International Journal of Advance Engineering and Research Development (IJAERD)
Volume 1,Issue 6,June 2014, e-ISSN: 2348 - 4470 , print-ISSN:2348-6406

Maximum Lifetime Data Aggregation (MLDA) in Wireless Sensor Network

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Abstract – Wireless sensor network is collection of tiny sensor nodes. Sensor nodes have limited range of sensing, computational storage and communication resources. We can say Sensor networks are resource-constrained. Extensive use of computational and communication resources can potentially reduce the battery life of Wireless sensors. Lifetime of a WSN depends on Lifetime of Sensor nodes. Energy must be conserved for network lifetime maximization. Data aggregation process can conserve the energy of sensor nodes. Data aggregation process combines the gathered data of multiple sensors and transmit this combined data to base station. Mainly, Flat routing protocols and Hierarchical routing protocols supports data aggregation process. LEACH is the most famous Hierarchical clustering protocol which had been a basis for many further clustering protocols. LEACH protocol is using "No Intelligence" in data aggregation. In LEACH, whenever it's CH's turn to send the data to BS then it's buffer data will be extracted and whole buffer data will be sent to BS. Our Modified LEACH is calculating the aggregated value from collection of Sensed Data and sending aggregated value to BS. The consumed energy to process aggregated data is very less compared to process bunch of data. As data aggregation logic is reducing the consumption power of sensor node, the lifetime of sensor node is increased. As lifetime of sensor node is increased, lifetime of sensor network is increased. Thus, Our Modified LEACH is achieving Maximum Lifetime of sensor network by utilizing Data Aggregation.

Keywords– WSN , DA, LEACH

I. INTRODUCTION

Wireless Sensor Network (WSN) is a collection of large number of sensor nodes that are deployed in a particular region [see figure: 1]. Wireless sensor network is a popular area for research nowadays, due to vast potential application of sensor networks in environmental, health, industrial and military applications. By networking tiny sensor nodes, it becomes easy to obtain the data about physical phenomena which was very much difficult with conventional ways. Wireless sensor network typically consist of tens to thousands of nodes. These nodes collect process and cooperatively pass this collected information to a central location (Base Station).

Sensor node is made up of four basic components as shown in Figure 2: (1) Sensing Unit (2) Processing Unit (3) Transceiver Unit (4) Power unit.

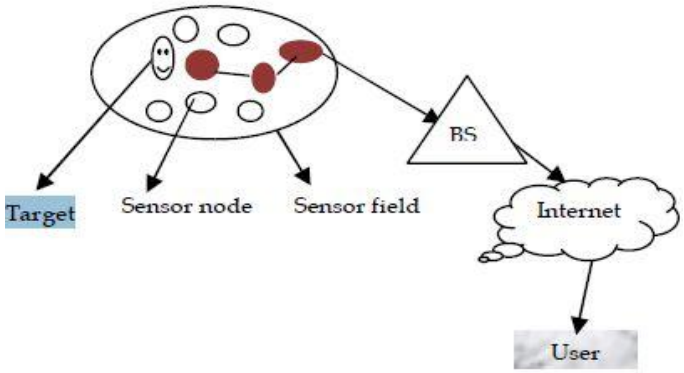

Figure. 1 Architecture of WSN [3]

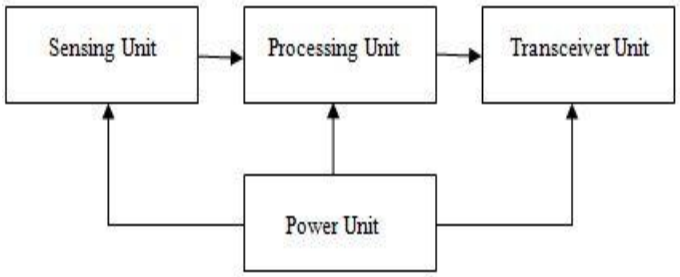

Figure 2 Sensor Node Architecture

The main limitation of WSN is that it is resource-constrained. The Sensor nodes have limited computational storage and communication storage. Due to Extensive use of such resources sensor node will die early. Lifetime of sensor network depends on lifetime of Sensor nodes. Energy of individual nodes must be conserved for network lifetime maximization. Data aggregation can be utilized for energy conservation.

The rest of the paper is as follows. In section 2 we give an overview of Data aggregation. In section 3 related work regarding data aggregation and lifetime maximization, that is LEACH protocol is described. In section 4 analysed limitations of LEACH protocol and our proposed algorithm is described. Section 5 describes simulation results and finally section 6 describes the conclusion and future work of our research work.

II. DATA AGGREGATION

What is Data Aggregation?

Data Aggregation is defined as the process of aggregating the data from multiple sensors to eliminate redundant transmission and provide fused information to the base station[4]. Data aggregation usually involves the fusion of data from multiple sensors at intermediate nodes and transmission of the aggregated data to the base station (sink).
Data Aggregate functions take multiple input values and calculate an aggregated value from them. MAX, MIN, AVG, COLLECT, DISTINCT are examples of aggregation function. MAX find the largest value in a numeric column. MIN find the smallest value in a numeric column. AVG calculates the average of a numeric column. COLLECT collects all the values into a list. It will ignore NULLs. All aggregation functions generally uses the DISTINCT modifier, which removes duplicates from the values.

Why to use Data Aggregation?

As sensor network is utilized for monitoring certain phenomenon, Sensor nodes may generate significant redundant data. So, Similar packets from multiple nodes can be aggregated to reduce the number of transmissions. Due to this minimum use of battery and resources occur at each node in WSN. As lifetime of nodes is prolonged, lifetime of wireless sensor network is also prolonged.

Impact of Data Aggregation on WSN [4]

Figure 3 contains two models. One is DA model and other is Non-DA model in which sensor nodes 1, 2, 3, 4, 5, 6 are regular nodes that collecting data packet and reporting them back to the upper nodes where sensor nodes 7, 8 are aggregators that perform sensing and aggregating at the same time. In this aggregation model, 3 data packet travelled within the network and only one data packet is transmitted to the base station (sink). In non-DA model 3 data packet travelled within the network and all data packets are sent to the base station.

Advantage of Data Aggregation:- First advantage of data aggregation process is that it can enhance the robustness and accuracy of information which is obtained by entire network.
Second advantage is that it reduces the Redundancy in Data. Certain redundancy exists in the data collected from sensor nodes thus data aggregation process is needed to reduce the redundant information.
Third and main advantage is that data aggregation process combines the data packets into smaller data packets it reduces. So data to be sent to BS is less. Hence, data aggregation reduces traffic load and conserve energy of the sensors.

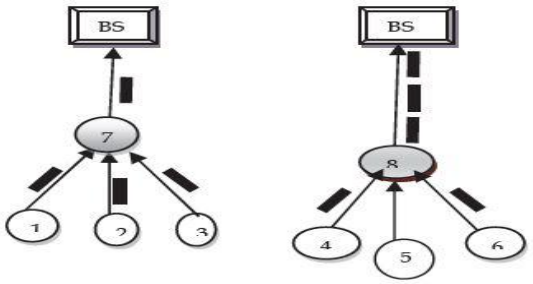

Figure 3 DA model vs. Non-DA model [3]

Disadvantage of Data Aggregation:-
Main disadvantage due to data aggregation is that, we have to compromise with Data Freshness and Latency. For some real time applications like enemy tracking on-time and fresh data is required. For such applications, we can't use data aggregation.

III. RELATED WORK [2][3][10]

The buzzword "Data Aggregation" is issue of network layer and data aggregation process is performed by specific routing protocol of network layer. Mainly, Data-centric (Flat) routing protocols and Hierarchical routing protocol supports data aggregation. Hierarchical Routing protocols are more energy-efficient then Flat Routing Protocols. Because energy dissipation in Flat networks is not uniform in nature while hierarchical routing protocols have uniform energy dissipation due to Clustering technique. We have chosen LEACH ptocol as hierarchical routing protocol for further improvement. Here, we are explaining basics of LEACH protocol.

LEACH is a self-organizing, adaptive clustering protocol that uses randomization to distribute the energy load evenly among the sensors in the network. In LEACH, the nodes organize themselves into local clusters, with one node acting as the local base station or cluster-head. If the cluster-heads were chosen a priori and fixed throughout the system lifetime, as in conventional clustering algorithms, it is easy to see that the unlucky sensors chosen to be cluster-heads would die quickly, ending the useful lifetime of all nodes belonging to those clusters. Thus LEACH includes randomized rotation of the high-energy cluster-head position such that it rotates among the various sensors in order to not drain the battery of a single sensor.

Sensors elect themselves to be local cluster-heads at any given time with a certain probability. These cluster-head nodes broadcast their status to the other sensors in the network. Each sensor node determines to which cluster it wants to belong by choosing the cluster-head that requires the minimum communication energy. Once all the nodes are organized into clusters, each cluster-head creates a schedule for the nodes in its cluster. This allows the radio components of each non-cluster-head node to be turned off at all times except during its transmit time, thus minimizing

the energy dissipated in the individual sensors. Once the cluster-head has all the data from the nodes in its cluster, the cluster-head n`ode aggregates the data and then transmits the compressed data to the base station.

LEACH is divided into two phases as shown in figure 4.

I. Setup Phase
II. Steady Phase or Data Transmission Phase

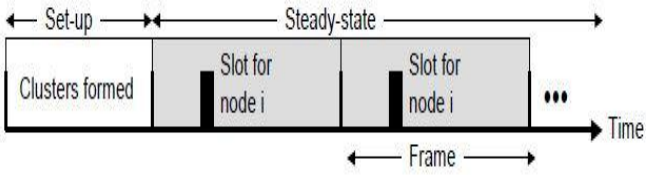

Figure 4 Phases of LEACH protocol[10]

I) SETUP PHASE [10]:

It consists of Cluster-head Selection, Cluster Formation, TDMA Schedule Creation, Schedule Distribution as Sub-phases. Initially, when clusters are being created, each node decides whether or not to become a cluster-head for the current round. This decision is made by the node n by choosing a random number between 0 and 1. If the number is less than a threshold T(n), the node becomes a cluster-head for the current round. Each node that has elected itself a cluster-head for the current round broadcasts an advertisement message to the rest of the nodes. The non-cluster-head nodes must keep their receivers on during this phase of set-up to hear the advertisements of all the cluster-head nodes. After this phase is complete, each non-cluster-head node decides the cluster to which it will belong for this round. This decision is based on the received signal strength of the advertisement. After each node has decided to which cluster it belongs, it must inform the cluster-head node that it will be a member of the cluster. The cluster-head node receives all the messages for nodes that would like to be included in the cluster. Based on the number of nodes in the cluster, the cluster-head node creates a TDMA schedule telling each node when it can transmit. This schedule is broadcast back to the nodes in the cluster.

II) STEADY PHASE[10]:

Steady phase can be considered as data transmission phase. Every sensor node transmit their data while their turn comes. In Steady Phase, every Non-CH node waits for their turn to transmit the data. They may turn-off their radio until their turn comes. At the same time, CH's can't turn off their radio. They have to collect data from every non-CH nodes and aggregate them. After aggregating them CH's have to send this aggregated data to BS node. The steady-state phase is long compared to the set-up phase.

IV. PRACTICAL ANALYSIS OF LEACH PROTOCOL

LEACH.cc is the implementation of LEACH protocol in NS2. Following section describes the analysed limitation of LEACH protocol.

Analysis: Limitation of LEACH protocol

1) Cluster Formation is not uniform.

When we simulated the topologies with different number of nodes, it is analyzed that cluster formation is not uniform.

Result of experiment_1.tcl: [20 Node Topology]

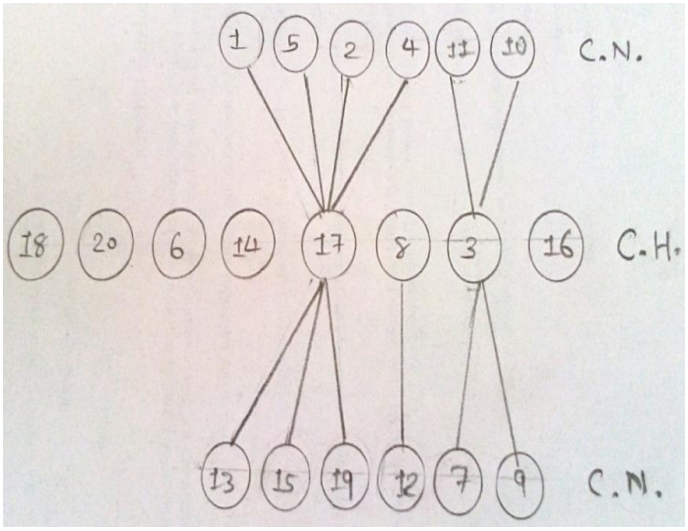

Figure 5 Cluster Formation in 20 Nodes Topology

In Figure 5, Nodes of middle row are CHs and Other nodes are Cluster nodes. E.g. 17 is a CH and 1, 5, 2, 4, 13, 15, 19 are CNs of that CH.

Result of experiment_2.tcl: [30 Node Topology]

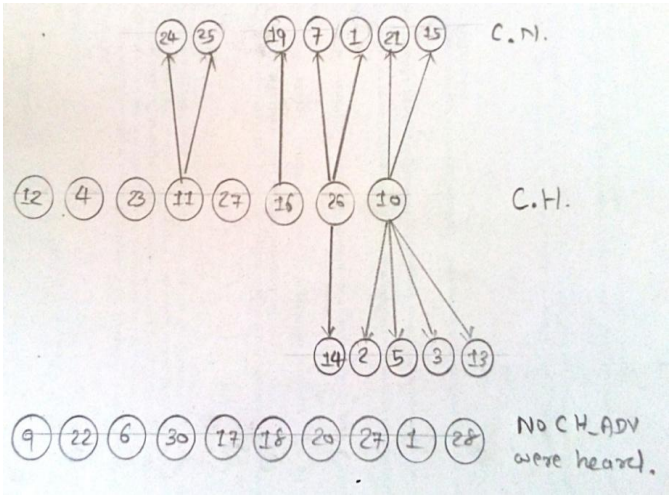

Figure 6 Cluster Formation in 30 Nodes Topology

In Figure 6, Nodes of middle row are CHs and other nodes are Cluster nodes. The nodes of of Last row didn't get any CH_ADV massage. They will send their data on their own. E.g. 26 is a CH and 7,1 and 14 are CNs of that CH.

Result of experiment3.tcl: [40 Node Topology]

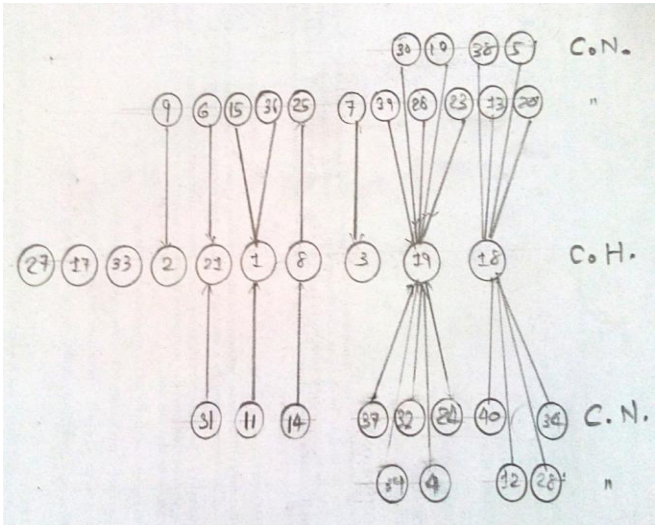

Figure 7 Cluster Formation in 40 Nodes Topology

In Figure 7, Nodes of middle row are CHs and Other nodes are Cluster nodes. E.g. 1 is a CH and 15, 36, 11 are CNs of that CH.

2) **Cluster-Head selection criterion is not based on Residual Energy of Node.**

Cluster-Head selection criteria in LEACH protocol is as follows[10]:Every node generates random number between 0 and 1. If this random number is less then Threshold value [T(n)] then that node can become CH for current round. Threshold value is Calculated as per Following Formula:

$$T(n) = \frac{p}{1 - p * \left(r \bmod \frac{1}{p}\right)}, if\ n \in G$$

Where, p is desired percentage of CH (e.g. 0.05) , r is current round and G is set of nodes that have not been CH in the last 1/p rounds.

Why selection criteria should be based on residual energy of node?

Due to such randomized selection criteria, there would be chances of nodes with less energy to be selected as CH. As residual energy of node will be less, such CH will not be able to send Cluster Data to Base Station. This results in loss of data of particular Cluster. So CH selection Criteria must be based on Residual Energy.

3) "No Intelligence" in data aggregation.

Data aggregation of LEACH protocol is as follows:

1. Each Node having a Buffer for storing the Sensed Attribute. Each node will sense the Sensing Environment.
2. The sensed data will be stored in Buffer. If the Buffer is Full then first sensed data will be dropped from Buffer (as per FIFO Policy).
3. Whenever it's CH's turn to send the data to BS then this buffer data will be extracted and whole Buffer Data will be sent to BS.

There should be application of aggregation function like Max, Min, Avg for calculating aggregated value from Data. The job of Aggregation Function is to extract Information out of Data. Due to aggregation function, only useful information will be sent to BS. By applying such aggregation function, Lifetime Maximization of sensor network can be achieved. As the LEACH protocol is not using such aggregation function, I concluded that LEACH is using "No Intelligence" in Data aggregation.

Proposed algorithm to counter this issue: My proposed algorithm is focusing on counter third issue from above. Following are functions of LEACH.CC. Whenever any node is about to transmit the data to BS, it will call the disseminateData() function. Internally this function is calling mergeSensedData() function for extracting the Buffer of SensedData. In Leach Protocol, collection of SensedData will extracted from Buffer, and whole Buffer Data will be sent to BS. But my proposed algorithm will send Only aggregated value from SensedData to the BS.

Function:: disseminateData() calls mergedSensedData()

LeachApp:mergeSensedData(SensedData *data)

1. Get the collection of Sensed data.
2. Make aggregate Function (MAX, MIN, AVG) and get an aggregated value from collected sensed data.
3. Now, Sensed data is aggregated value so only aggregated Value will be sent to BS.

Thus, My proposed algorithm is using data aggregation logic and sending only aggregated value to BS. Now it is vey clear that consumed energy to process 1 data is very less compared to consumed energy to process 100 data. Due to aggregation logic, consumed energy of the sensor node will be less. This results in battery saving of sensor node and increased lifetime of node. Modified LEACH is implementation of this proposed algorithm. In next section, We have shown result of different measures with LEACH and Modified LEACH protocol.

V. SIMULATION AND PERFORMANCE EVALUATION

This section shows the simulation results with different performance measures like Lifetime of sensor network, data accuracy, latency, data freshness. The simulation is done with network simulator 2.35. Here, Modified LEACH is implementation of our proposed algorithm. The simulation parameters are shown in table 1.

PARAMETERS	VALUE
Simulator	NS 2.35 with Mannasim Module
Studied Protocol	LEACH, modified LEACH (which contains data aggregation part)
MAC protocol	MAC/802_11
Physical Layer	Phy / WirelessPhy-Mica 2
Battery	EnergyModel / Battery
BS Location	Centre
Number of BS	1
Transmission Range of BS	100m

Energy of BS	5 Joule
Number of Nodes	10 to 100 nodes
Simulation Area	100 m * 100 m
Simulation Time	500 sec.
Application	Environment Monitoring

Table 1. Simulation Parameters

1) Lifetime of Sensor Network: Mannasim considers the lifetime of sensor network as time till "first SET of selected CH's" ran out of their energy.
Following plot considers Lifetime of Network with LEACH protocol for 20 Node Topology with 0.25 J, 0.50 J, 1 J and 5 J energy respectively in each node VS. Lifetime of Network with Modified LEACH (which contains Data Aggregation Logic) protocol for same topologies.
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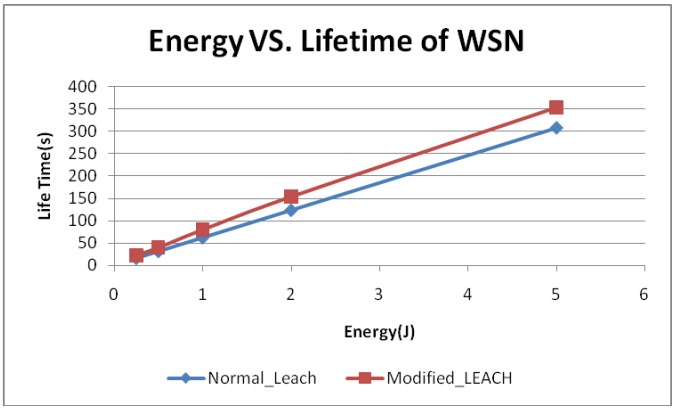

Figure 8 Energy vs. Lifetime of WSN

Figure.8 shows the lifetime of sensor network in case of LEACH and modified LEACH protocol. It clearly shows that Modified LEACH is improving the lifetime of sensor network. As example, with 2 Joule energy and LEACH protocol, network lifetime is 123.23 seconds while with same 2 Joule energy and Modified LEACH protocol, Lifetime of Network is 153.99 seconds.
The reason behind this improvement in Lifetime is 'Data Aggregation'. As data aggregation logic is reducing the consumption power of sensor node, the lifetime of sensor node will be increased. As Lifetime of Sensor node is increased, Lifetime of Sensor network will be increased.

2) Data Accuracy: The definition of data accuracy in sensor network varies from application to application. Wireless Sensor Networks (WSNs) can be used to achieve continuous monitoring in the area of interest. In continuous-monitoring applications, each sensor node transmits its sensed data to the BS periodically. For target localization problem, all the data generated in network must reach to BS for accurate target location estimation. But, for temperature monitoring problem as temperature varies in small amount, aggregation of sensed data is enough for accurate temperature estimation. Thus, the definition of data accuracy depends on the specific application for which the sensor network is designed. As we are considering temperature monitoring problem, aggregated value of the multiple readings will also show the accurate value of temperature.

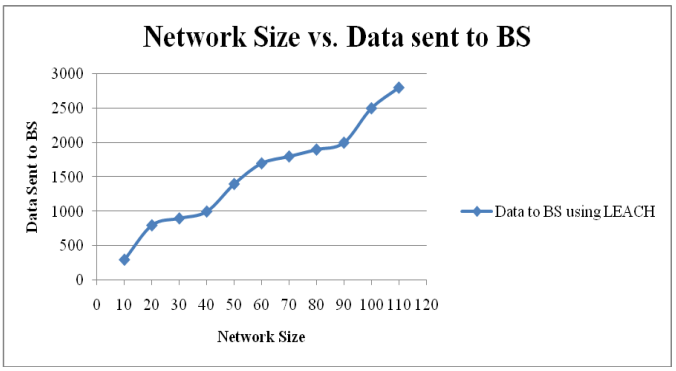

Figure 9 Network Size vs. Data sent to BS

Figure 9 shows the plot of Network Size vs. Data sent to BS using LEACH protocol. Here, each topology has 0.25 J energy in each node. While simulating 70 node topology, 1700 readings will be received at BS from different clusters of the Network. But these readings don't make much sense for BS. BS have to extract out information from such large amount of Data. Thus, LEACH protocol is not providing accurate information to BS, it is just providing bunch of readings to BS.

Instead of this, Modified LEACH is applying data aggregation logic at CH. Due to this only average value of the collected readings will be sent to BS. So, the given case will send only 17 averaged value readings of different clusters to BS. Hence, BS will receive very few and important readings from different clusters. Thus, data aggregation logic gives information to the Base Station instead of bunch of Data.

3) Latency: In case of sensor network, Latency can be defined as time difference between the data generated at source node and data received at BS[3].

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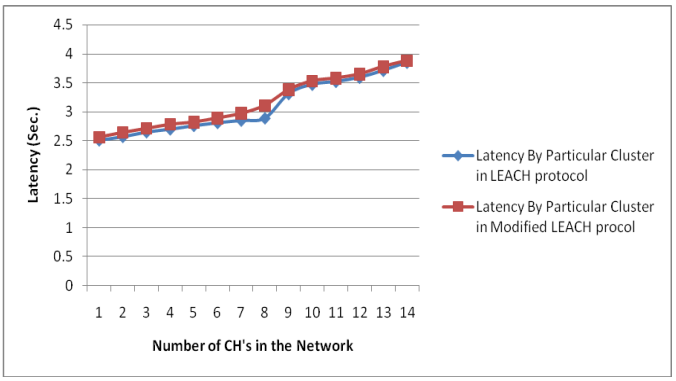

Figure 10 Latency with 14 CH's in the Network

Figure: 10 shows the Latency Plot for 50 Node topology with 0.25 Joule energy in each node. Simulation with both protocols generates 14 Cluster Heads. Each cluster sends it's data using CH to BS. In simulation, once the topology of 50 node is created, every node starts to sense the data. For given simulation, first data reading is generated on 0.0131 second. Now, out of 14 CH's, Data of First CH sent to BS on 2.5321 second. Thus, Latency involved in Data of First Cluster is 2.51 Second. Figure 10 shows the Latency involved in Data of all 14 CH's. Here, Blue Line shows the Latency by particular cluster in LEACH protocol and Green Line shows the Latency by Particular cluster in Modified LEACH protocol.

The average latency involved in the Network due to LEACH protocol is 3.1 second and average latency involved in the Network due to Modified LEACH protocol is 3.2 second. As there is negligible difference in Latency due to LEACH and Latency due to Modified LEACH, we can conclude that Modified LEACH is not affecting the Latency.

4) Data Freshness: Data Freshness measure ensures that the data are recent. If the data reaching to BS is not fresh then there is no meaning of that data. In LEACH protocol, when it's turn of CH to send data to BS, Recent 100 readings of its Buffer will be sent to BS. In modified LEACH protocol, when its turn to send data to BS, average of Recent 100 readings of its buffer is sent to BS. It suggests that both protocol, deals with recent data. Thus, we can conclude that data reaching to BS using LEACH protocol and Modified LEACH protocol are Fresh and usefull for BS.

IV. CONCLUSION & FUTURE WORK

In order to save energy and resources, data must be aggregated to avoid tremendous amount of redundant traffic. The buzzword "Data Aggregation" is issue of network layer and data aggregation process is performed by specific routing protocol of network layer. We have considered LEACH routing protocol as Network layer Routing protocol. LEACH protocol is using "No Intelligence" in data aggregation. Whenever its CH's turn to send the data to BS then its buffer data will be extracted and whole Buffer Data will be sent to BS. Our modified LEACH is calculating the aggregated value from collection of Sensed Data. Consumed energy to transfer aggregated data is very less compared to consumed energy to transfer bunch of data. This results in battery saving of sensor node and increased lifetime of node. Our modified LEACH is not compromising with data accuracy, but it further improves the accuracy of data. Data reaching to BS using LEACH protocol and Modified LEACH protocol are Fresh as both protocol deal with recent data of the buffer. The average latency involved in the Network due to LEACH protocol and average latency involved in the Network due to Modified LEACH protocol is almost same. Hence, we can conclude that our modified LEACH is not affecting the Latency. Thus, finally we can conclude that our modified LEACH is maximizing the lifetime of sensor network by utilizing data aggregation logic.

Further improvement of LEACH protocol is possible by choosing CH selection criteria based on residual energy and Implementation of better Clustering technique which can make cluster formation uniform.

ACKNOWLEDGEMENT

My Sincere thanks to my guide Prof. Nirav M. Raja, for providing me an opportunity to do my research work. I express my thanks to my Institution namely G. H. Patel College of Engineering and Technology for providing me with a good environment and facilities like Internet, books, computers and all that as my source to complete this research work. My heart-felt thanks to my family, friends and colleagues who have helped me for the completion of this work.

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