to be the same, initially, so there is no need to check the energy of the nodes at the time of chain construction before sending the data. However, evaluation of energy level after every transmission is essential for each node before next round of transmission. So, if a node does not have enough energy to transmit data, it is considered as a dead node and the node is omitted from the chain. The flow chart for data gathering is shown in Figure 6.

E. Operation to Achieve Low Latency

This is the second part of the proposed protocol, which concerns reducing the time required for completion of one round with same volume of data. The data gathering operation is performed in the same way but it is different in terms of chain construction as that of energy efficient operation.

In PEGASIS, a long chain is formed as all nodes are concatenated in one chain. Due to formation of this long chain, more time is required for completion of one complete round with the same data volume, so excessive time delay is associated with the PEGASIS. As time required for the information to reach the base station depends on the length of the chain, so we can reduce the time delay by shortening the chain length. The length of the chain is directly related to the number of nodes attached in the chain, so to shorten the chain length some nodes are skipped during the formation of chain. But it causes another problem that the entire data does not reach the base station as some nodes are missing and entire field area is not covered. To overcome this problem the entire sensing target field is sub divided into different regions and

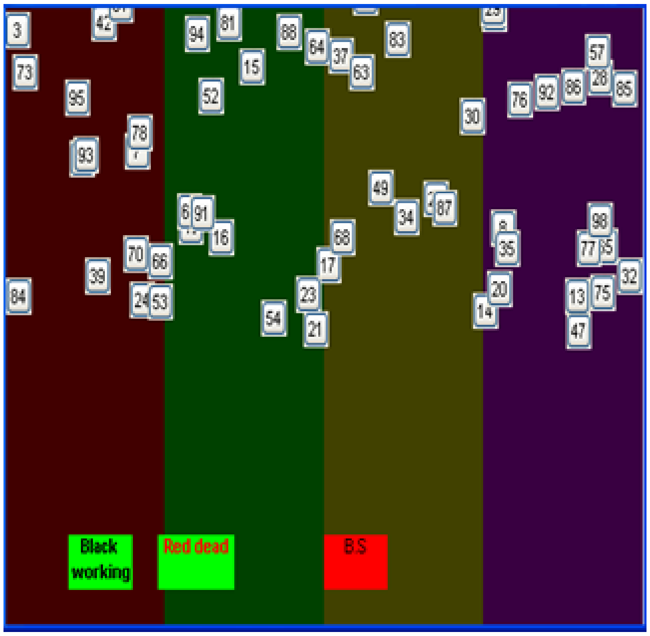

Fig. 8: Topology for four regions

each region has its own and separate chain. Initially, divide the sensing field into two regions and each region has its own chain for data gathering and lead node transmits this diffused data to base station. By employing this idea, the time required to reach the base station is almost half for the same data volume as that for the single chain. Keeping this in view, the entire region is sub divided into different regions. In other words we shorten the chains, which decrease the time delay. Figure 7 presents the flow chart for these chain formations. The time required for reception of data at base station depends on the number of subdivisions of entire sensing field.

Figure 8 shows the topology of four subdivisions of entire sensing field and each region is mentioned by different colors. In this particular case the sensing field is divided in four regions just on basis of location i.e. each region is 100*25 m^2 of area.

V. RESULTS

A. *Energy Efficiency*

The nodes are employed at random location in the sensing field. The simulation compares PEGASIS, PDCH and PICF protocols. The results are computed for 10%, 50%, 80% and 100% dead nodes in rounds of transmission. The nodes in all the routing protocols have the same initial energy level of 1 Joule.

Error! Reference source not found. presents life time comparison of the three protocols. These results show that the modification in PEGASIS has improved the life time of WSN. This is because the nodes located nearer to base station are used to transmit data to the fixed base station. As the dissipation energy during transmission is directly related to the square of the distance, hence, reduction in distance reduces the dissipation energy. The result for the nodes to be alive in the sensor network is depicted in Figure 9. Initially more nodes

Table 1: LIFE COMPARISON OF PROTOCOLS

Protocol/ Dead Node	**10%**	**50%**	**80%**	**100%**
PEGASIS	510	740	1350	1640
PDCH	790	990	1745	2270
PICF	615	1390	2080	2440

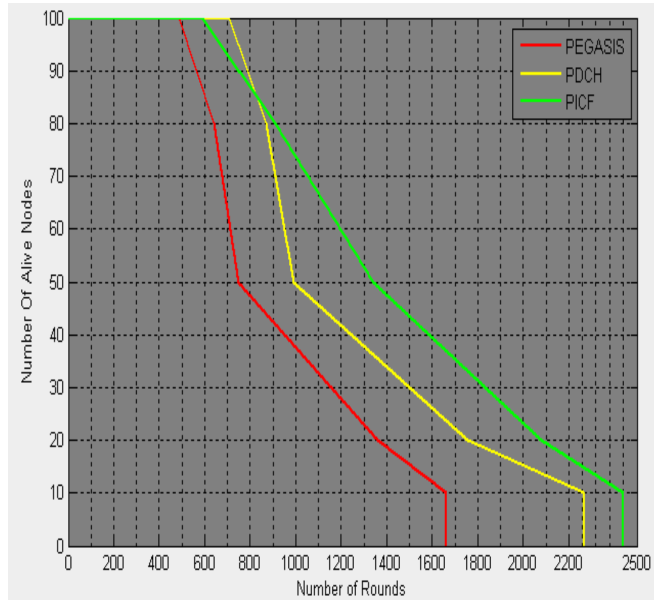

Fig. 9: Alive nodes for number of rounds

are alive for PDCH, but after long run, more nodes are alive for PICF.

Figure 10 compares PDCH and PICF in terms of number of rounds. One round is one complete cycle of reception of sensed data from the sensor node to base station. The number of rounds is more for PICF. It performs more number of transmissions as compared to PDCH. Therefore, PICF has prolonged the lifetime of WSNs. Overall, PICF is more energy efficient than PDCH and PEGASIS.

To get more insight, energy consumed for one round is calculated. Figure 11 shows that more energy is consumed in

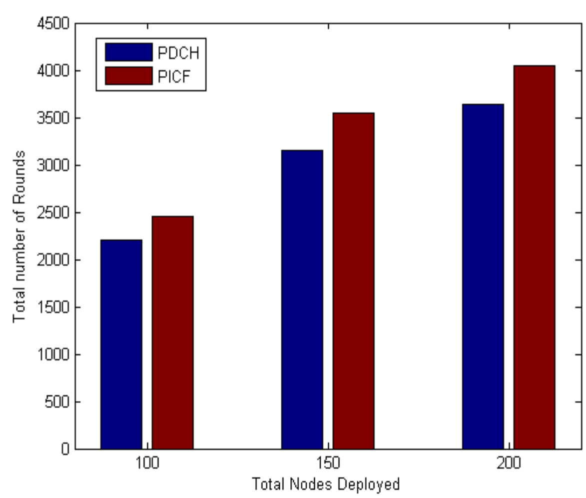

Fig. 10: Number of rounds

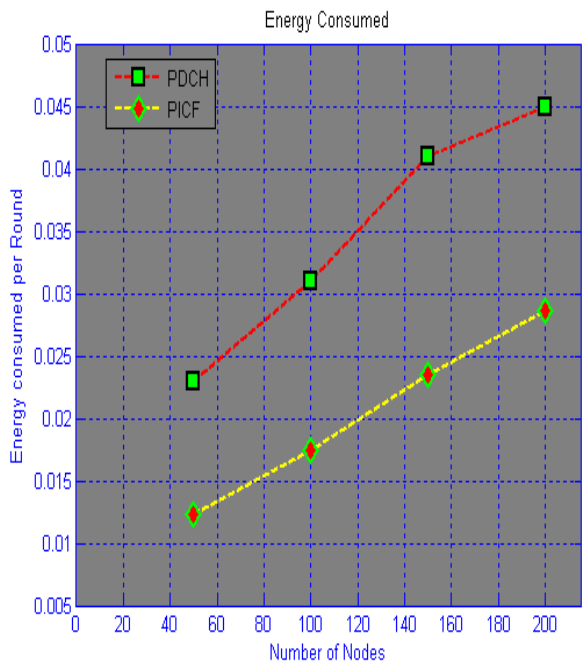

Fig. 11: Energy consumed for one round

PDCH than PICF. Hence, PICF is more energy efficient as compared to PDCH.

B. Low Latency

For analysis of time delay, the results are computed using MATLAB GUI by develpoing the above mentioned flowchart code . It is assumed that all of the sensor nodes are of same type and make so time consumed for processing is same for all nodes. As simulation is performed for same conditions and parameters for algorithm and we assumed that 40 msec time is required for per meter distance transmission and 1 msec for processing of each node. Table 2 compares the latency for PDCH and PICF. In PICF, the subdivisions are 1, 2, 3 and 4. PDCH has low latency than PICF with 1 subdivision, which depicts the entire field. But, as the number of subdivisions increases, PICF has low latency than PDCH.

Increase in the number of subdivisions decreases the time delay because subdivision of the entire sensing field results in shorter chain. By increasing subdivisions, the number of nodes decreases which lowers the total life time of wireless sensor networks as expressed in Figure 12.

It is clear from the above results that as the chain length shortens the latency is reduced. So, time for the reception of data at base station can be reduced by increasing the number of subdivisions of the sensing field.

VI. Conclusion

An energy efficient protocol for wireless sensor networks is presented in this paper. It is compared with two of the existing protocols. All the protocols have been simulated for the same radio model of the nodes, so that, their results can be compared. The results depict that lifetime has increased for wireless sensor networks by decreasing the distance between upstream and downstream nodes. Energy consumption has also reduced due to reduction in distance. The results elaborate

Table 2: LATENCY

Protocols	PICF				PDCH
Subdivision/ No. of nodes	1	2	3	4	1
50	0.122	0.0610	0.0469	0.0349	0.100
100	0.178	0.0890	0.0685	0.0509	0.121
150	0.212	0.1060	0.0815	0.0606	0.130
200	0.256	0.1280	0.0985	0.0731	0.150

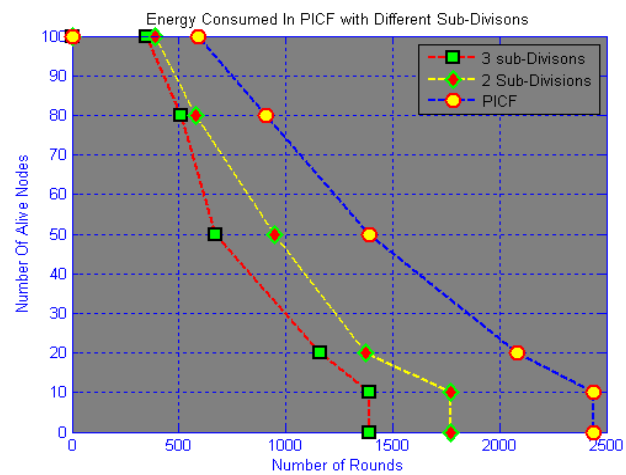

Fig. 12: Energy comparison with different sub division

that as the number of subdivisions increases, the latency decreases due to smaller chain length. But the life time decreases with increase in number of subdivisions of entire region. It is due to increase in distance between two consecutive nodes in the chain. The proposed protocol suggests a tradeoff between energy conservation and latency of data to reach the base station.

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