Analysis on Enhancements in LEACH Protocol for WSN

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Abstract— *Owing to recent technological advancements in wireless sensor and communication technologies, WSN has become a prominent research topic tapping the potential use of it to a wide range of applications. A large quantity of miniscule sensor nodes collaborating and communicating through a wireless medium, collect and propagate data finally to a base station or sink for useful analytical purposes constitutes a WSN. Routing becomes imperative in WSN due to resource constrained nature of the sensor nodes. LEACH (Low Energy Adaptive Clustering Hierarchy) is the most popular and conventional cluster based hierarchical routing protocol which is generally accepted in all its ramifications and its importance cannot be overemphasized. LEACH however popular and robust has not yet achieved perfection. Enhancements have been proposed in terms of various fields such as cluster head selection scheme, cluster formation algorithms, reducing energy overheads, taking residual energy into consideration etc., which aim to increase the efficiency and robustness of LEACH. In this paper we discuss the enhancements and descendents of LEACH that are proposed over the years for its efficient and robust functioning and also provide a comparative analysis of LEACH, TEEN and SEP protocols for WSN.*

Keywords — *Wireless sensor networks, Hierarchical Routing, LEACH, Clustering, Energy Efficiency, Lifetime.*

I. INTRODUCTION

Wireless sensor networks have a history that dates back to the days of cold war during 1950's when the U.S. Navy connected many hydrophones and made a mesh out of them called SOSUS (Sound Surveillance System). SOSUS was innovatively built to locate the soviet submarines underwater [10]. During the 1980's, DARPA (Defense Advanced Research Projects Agency) started communication between nodes by use of ARPANET. The main idea was to make use of a distributed architecture of inexpensive sensing nodes to communicate among themselves to collect data. In 1998 sensor technology became a hot topic of research and as a result sensors were made still smaller, powerful, efficient and sensitive. This led to opening a new research field of wireless sensor technology. From early 2000 there has been immense research in the field of sensor technology which has led to wireless sensor network become an intrinsic part of our daily applications to present days. [15]

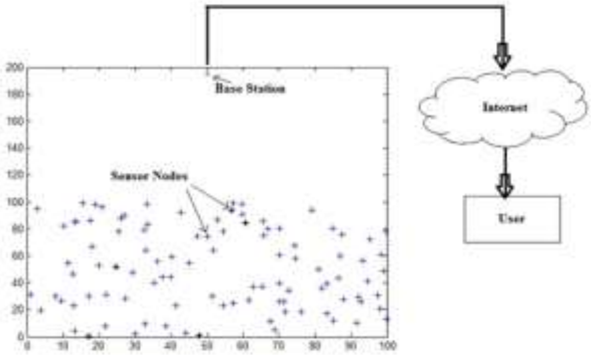

Fig-1: Wireless Sensor Network Architecture

Fig.1 shows the architecture of a WSN which has sensor nodes deployed randomly. The sensor nodes collect the data from the location and then collaborate with each other to propagate the sensed data to be forwarded to a base station where it can be used for further analysis, for example as shown in figure can be communicated via internet to a workstation of a user.

WSN finds applications in many fields some of which are, to provide an early warning for drought, hurricanes, earthquakes etc. Civil monitoring applications are traffic, office, home, distant locations etc. WSN also find applications in healthcare appliances which include for example, heartbeat monitoring. They are also popular in military surveillance systems which have harsh environments.[26]

This paper is organized as follows: Section 1 gives an introduction to WSN, its history and application. Section 2 provides an insight into the enhancements in LEACH and its descendents proposed for WSN. In Section 3 and 4 we compare and analyze LEACH, TEEN and SEP protocols. Finally, Section 5 concludes the paper.

II. ENHANCEMENTS IN LEACH AND ITS DESCENDENTS

In this section we provide an overview of descendents of LEACH protocol and various enhancements proposed over the years.

A. Heinzelman et al. [1] have proposed LEACH (low energy adaptive clustering hierarchy) protocol for WSN. This protocol aims at utilizing the maximum potential of low energy microsensor networks. In LEACH whole of the network is divided into clusters, each containing a Cluster Head. A cluster head is selected at the beginning of each round with certain probability and selected stochastically. Data is sensed by the nodes and aggregated at the Cluster Head which is then propagated to the base station. Also the role of cluster head drains more energy with respect to other sensor nodes.

Cluster head selection is done according to a stochastic probabilistic calculation based on the following formula:

$$T(n) = \begin{cases} \dfrac{p}{1 - p \times (r \bmod p^{-1})}, & \forall n \in G \\ 0, & \forall n \notin G \end{cases}$$

Where n is a random number between 0 and 1, p is the cluster head selection probability and is the set of nodes that have not been CH for previous rounds

The working of LEACH is divided into two phases. In setup phase formation of clusters and cluster heads take place whereas in steady phase data transmission occurs. Cluster head formation in further rounds depends upon residual energy of the node. LEACH uses randomized rotation of cluster heads to evenly distribute energy load among sensors. It uses localized coordination to enable scalability and incorporates data fusion to reduce amount of information that must be transferred to the base station. The energy is evenly distributed which then increases the useful lifetime of the system. Simulation results show that the proposed LEACH outperforms other protocols such as direct transmission, minimum transmission energy and static clustering.

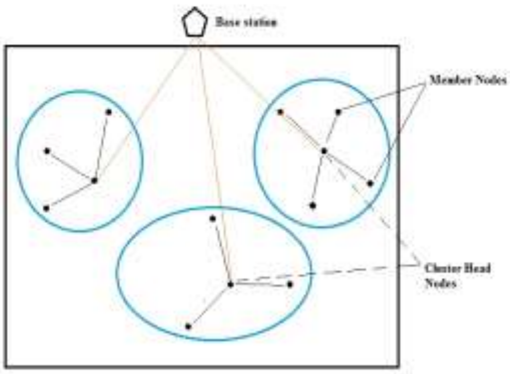

Fig-2: LEACH protocol architecture

B. Manjeshwar and Agarwal [2] proposed TEEN (Threshold sensitive Energy Efficient sensor Network Protocol). After the formation of cluster, the CH broadcasts two thresholds: hard and soft. Whenever the sensed value exceeds the hard threshold and the change of value in respect to previous value is greater than or equal to the soft threshold then the sensor node sends data. The sensor nodes always are in sensing mode and do not go to sleep mode but energy conservation takes place because the sensor node only transmits the data when sensed value exceeds hard and soft threshold. The user can change the hard and soft threshold according to the needs of the situation and application. TEEN gives better performance in terms of lifetime as compared to LEACH.

C. Heinzelman et al. [3] have proposed LEACH-C(LEACH- Centralized) with a centralized clustering approach in which optimum cluster heads are selected. It reduces the data transmission cost which was a problem in LEACH due to close positioning of CH to one another. The member nodes in LEACH had to expend greater energy to send data to their respective CH. The author proposes a centralized algorithm in which global knowledge of member nodes location is with the base station. Thus the base station sends message of optimum CH to all the nodes in the network. GPS system is used for determining the location of nodes in the network. The energy efficiency of the network increases and so is the lifespan. Results show that LEACH-C outperforms LEACH in terms of lifetime and energy conservation.

D. Smaragdakis et al. [5] have proposed SEP (Stable Election Protocol) which takes into consideration the heterogeneity among nodes. The heterogeneity may be present beforehand as some nodes have more energy than others or after one round of operation of LEACH the CH drains more energy than other nodes. The authors have shown that behavior of network in presence of heterogeneity or when the first node dies becomes unstable. The SEP protocol proposed is shown to have longer stability period with respect to LEACH. The main idea the author has proposed is that the nodes that have higher energy are forced to expend more energy within in a round's operation. Simulation results confirm the authors' claim that SEP has better performance than LEACH in terms of lifetime and successfully extends the stable region.

E. Loscri et al. [7] have proposed TL-LEACH (Two Level LEACH) which introduces two level hierarchy for better energy distribution among the member nodes. The main idea is to introduce a two level hierarchy in terms of Cluster Heads (primary and secondary). The primary Cluster formation is same as that of LEACH but after selection of primary cluster head, advertisement messages are send to the primary cluster head for selection of secondary cluster head. A grant message is then sent to all those nodes that are eligible to be made secondary cluster head by the primary cluster head. It results in more data packets being sent to base station in comparison to LEACH protocol. TL-LEACH also increases scalability as there is localized coordination within the cluster.

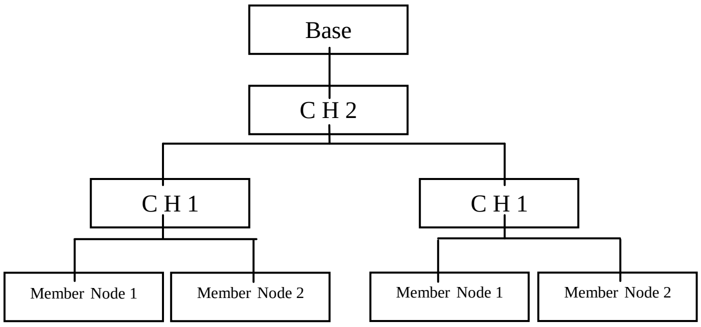

Fig-3: TL-LEACH Architecture

F. Qing et al. [8] have presented DEEC (Distributed Energy-Efficient Clustering) with a clustering algorithm to reduce energy consumption. DEEC takes into consideration the heterogeneity of the nodes in a wireless sensor network. The author proposes to elect cluster heads based on ratio between residual energy of each node and average energy of the network. Nodes that have more residual energy have better chance to become cluster heads than other nodes having low residual energy. The algorithm basically works in three steps, firstly cluster head is selected then secondly, average energy of the network is calculated, thirdly, calculation of ratio and comparison with the residual energy of the previous cluster head to select new cluster head. Results show that DEEC has better lifetime and delivers more packets than LEACH.

G. Xiangning et al. [9] have presented Energy-LEACH and Multihop-LEACH with different enhancements over LEACH protocol. In the first protocol which is Energy-LEACH it is proposed that the residual energy of the node is to be taken into account which is considered for CH selection. A matrix is used for storing the residual energy which is then used for comparing and selecting the cluster head. As the proposed method balances energy in the whole network which leads to extending lifetime of the entire sensor network. The second proposed Mutlihop-LEACH protocol makes use of multihop communication. Sometimes a CH node is out of range and is not able to communicate to the base station due to low energy or geographical constraints. Then the CH node finds an optimal multihop path and sends the signals to its nearest CH node which then propagate the signals to the base station. Simulation results have shown an improvement in lifetime and packets received at the base station.

H. Junping et al. [11] have proposed TB-LEACH (Time Based-LEACH) which makes use of a fixed time period for cluster head selection. The working is based on LEACH and is same as that of LEACH with certain improvements. The number of nodes that can become cluster head is fixed. The number of cluster heads constraint is maintained by the use of a counter which is set before hand. The operation of steady phase is same as that of LEACH and data is aggregated and sent to the base station ultimately. In the proposed scheme the nodes select a fixed time period for which it would like to remain a cluster head. The nodes after selecting the time period would be compared and the node having least value is selected as the CH. Network lifetime is improved with comparison to LEACH.

I. Hou et al. [12] have presented ED-LEACH (Energy and Distance LEACH) which improves the cluster head distribution in the wireless sensor network. Cluster heads inherently get placed close to one another and sometimes far away due to random deployment. This method proposes to make use of Euclidean distance between nodes for better placement of cluster heads in a region. It also takes into consideration the remaining energy of nodes after a round’s performance for cluster head selection. Simulation of ED-LEACH shows better results in terms of number of packets sent and network lifetime.

J. Tong et al. [13] have presented LEACH-B (LEACH Balanced) where number of cluster heads is kept optimal. The main idea is to consider residual energy of candidate nodes that are to be selected to form cluster head. The energy consumption is lowered as clusters formed are balanced. Apart from selecting a random number between 0 and 1 as in LEACH there is another stage that takes into consideration residual energy. Thus LEACH-B guarantees optimal cluster heads formation in each round. Authors have shown that the optimal number of cluster heads is between 3% and 5%.

K. Farooq et al. [14] have proposed MR-LEACH (Multihop Routing LEACH) which induces multihop routing in LEACH protocol to prolong the lifetime of wireless sensor network. This work proposes network to be partitioned into different layers of clusters. Various cluster heads in different layers communicate with other layers to propagate the data in the sensor network. Due to hierarchy the upper layer cluster heads tend to behave as super cluster heads for lower layer cluster heads. The base station selects the cluster heads for upper and other respective levels. Cluster heads once formed then make TDMA schedule for sending data to the base station. Results prove that MR-LEACH has better network lifetime and energy consumption than LEACH.

L. Liu et al. [16] have proposed LEACH-GA (LEACH-Genetic Algorithm) that uses a genetic algorithmic approach for prediction of probability of selection of cluster heads. Optimal probability of selection is the optimal percentage of member nodes to be selected as cluster heads. LEACH-GA proposes a preparation phase to be augmented to the previous working of LEACH and this preparation phase is performed once. During the preparation phase the nodes after selecting a value between 0 and 1 (as in LEACH) send their location information, ID and their calculated choice of becoming a cluster head to the base station. The base station then applies a genetic algorithm to calculate optimal probability and broadcasts it to all the member nodes. The working following then is same as of LEACH. Results show that LEACH-GA prolongs the lifespan of wireless sensor network.

M. Bakr et al. [17] have proposed LEACH Spare Management (LEACH-SM) where spare nodes are added and managed to improve energy efficiency and lifetime of the network. An algorithm is proposed called DESST (Decentralized Energy efficient Spare Selection Technique) for selection of spare nodes in the network. The algorithm is executed in the spare selection phase that precedes the setup and steady phase of LEACH. Every node in the network performs DESST to find out if it can become a spare node. A target coverage is also maintained in selection of spare node so the area to be sensed is not left out. The spare nodes then go in sleep mode for energy conservation and would come to wake up state whenever a node gets its residual energy below a threshold value. Results obtained during simulation show that proposed LEACH-SM prolongs network lifetime and improves energy efficiency of the wireless sensor network.

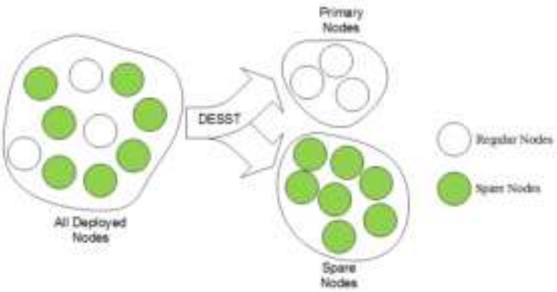

Fig-4: Spare nodes in LEACH-SM [17]

N. Zhao et al. [18] have proposed an improvement in LEACH protocol for wireless sensor network to improve energy conservation and to lessen energy dissipation during overheads of cluster head selection. The main idea here is to use a VCH (vice cluster head) within each cluster in the network. Cluster heads in their respective clusters calculate every node’s energy change and based on the residual energy propose a vice cluster head. This reduces the reclustering overhead which leads to energy conservation and extends the lifespan of the network with comparison to LEACH.

O. Yektaparast et al. [19] have proposed Cell-LEACH which is an improvement over LEACH protocol for WSN. Cell-LEACH proposes uniform clustering in the network. The sensor network is divided into sections called cells. There exists a cell head and a cluster head which collaborate to collect data and then propagate it to the base station. A cluster is made up of seven adjacent cells. The cell heads and cluster heads rotate for energy conservation but there is no reclustering and recelling. The cell head prepares a TDMA schedule for all the nodes and the data is collected by the cell heads which is then send to the cluster head for aggregation and finally sent to the base station. The main idea here is to turn off the transmitter of all the nodes when the data is transferred from cell head to the cluster head and the direct communication cost from the nodes to the cluster heads is also reduced. Simulations using JSIM simulator shows Cell-LEACH performs better than LEACH and LEACH-C protocols.

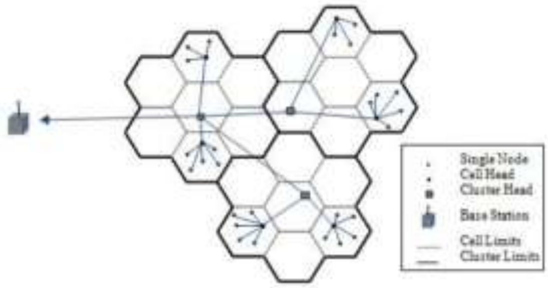

Fig-5: Cell-LEACH Protocol [19]

P. Ahlawat and Malik [20] have proposed an extended Vice-Cluster Selection approach. It is basically an extension to improve V-LEACH protocol in wireless sensor network. Authors have focused on improving the vice cluster head selection procedure. Maximum residual energy, minimum energy and minimum separation distance have been taken into account for selection of vice cluster head. The minimum distance is calculated by received signal strength (RSS). In classical LEACH whenever the cluster head dies due to operations of sending, receiving and overhearing, the cluster becomes useless. Whenever the CH dies its position would be replaced by a vice CH. This leads to a better performance and increases the network lifetime by 49.37% with respect to original LEACH.

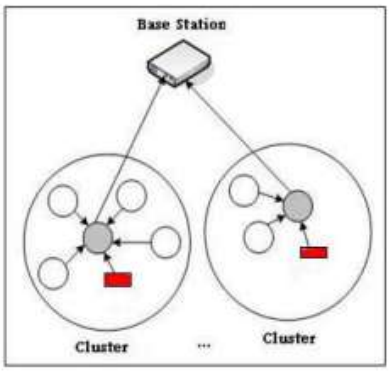

Fig-6: Improved V-LEACH Protocol [20]

Q. Solanki and Patel [21] have proposed LEACH-SCH (LEACH- Supporting Cluster Heads) to improve network lifetime of sensor networks. Apart from providing a survey of different classification of routing protocol authors propose to induce a supporting CH with addition to already selected CH to reduce the reclustering overheads during the setup phase. Sensor nodes select two random variable r1 and r2 between 0 and 1. The first is used for selecting CH whereas the second is for selecting the Supporting Cluster Head. The simulation results (in MATLAB) of LEACH-SCH shows improved lifetime as compared to LEACH.

R. Antoo et al. [22] have proposed EEM-LEACH (Energy Efficient Multihop-LEACH) that uses multihop communication and minimum communication cost from nodes to the BS. The cluster head is chosen such that it has minimum energy consumption and maximum residual energy as average energy consumption is considered for CH selection. The CH discovers a multihoop path to the base station. As CH is used to find the multihop path for data transmission thus need for global knowledge is abolished. The communication cost per packet gets reduced because of multihop communication which improves the network lifetime.

S. Mechta et al. [23] have proposed LEACH-CKM (LEACH-Centralized K-Means classification) which is an improvement over LEACH-C i.e. LEACH Centralized where global information of nodes is conveyed to the base station for improving the CH placement. Nodes that are far away from base station and are not able to communicate become isolated and lead to inefficient cluster formation and therefore leads to data loss. To improve network performance authors have proposed to make use of K-means classification for grouping of nodes. Secondly the data must be transmitted by MTE(Minimum Transmission Energy) protocol. LEACH-CKM allows entire area coverage and outperforms LEACH-C protocol and improves lifetime by 30%.

T. Gambhir and Fatima et al. [24] have proposed Op-LEACH (Optimized LEACH) that aims to reduce energy consumption and improve the lifetime of the network. LEACH protocol suffers from a drawback that the nodes sometimes do not have data to send in the allocated TDMA time slot. Op-LEACH makes use of these unused TDMA time slots to send data and reduces energy consumption within the network. If the sensor node has data to send in its time slot then it sends the data but if there exists no data to send then the node donates its slot to next node and goes into sleep mode. This process is repeated until TDMA frame is completed. The simulation is done in OMNET++ which shows that Op-LEACH outperforms LEACH.

U. Patra and Chauhan [25] have proposed IEEHCS (Improved Energy Efficient Hybrid Clustering) protocol for wireless sensor networks. In IEEHCS the cluster head is reselected based on a cluster head selection and cluster formation algorithm. The clustering process is not repeated and the cluster head position is retained by the selected CH or shifted to a most eligible member node. This reduces the overheads of reclustering after each round which leads to energy conservation. The CH is selected taking into consideration the node density, remaining energy of node and minimum distance of separation so that control message overheads are reduced. IEECHS reduces energy dissipation and first node death improves upto 45.39% over LEACH-C.

V. Khan et al. [26] have proposed $(LEACH)^2$ where authors have combined LEACH with a linearly enhanced approach for cluster handling. In this proposed work authors have divided the entire sensing region into four regions. Network performance is studied in the presence of one, two and three sinks. The sensor nodes associate with the cluster head or the sink on the basis of the received signal strength. This improves the energy efficiency of the network. It is assumed that the nodes always have data to send and data transmission takes place as in traditional LEACH. MATLAB simulation results show that arrangement with three sinks outperforms in terms of network lifetime, throughput and energy dissipation.

W. Singh and Chugh [29] have proposed MEDC (Mutual Exclusive Distributive Clustering Protocol) that uses mutual exclusion principle for selection of cluster heads. Only one cluster head is selected within a sensor’s communication range. MEDC proceeds in iterations same way as LEACH. Cluster head is chosen after every iteration. Cluster head is chosen that has the maximum residual energy after the iteration. Authors have also reviewed information fusion and various ways of change point detection. MEDC protocol outperforms HEED as shown by simulation in terms of lifetime of WSN.

We now summarize the above discussion in the form of table as follows:

TABLE I

Protocol	Year	Important Enhancement Proposed	Result of Enhancement
LEACH -C	2002	Centralized clustering approach with known location of member nodes	Reduces data transmission cost and increases lifetime
TL-LEACH	2005	Two level hierarchy of cluster heads	Better throughput and scalability
DEEC	2006	CH selection based on residual energy and averae energy of network	Better throughput and lifetime
Energy LEACH & Multihop LEACH	2007	Residual energy of nodes considered and multihop communication	Better throughput and lifetime
TB-LEACH	2008	Fixed time period for CH selection	Better network lifetime
ED-LEACH	2009	Residual energy with Euclidean distance used for CH selection	Improves CH distribution and lifetime
LEACH-B	2010	Number of CH kept optimum	Lower energy consumption
MR-LEACH	2010	Multihop routing and hierarchy of cluster heads	Better network lifetime
LEACH-GA	2011	Genetic Algorithm used to find optimal CHs	Prolonged lifetime
LEACH-SM	2011	Spare nodes added and managed	Better lifetime and energy efficiency
V-LEACH	2012	Proposal for use of vice cluster head	Prolonged lifetime
Cell-LEACH	2012	Cluster divided into cells with cell head and cluster head	Uniform clustering and better lifetime
Improved V-LEACH	2013	Maximum residual energy, minimum energy and minimum separation distance for Vice CH selection	Improved network lifetime
LEACH-MAE	2013	Better CH selection for mobile sensor nodes	Equal energy distribution and prolonged lifetime
LEACH-SCH	2013	Supporting CH to reduce clustering overheads	Improved network lifetime
EEM-LEACH	2014	CH used to find multihop path	Prolonged lifetime
LEACH-CKM	2014	K-means classification used and data transmitted by MTE	Improves coverage and prolongs lifetime
Op-LEACH	2014	Unused TDMA slots used for data transmission	Better throughput and lifetime
IEEHCS	2014	CH is reselected based on node density, remaining energy of node and separation distance	Reduction in energy dissipation and better lifetime
$(LEACH)^2$	2015	Sensing region divided into four regions and multiple sinks used	Better throughput and lifetime
MEDC	2015	Mutual exclusion used for CH selection, one CH within one sensor's range	Better network lifetime

III. SIMULATION

The simulation parameters used are discussed in this section and given in table 2. The simulation is performed in MATLAB. The base station is kept far away from the network at (50, 195) and the heterogeneity parameters are taken as m=0.4 and a= 0.5 which means that 40% of the nodes have 50% higher energy than others.

TABLE 2

PARAMETERS	VALUES
Simulation Area Size	100 m x100 m
Number of nodes	100
Initial Energy of nodes	1 Joule
Percentage of CH (P_{opt})	5%
Data Packet size	4800 bits
Transmission & Receiving Energy (E_{elec})	50 nJ/bit
Free space Transmitter Amplifier Energy (E_{fs})	10 pJ/bit/m^2
Multipath fading Transmitter Amplifier energy (E_{mp})	.0013 pJ/bit/m^4
Data Aggregation Energy (E_{DA})	5 nJ
Type of distribution	Random

IV. RESULTS AND ANALYSIS

Following network performance metrics are used for analyzing the simulation results:

1. *Network Lifetime*: It is defined as the time for which the network remains functional and till all the nodes die and stop transmission.
2. *Energy Consumption*: Amount of energy dissipated during transmitting (by member nodes) and receiving (by CH nodes) of packets by the nodes during the lifespan of the sensor network.

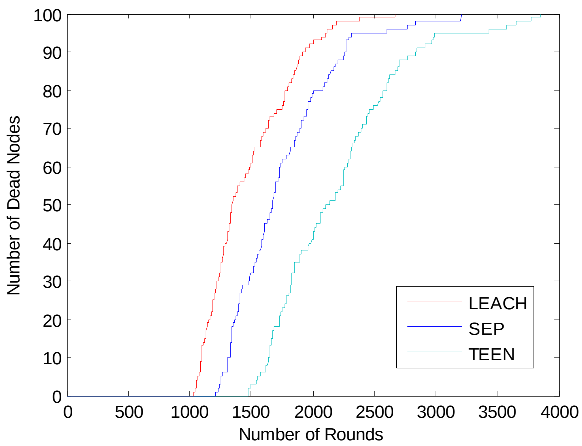

Fig-7: Number of Dead Nodes Vs Number of Rounds

Figure 7 shows the number of nodes that are dead as the functioning of the wireless sensor network proceeds in terms of number of rounds. As shown in the figure SEP has better lifetime than LEACH due to the fact that it uses better cluster head election procedure which makes use of heterogeneity of the network. Heterogeneity may be present or may come into existence as the operation of the network evolves since some nodes expend more energy than others (for example cluster heads due to long range transmission). TEEN on the other hand is a reactive routing protocol and is sensitive to changes that occur in the sensed attributes. The nodes sense the environment all the time but the nodes send the data only when measured value is beyond a certain threshold which helps in conserving energy. As there is no periodic data transmission so sensor nodes have to switch on their transmitter only when sending data in contrast to its counterparts. Hence, TEEN gives the highest lifetime of the wireless sensor network. Table 3 shows an increment of 19.2% in case of in case of SEP and 48.34% in case of TEEN with 1J of energy of node.

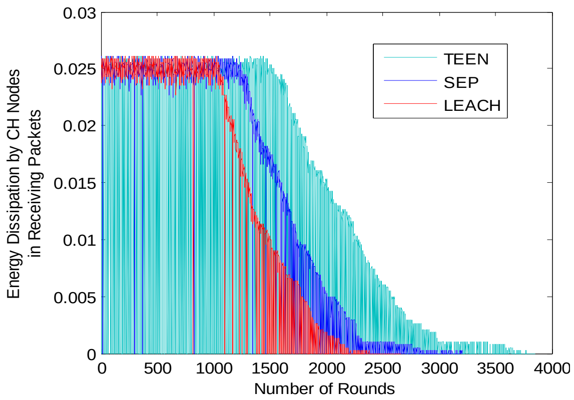

Fig-8: Energy dissipated by CH Nodes Vs Number of Rounds

In Figure 8 a graph between energy dissipation of cluster head nodes versus number of rounds proceeding of the sensor network is drawn. As the CH Nodes does the data processing and data aggregation on the data before sending it to the base station which consumes energy. Figure 9 shows that there is no change in energy dissipation in case of LEACH and SEP protocols, which is consistent with the fact that SEP uses heterogeneity and weighted probability to extend the lifetime of the network. The plot of SEP shows more energy dissipation because of more number of nodes alive due to increased lifetime. Hence, energy dissipation is same in LEACH and SEP. TEEN on the other hand is a reactive routing protocol. The member nodes do not send data periodically, thus it can observed from Figure 8 that energy dissipation varies from 0 to around .025 and the readings are not constant, thus the energy consumption of TEEN is the lowest among all three due to the fact that the CH Nodes will receive data only when the sensed value varies beyond a certain threshold.

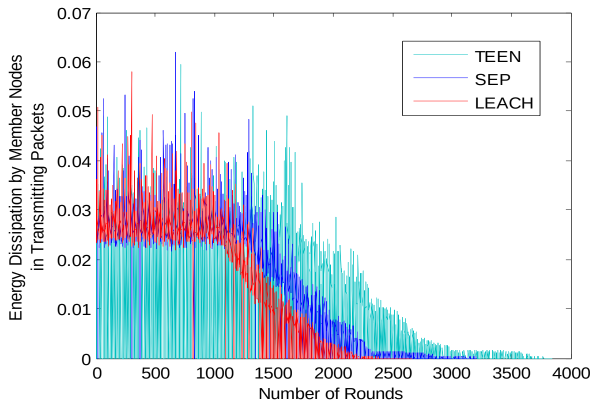

Fig-9: Energy dissipated by Member Nodes Vs Number of Rounds

Figure 9 shows energy dissipated by member nodes plotted with number of rounds of the sensor network. It is inferred from this figure that the energy dissipation of LEACH and SEP is same for the same reason that SEP does not make use of energy conservation to improve lifetime of the network. TEEN on the other hand has less dissipation of energy which can clearly be seen from Figure 10. It is due to reactive nature of TEEN as the nodes do not send their sensed data periodically to the respective cluster heads. This explains the wide variation of energy dissipation measurements in the figure. Hence the energy dissipation of TEEN is least.

TABLE 3

	ROUNDS WHEN NODES DIE											
	FND	10%	20%	30%	40%	HNA	60%	70%	80%	90%	LND	Avg.
LEACH	1033	1096	1159	1226	1285	1343	1488	1620	1776	1920	2663	
SEP	1264	1307	1367	1476	1587	1671	1731	1896	2003	2264	3204	
Increase	22.36	19.25	17.74	20.39	23.50	24.41	16.33	17.03	12.78	17.91	20.13	19.2
TEEN	1473	1631	1729	1821	1962	2088	2245	2388	2566	2838	3850	
Increase	42.25	48.81	49.18	48.53	52.18	55.47	50.87	47.40	44.48	47.81	44.57	48.34

V. CONCLUSIONS

In a wireless sensor network most important concerns are energy efficiency and lifetime of sensor network. In this paper we have discussed the enhancements proposed over the years for addressing the mentioned issues. We have also simulated and compared three popular protocols viz. LEACH, TEEN and SEP. The protocols designed have an application domain that is best suited for them respectively. Significant research work is ongoing in WSN and LEACH protocol and this paper will help those researches to design and develop efficient protocols in the time to come.

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