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Weighted Energy Efficient Clustering Hierarchy for Multi-hop Communication in Wireless Sensor Networks

Khan Afsar[1], Ali Nawaz Khan[1], M. Waqas Anwar[3], Ehsan Ullah Munir[2] and Munal Akhtar[1]

[1]Department of Electrical Engineering,
COMSATS Institute of Information Technology, Lahore, Pakistan
[2]Department of Computer Science
COMSATS Institute of Information Technology, Wah, Pakistan
[3]Department of Computer Science
COMSATS Institute of Information Technology, Abbottabad, Pakistan

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ABSTRACT

Wireless Sensor Networks are constrained in terms of energy resources and therefore require efficient energy management during collection, processing, aggregation, communication and eventual utilization of sensor's data in several customized applications related to healthcare, group and habitat monitoring, security and surveillance etc. Cluster based hierarchical routing is known to be superior than flat routing as all nodes in the cluster send their data to cluster head for forwarding to base station. Existing cluster based hierarchical routing protocols either assume the direct communication between cluster heads and base station or through multi-hops in some scenarios. In this paper, a new energy efficient hierarchical clustering and multi-hop communication protocol has been presented. Simulation results confirm the superiority of proposed protocol as compared to standard LEACH protocol and it's variants in terms of average lifetime, dissipation of energy and effect of node density in wireless sensor networks.

KEYWORDS: wireless sensor networks, clustering hierarchy, multi-hop communication, energy efficiency, network lifetime

1. INTRODUCTION

Wireless sensor networks have received fair share of attention and importance from researchers and engineers all over the world due to its applications in disaster management, health care, environmental monitoring, fault tolerance, border protection and security & surveillance etc. [1]. Sensor networks can be formed through dense deployment of tiny and low cost nodes that have the ability of communicating with each other or directly to external sink or base station (BS) over wireless interface. These sensors are deployed uniformly in certain situations or randomly either inside or very close to the phenomenon that is being monitored in most cases [2]. Compared with other traditional wireless networks like mobile ad-hoc networks or cellular networks, sensor networks are equipped with sensing, computing, processing and memory constraints [3]. Designing and operating such networks would require scalable architecture and manageable strategies. In hostile environments, sensor nodes may be left unattendedwhich make it impossible to recharge or even replace their batteries. So, in order to extend the life time of sensor networks, available scarce energy resources should be managed wisely.

Generally, the energy consumption in sensor networks can be divided into three categories: sensing, data processing and data communication. Of these three categories, maximum energy is expanded in data communication [4]. So, the major design consideration in sensor networks applications is development and employment of energy efficient routing protocol to prolong network lifetime. To date, many researchers have done their research in the area of energy efficient routing protocols. However, relationship between energy consumption and multi-hop routing has been less explored.

The routing protocols can be classified into data centric, hierarchical and location based routing [5]. In data centric both data size and number of packets can be reduced by data aggregation. Similar information may be collected by many nearby nodes. So there may be similarity among the collected raw data [5]. Sensor protocol for information via Negotiation (SPIN) [6] and directed diffusion [7] can be studied as data centric routing protocols in which energy can be saved by reducing the data redundancy by negotiation method. Hierarchical routing protocols [8] not only provide good scalability for hundreds or thousands of sensors but also introduce the concept of data aggregation by cluster head (CH) within each cluster. In WSN most famous hierarchical routing protocol are discussed in [9] [10] [11]. In location based routing protocols, location information can be obtained by either using

*Corresponding Author: M. Waqas Anwar, Department of Computer Science, COMSATS Institute of Information Technology, Abbottabad, Pakistan. e-mail: waqas@ciit.net.pk

global poisoning system (GPS) or through some other algorithms that are based on received signal strength [12]. After getting location information, energy consumptioncan be reduced through adjustable power control mechanism. MECN [13] can be viewed as a location based routing protocol as it minimizes the energy consumption using low power GPS.

In this paper we have implemented Weighted Energy Efficient Clustering Scheme (WEECS) to prolong the network life time. WEECS has three phases: Clustering, Intra-cluster transmission and inter cluster multi-hop transmission. Initially cluster heads are chosen randomly and each node decides whether or not become a cluster head for current round depending upon value of threshold. Path selection of transmission takes advantage of distance of transmitting cluster head from base station. After determination of optimal route data transmission starts. Following features make WEECS distinct.

1) Energy balance of cluster heads is balanced by uneven clustering.
2) Node energy is saved by multi hop inter clustering routing mechanism.
3) It combines the advantages of direct transmission and multi-hoping.

The rest of paper is organized as follows: Section II overviews existing schemes. Section III presents proposed algorithm. In Section IV we presented different simulation parameters. A complete comparison in terms of network life time, accumulative energy and effect of different node densities is presented in Section V. Section VI concludes our work and introduces future extensions of our research work.

2.EXISTING SCHEMES

2.1.

2.2. LEACH protocol and it's variants

In WSN most important hierarchical routing protocol is Least Energy Adaptive Clustering Hierarchy (LEACH) [9]. In LEACH, network life time can be prolonged as compared to other routing protocol such as direct transmission and minimum transmission energy (MTE) routing protocol. It also introduced the concept of cluster heads (CHs) that are elected randomly and periodically. Each node selects a random number between 0 and 1. If that number is less than a threshold *T (n)* that node becomes a cluster head for that round [9].

$$T(n) = \begin{cases} \dfrac{P}{1 - P*(r \bmod (1/p))} & , n \in G \\ 0 & n \notin G \end{cases} \qquad (1)$$

Where *r* represents the current round, *P* is the desired percentage of CHs. *G* is the group of CHs that has not been elected as CH in last *P* rounds. After the election of CH, information is broadcasted to rest of nodes. Based on this information nodes will decide to which CH they will communicate. Each node will communicate to its CH by usingdifferent CDMA code. After receiving information from its members CHs perform data fusion to minimize the overhead. Then information is then sent to BS or sink through direct transmission.

Although, LEACH is a standard protocol and is more efficient than direct transmission of each nodes to BS and MTE, but still it has drawbacks of random election of CHs, fixed probability of being a cluster head and non-uniform distribution of CHs. Beside these drawbacks LEACH also suffer from one major drawback of direct transmission of information from CHs to BS or sink. This restricts LEACH protocol to use for larger areas or dimensions. Based on LEACH, there are many variants, such as [10] [14] [15] [16] [17]. In LEACH-E [17] nodes with higher energy are selected as cluster head. LEACH-C [17] determines the optimum number of cluster heads by taking into account the energy spent by all clusters.

Since all the existing techniques mentioned above do not account for overall network energy resources and multi-hop communication, while providing a communication link between sensors and sink.***We wish to extend and enhance LEACH to incorporate energy efficiency, multi-hop routing, and near optimal clustering of sensor node in WSN.***

2.2 Energy Model

A sensor network has four major components a processing unit, micro-sensor, communication system, amplifier and power supply unit [3]. Energy is dissipated in all these components of sensors node. In this paper we mainly focus on the energy dissipated in radio component of sensors. We used the same first order radio model as in LEACH. So, in order to transmit *L* bits data message from a distance d , energy cost E_{Tx} is given as:

$$E_{Tx} = \begin{cases} LE_{elec} + L\varepsilon_{fs}d^2 & if \;\; d < d_o \\ LE_{elec} + L\varepsilon_{mp}d^4 & if \;\; d \geq d_o \end{cases} \qquad (2)$$

To receive L bits data message over a distance d, energy cost E_{Rx} is

$$E_{Rx} = LE_{elec}$$

E_{Tx} *and* E_{Rx} represents the energy consumption during communication. As the channel is wireless, so the path loss is approximated by both the free space propagation model and two ray ground propagation model. The energy required by the transmit amplifier is given by

$$E_{mp}(d) = \begin{cases} \varepsilon_{fs}d^2 & ifd < d_o \\ \varepsilon_{mp}d^4 & ifd \geq d_o \end{cases} \qquad (3)$$

ε_{fs} and ε_{mp} represents the amplifier characteristics corresponding to free space and two ray models. Threshold distance d_o can be calculated as;

$$d_o = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \qquad (4)$$

3.WEECS Algorithm

In LEACH protocol, CHs send information to BS or sink via direct transmission. So, nodes furthest from BS or sink required larger transmit power as compared to the nodes that are closer to BS. Nodes furthest from BS will definitely have fewer lifetimes as compared to nodes that are closer to BS. Also these nodes will die out earlier; as a result a vacuum will be created at the region far from BS. Similarly, Election of cluster head is performed in entire wireless sensors network which results in larger amount of energy dissipation and reduction in network life time. To address these drawbacks of LEACH protocol, we proposed Weighted Energy Efficient Clustering Scheme (WEECS) for multi hop wireless sensor networks.

In WEECS algorithm, election criteria of CHs and non-cluster heads node association will be same as in LEACH protocol. Each CH will then calculate its distance from sink or BS and from other neighbour cluster heads as well. In case, calculated distance is greater than d_o CHs will send information to BS, or sink through multi-hoping. Otherwise, information will be transmitted through direct transmission. The remaining energy of the cluster-head that sends its data to next cluster-head can be calculated.

$$E_{Rem} = \begin{cases} E_{Current} - (E_{TX} + E_{DA})*l + l*E_{fs}*(d_{\text{int}})\wedge 2 & if\; D \leq d_o \\ E_{Current} - (E_{TX} + E_{DA})*l + l*E_{fs}*(d_{\text{int}})\wedge 4 & if\; D \geq d_o \end{cases} \qquad (5)$$

WEECS is localized and distributed scheme for practical sensor networks. It combines direct transmission with hop-based transmission during routing in sensor networks. Whole network knowledge such as, location of all nodes in network is not required for WEECS. However, it only requires relative distance to neighbors and base station. Every sensor node builds a routing table that contains information about neighbors, e.g. relative distance between them, distance to base station and residual energy etc. Hence, based on this routing table every sensor can make intelligent decision of its next hop sensor. It's easy to implement this routing strategy for practical applications. The strength of WEECS scheme is that given the distance from source to sink i.e. *d*, and hardware parameters listed in **table. 1**, we can find energy efficient multi-hop routes by selecting the path intelligently. In this way network lifetime can be prolonged by reducing the energy consumption.

3.1 General Requirements

In this research work we have made the following assumptions:

a) All sensors are homogenous and stationary.

b) All sensors know the relative distance to their neighbors and base station.
c) There are symmetric communication links.
d) There is no major obstacle between source and sink.

We did not use mobile sink or sensor nodes and it is assumed that all the sensor nodes are of equal capability in terms of information processing, communicating and power etc. Relative distance from neighbors and base station can be obtained using some algorithms such as, triangulation, or using coordinate system or GPS (installed on source nodes).

3.2 Route setup

Let us consider *N* stationary and homogeneous nodes are deployed randomly in unit area *A*. These nodes arrange themselves into local clusters. In each cluster one node acts as a cluster head or local base station. These local base stations broadcast their current status in their respective clusters. On the basis of minimum communication energy, each node in cluster than determine to which head it will communicate. The CHs in each cluster in now responsible for collecting data from each sensor in its cluster. Once a CH has some data to send to base station, it will first determine a route from source to sink. The summarization of route setup is given as:

a) Source CH will determine the transmission manner, i.e. whether it will use direct transmission or multi-hop transmission.
b) If the transmission manner is multi-hop, next hop will be determined as follows:
   i. Source CH will select series of its neighbor CHs that are closer to base station than itself.
   ii. From these neighbors, a CH with highest energy and minimum distance from BS will be selected as a next hop node.
   iii. Every next hop will repeat this process until data finally reach at BS.
c) If route set up process fails at any stage, information will be discarded and source CH will restart route setup process.

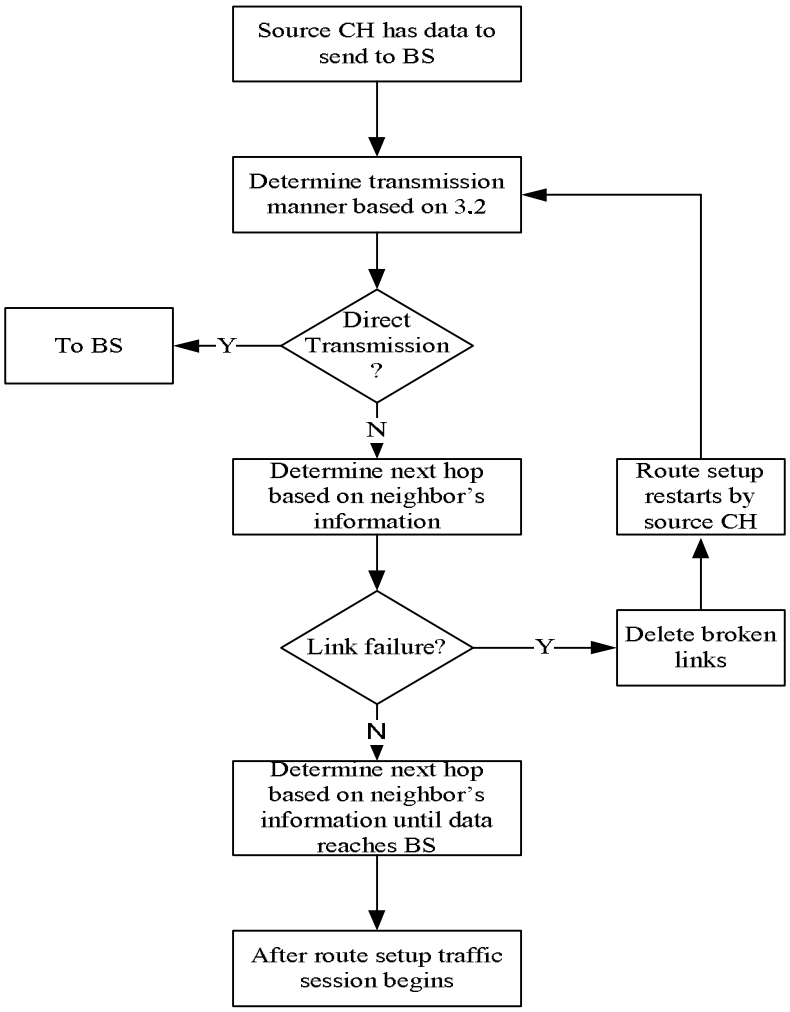

Fig. 1. Flow chart of WEECS algorithm

It is worth mentioning that other factors like optimal hop- number can also be considered in hop-based routing algorithm i.e. we can also choose number of hops for data transmission from source to sink. If data do not reach its destination with in specified number of hops, it will be simply discarded. In such case, network lifetime can be further prolonged. We will leave this factor for our future work.

3.3 Simulation Parameters

To compare the efficiency of WEECS and LEACH, we simulated both these protocols in MATLAB. Simulations results are averaged over 100 times run.

Table 1. Simulation Parameters

Parameter	Value
Network Size	100 *m* x 100*m*
Node Density	100, 200, 300, 400, 500
Sink Location	(0, -100)
Message Bits	4000
E_o	0.5 *J*
d_o	87.7 *m*
E_{elec}	50 *nJ/bit*
ε_{fs}	10 $pJ/bit/m^2$
ε_{mp}	0.0013 $pJ/bit/m^4$

Fig. 2. below shows the random distribution of sensors/nodes in an area of 100 x 100 m^2 .

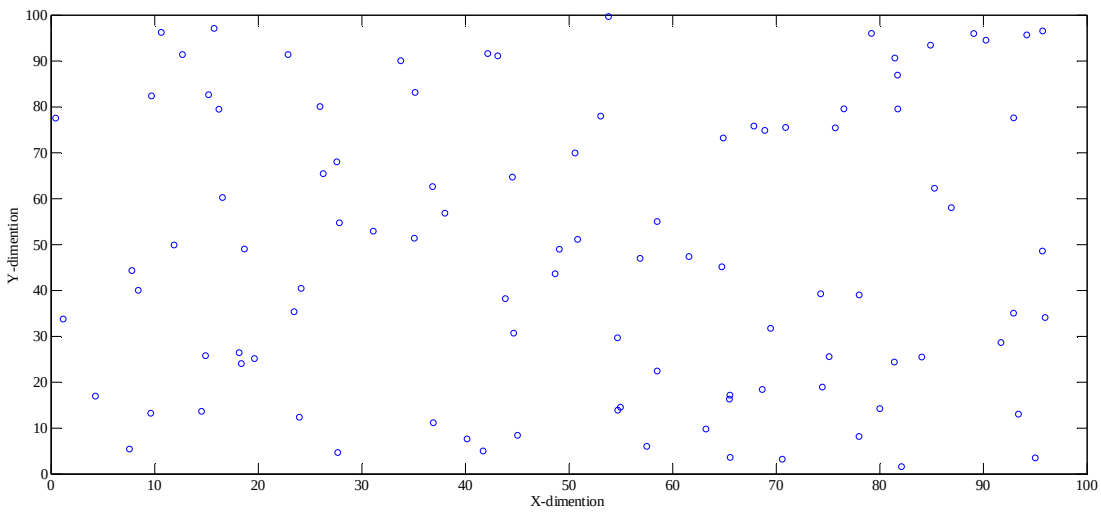

Fig. 2. Random deployment of nodes in area of 100m X 100m

4. Experimental Classification Results and Analysis

In this section our proposed scheme is compared with some existing schemes. Firstly, we have simulated our scheme by only considering the energy of CHs (LEACHSDR); than we again simulated by only considering the relative distance of CHs form BS (LEACHHRER). Secondly, we have combined the energy and relative distance of CHs from BS and compared results with previous results and some existing scheme such as, LEACH. The performance of proposed scheme is evaluated in terms of network lifetime, residual energy and effect of different node densities on the network life time.

4.1 Network Lifetime

Basic definition of a network life time varies from applications to applications. In many applications it is essential that sensor nodes stay alive as long as possible. So the network performance degrades as first node dies. So in such applications it's important to know when first node dies (FND). In other applications, first dead node does not affect the performance of a network, because adjacent or nearby nodes also sense/record the same information.

So the death of single or some nodes will not affect the performance of a network. So in such applications at least half or 80% dead nodes will degrade the network performance. Finally, last 20% alive nodes means end of a network. In this section we used three matrices i.e. first node dead (FDN), half dead nodes (HDN) and last dead node (LDN) for comparisons with the standard LEACH Protocol. **Fig. 3.** shows comparison between sensors that remain alive after each round for LEACH and WEECS. Overall network life time is same both for LEACH and WEECS but, WEECS performs better than LEACH in terms of first dead node and half dead node.

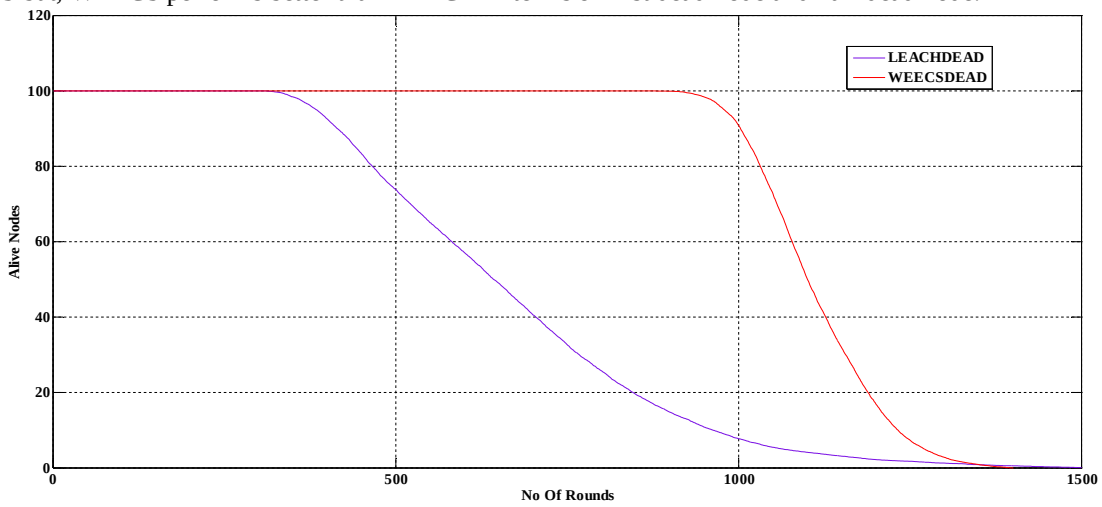

Fig. 3. Network Lifetime comparison

Fig. 4 depicts the comparison between LEACH and WEECS in terms of network first death node (FDN), halfdeath nodes (HDN) and last dead node (LDN). In this, we see that all sensor nodes were alive till 260 rounds in LEACH where as in WEECS it was up to 860 rounds. Similarly, half of sensor nodes were alive till 610 rounds in LEACH and up to 1030 rounds in WEECS. Finally, all nodes survive only for 810 rounds in LEACH and 1190 rounds in WEECS. So, our proposed scheme performs better in all three cases.

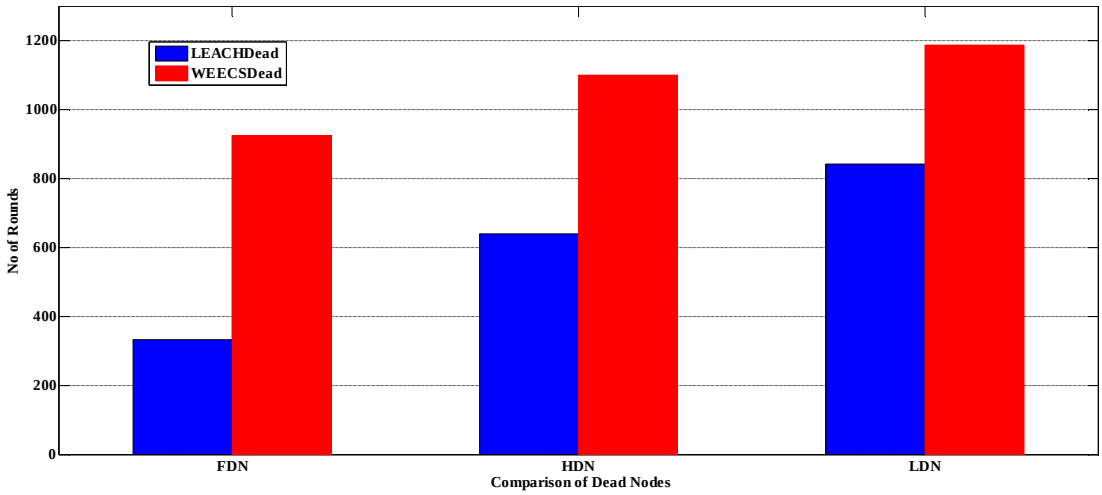

Fig. 4 Network lifetime comparison for first dead node (FDN) half dead node (HDN) and last dead node (LDN)

Fig. 5. depicts the detailed comparison between LEACH, LEACHSDR, LEACHHRER and proposed scheme. In this, it can be seen that our proposed scheme performs better than LEACH and LEACHSDR in terms of first dead node, half dead node and overall network life time. In LEACHHRER, sensor nodes were alive till rounds 970 where as in WEECS it was up to 928. But number of nodes alive in our proposed scheme lasts for more than 1375 rounds where as in LEACHHRER it's near about 1050. Thus, the lifetime of our proposed scheme is comparatively better than all these schemes.

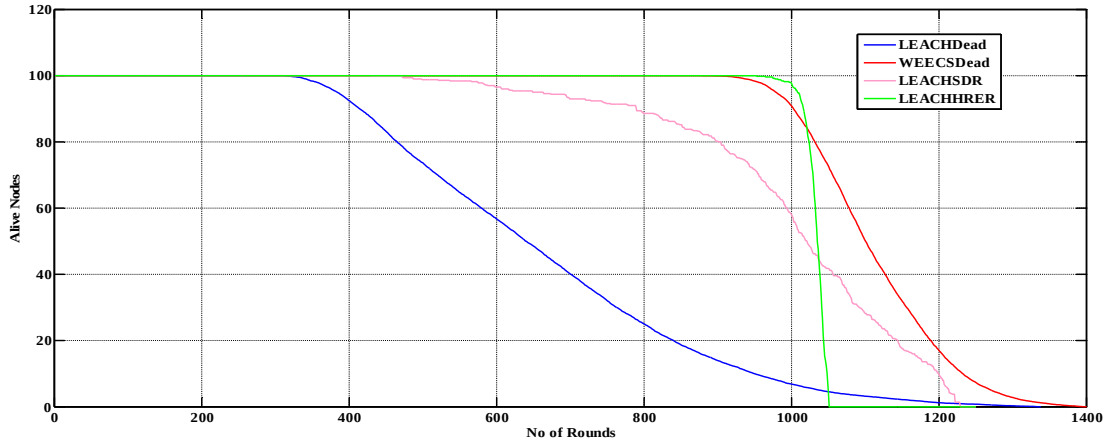

Fig. 5 Comparison between LEACH, LEACHSDR, LEACHHRER and WEECS

Proposed algorithm is also validated with different initial energy E_0. From the result shown in **table. 2**, it can be seen that death of first node in WSN in proposed scheme is at latter rounds than in LEACH. Any routing algorithm should be capable of extending the death of first node in a network as much as possible so that a network should be capable of sending the required information to base station or end user.

Table. 2 Lifetime comparison for different node density

Energy	Protocol	FDN	HDN	LDN
0.25 J	LEACH	163	333	440
	WEECS	470	560	591
0.5J	LEACH	333	638	837
	WEECS	925	1100	1188
1J	LEACH	672	1289	1623
	WEECS	1904	2208	2355

As compared to LEACH our algorithm has the ability to extend the network lifetime. Energy consumption in LEACH protocol is also un-even as can be seen from the difference between the death of first node and last node whereas, in WEECS; energy consumption is distributed evenly among the sensing nodes.

4.2Cummulative Energy

Fig. 6 shows the average energy consumption comparison between LEACH and proposed scheme. The network is initiated with 100 nodes with 0.5 J of energy for every sensing node. There exists a direct relationship between number of rounds and average energy consumption. It can be verified from **fig. 6** below that average energy level of LEACH scheme is decreasing more rapidly as compared to WEECS. The cumulative energy level in LEACH protocol lasts till 1000 rounds whereas, in WEECS, it is more than 1250 rounds. Moreover, decay curve of WEECS is also better than LEACH in terms of energy consumption.

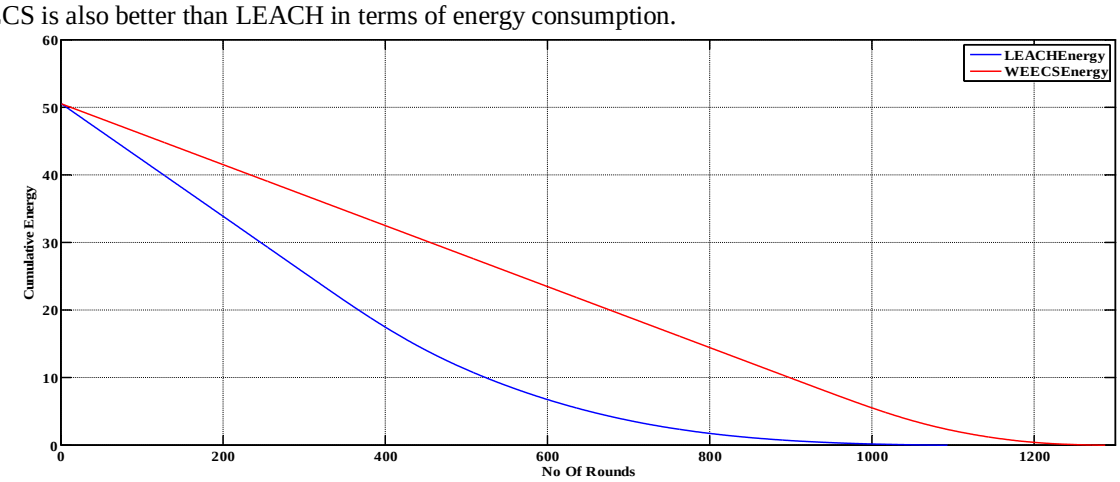

Fig. 6 Cummulative energy comparison for LEACH and WEECS

4.3 Lifetime Comparison for different node density

Finally, we have compared WEECS for different node densities. Keeping all network parameters same, we changed node density from n=200 to n=200, 300, 400 and 500. It can be verified from the results shown in **Fig. 7** below that network lifetime increases by increasing the node density.

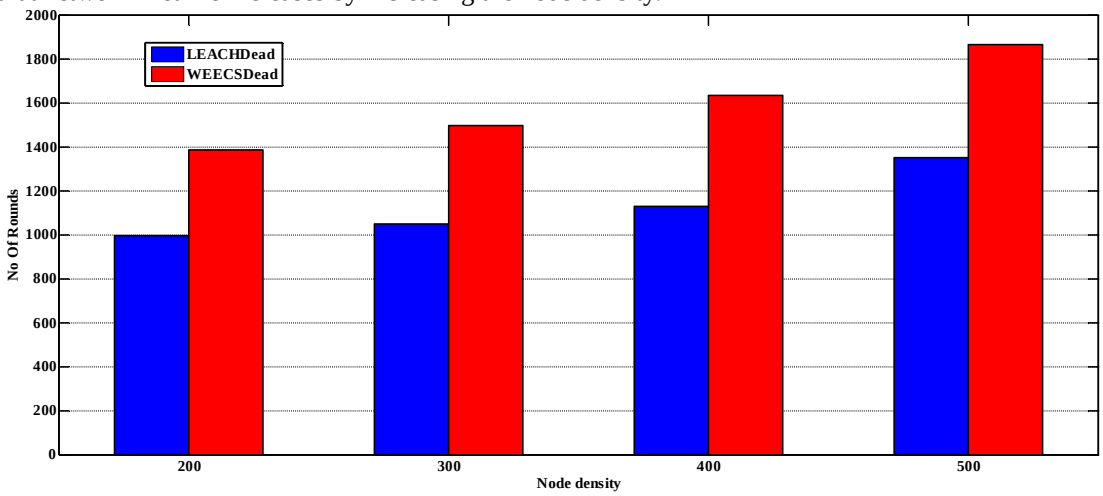

Fig. 6 Lifetime comparison for different node density

5. CONCLUSION

Multi-Hop communication improves the energy efficiency of wireless sensors network as compared to direct communication in most scenarios involving network topologies where line of sight communication is not possible between wireless sensor nodes and sink. In this paper primary focus was to introduce multi-hop communication in WSN to improve the drawback of LEACH protocol and prolong network lifetime. Superiority of proposed algorithm in terms of network life time, residual energy and efficient multi- hop routing from sensor to sink isvalidated through several realistic simulation scenarios in MATLAB. Experimental result shows that proposed scheme is 178% efficient than LEACH for FDN, 72% for HDN and 42% for LDN (number of nodes=100, initial energy=0.5*J*). Therefore, proposed scheme is an excellent candidate for implementing in practical sensor networks.

In future we wish to extend our research work to study the relationship between multi-hop and other network matrices such as packet delivery ratio, communication overhead and latency, so as to further improve the routing in wireless sensors network

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