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Enhanced Leach Protocol for Energy Efficient Wireless Sensor Networks

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ABSTRACT:-

Wireless Sensor Networks (WSNs) consist of a large number of low-cost, low-power, and multifunctional nodes with sensing and computational capabilities. Techniques adopted for communication among nodes include single hop, multi-hop, and clustering techniques. A major challenge of this important technological trend is the limited power available for its operation. In this paper, an energy efficient algorithm to extend the lifetime of WSNs is proposed. The system model was implemented in MATLAB and its responses to varying network parameters such as throughput, number of dead nodes and residual energy were investigated. It also evaluates how node energy and distance affect cluster head (CH) selection. The proposed scheme is validated with an existing conventional LEACH model and recent variants. From obtained results, the proposed scheme showed 69% improvement in throughput, 58% improvement in number of rounds of transmission before the last node dies, and 40% improvement in residual energy of the network on the conventional LEACH scheme.

Key words: WSNs, LEACH, BS, CH, NNs, Sensors.

I. INTRODUCTION

Wireless sensor networks (WSNs) comprise sensor nodes capable of collecting, processing, storing and transmitting/ receiving information from one node to another. These nodes are able to autonomously form a network through which sensor readings can be propagated. The WSN consist of two main components namely sensor nodes which cooperatively monitor physical and/or environmental conditions and base station, BS (also called Central Gateway) which collates the signals from the sensor nodes and serves as an interface between the network proprietor and the WSN nodes. Basic operation of the network: the sensor nodes detect variations in temperature, pressure, humidity, etc. and forward same to the BS node. The BS, through the internet, sends the analog equivalent of the received data to the PDA of the network proprietor who takes necessary action. Energy conservation in sensor nodes is prime concern to engineers in most of its applications. This becomes important as increase in the network lifetime depends mainly on minimizing the energy consumption in sensor nodes (Tripathi, 2012). As with any technology in its developmental phase, some challenges are encountered ranging from throughput, topology, routing, topography etc. Sensing, computing and transmitting/receiving information by tiny sized sensors with power constraint is not an easy feat. WSNs are totally different from general wireless networks due to various constraints and highly application specific nature of WSNs. In wireless communication, it is commonplace for signal strength to drop over a long distance due to signal reflection, scattering and fading and WSN is not an exception. In WSN, cost and other application specific issues affect the communication properties of the system. Particularly, radio communication in WSN is of low power and short range compared to any other wireless communication networks (Tripathi, 2012). The system performance characteristics vary considerably in WSN even though the same basic principles of wireless communication are used in WSN. The size, power, cost and their trade-offs are fundamental constraints in WSNs. Major issues affecting the design and performance of a WSN are deployment strategy, localization, clustering for hierarchal routing, coverage efficiency, efficient MAC, efficient database centric design, QoS implementation and acceptable security (Tripathi, 2012). The conventional routing schemes are inefficient when applied to WSNs as the performance of the existing routing schemes varies per application. Hence, there is a strong need for development of new efficient routing schemes/protocols, which can work considerably across the wide range of applications.

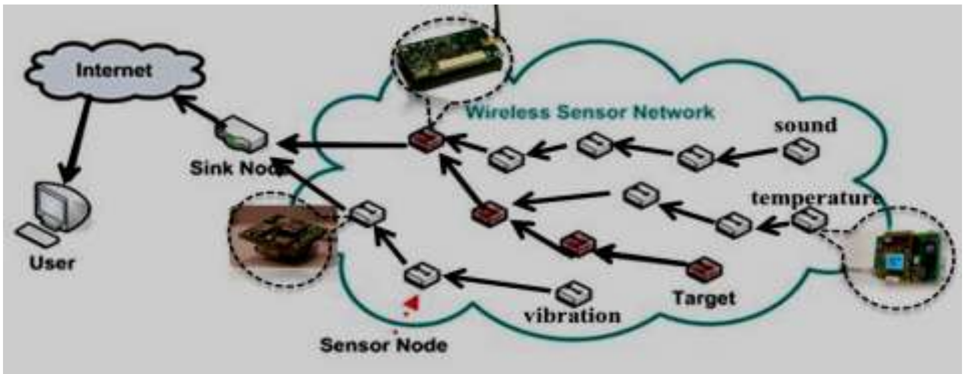

Figure 1. Architecture of Wireless Sensor Network

II. RELATED WORK

Classical approaches like Direct Transmission (DT) and Minimum Transmission Energy (MTE) do not guarantee balanced distribution of the energy load among nodes of the sensor network. In DT, the sensor nodes transmit data directly to the BS and as a result, nodes that are far away from the BS would die first. On the other hand, in MTE, data is routed over minimum-cost routes, where cost reflects the transmission power expended. In MTE protocol, nodes that are near to the Base Station (BS) act as relays with higher probability than nodes that are far from the BS. Thus, nodes near the BS tend to die first.

The solution of the above problems was first overcome in Low Energy Adaptive Clustering Hierarchy (LEACH), which guarantees that energy load is well distributed by dynamically created clusters and the CHs are dynamically elected according to a priori optimal probability. In LEACH, during the setup phase, when clusters are being created, each node decides whether to become a CH for the current round. This decision is based on a predetermined fraction of nodes and the threshold $T_{(s)}$, which is given by (1):

$$T_{(s)} = \begin{Bmatrix} \frac{P_{opt}}{1-P_{opt}x(rmod\frac{1}{P_{opt}})} & if\ s\varepsilon G \\ 0 & otherwise \end{Bmatrix} \quad - \ - \quad - \qquad (1.1)$$

where p_{opt} is the predetermined percentage of CHs, *r* is the count of current round. *G* is the set of sensor nodes that have not been CHs in the last $1/p_{opt}$ rounds. Using this threshold, each node will be a CH at some round within $1/p_{opt}$ rounds. After $1/p_{opt}$ rounds, all nodes are once again eligible to become CHs. LEACH does not consider the residual energy of each node so the nodes that have relatively smaller energy remaining can be the CHs. This makes the network lifetime shortened due to energy holes.

Chen, G., et al (2009) proposed and evaluated an Unequal Cluster based Routing (UCR) protocol for mitigating the hot spot problem in WSNs. It is designed for long lived, source-driven sensor network applications, such as periodical environmental information reporting.

Dilip, K. et al (2011) proposed the Multi-hop Energy Efficient Heterogeneous Clustering (MEEHC) scheme to obtain an optimal path between Cluster Heads (CHs) and the Base Station (BS) for data transmission. To analyze the lifetime of the network, they assumed three types of sensor nodes, distinguished primarily with different energy levels namely super, advanced and normal nodes.

Promod, K. and Ashivini, C. (2011) proposed EEHCA (an Energy Efficient Hierarchical Clustering Algorithm for WSNs) to balance the energy loads among all the nodes. They achieved this by reducing the number of hops needed for a node to transmit data to the CH using the k-tree clustering algorithm.

Vibhuti, P. and Amit, K. G. (2012) presented an analysis of the simulation results of existing clustering algorithms for heterogeneous WSNs. They analyzed three different routing protocols: LEACH, SEP and TEEN to show their effect on network lifetime, number of cluster heads selected and node failure in the network. The network was simulated using MATLAB.

Avadhesh, K. M. et al (2013) proposed an optimum balancing energy consumption LEACH (BEC-LEACH) Protocol using numerical simulation. They also adopted the two-level CH scheme called auxiliary and main cluster node. They assumed that the optimum number of CHs is 4. Their proposed model chooses CH based on center of gravity of the network, energy of the network and node distance to the BS.

In 2013, Chunyao F. U. et al proposed a two-level cluster head algorithm termed LEACH-TLCH based on the LEACH protocol. Here a secondary CH is elected to perform aggregation of all data from the individual sensor nodes. It then forwards the packet to the Cluster head which transmits the aggregated data packets to the BS. The challenge here is the unnecessary overhead created in its implementation.

Mahmood, D. et al (2013) proposed the MODLEACH (Modified LEACH) with dual transmitting power levels. It is based on the concept of maintaining the CH status by any given node after a round if its energy level is high compared to other nodes in the cluster whilst increasing transmission power levels of the nodes. Such technique improve packet delivery rate and impedes path losses and fading though at the expense of system lifetime.

In 2014, Navreet, K. et al proposed an activation matrix oriented base station implementation for optimizing energy of WSN. They opined that sensor nodes consume power for sensing, communicating and data processing, but, more energy is required for data communication than any other process. As such the energy cost of transmitting 1 Kb a distance of 100 meters (330 ft.) is approximately the same as that used for the execution of 3 million instructions by a 100 million instructions per second/ processor. Their technique involves making use of the minimum distance vector from the base station of every node to elect CH and save energy. This forms a dynamic matrix that keeps track of the distance and regulates signals transmission.

Yadav, N. and Yadav, K. (2014) presented a

fault analysis based approach to implement adequate target coverage of WSN without sacrificing the network life of the sensors. They discussed a fault tolerant transmission method between nodes and the base station with emphasis on improving the coverage area of the network.

Nilesh G. et al (2015) performed a survey on cluster head selection techniques for mobile Ad-Hoc networks. They were able to partition mobile host into distinct virtual groups. They observed that the CH of MANET plays vital role by maintaining network information thereby decreasing the computation cost and routing overhead.

II. MATHEMATICAL MODEL OF THE SYSTEM

i. Algorithm for Base Station Location

According to Tripathi et al (2012), the following steps can be adopted to find the optimal location of BS where energy consumed for transmission $E_{d^{2,4}}$ is minimized.

1. Find centroid (C_x, C_y) of the nodes distributed in the field. At this point, E_{d^2} is minimized, and this is given by:

$$C_x = \frac{\sum_{i=1}^{n} x_i}{n} \qquad (2.1)$$

$$C_y = \frac{\sum_{i=1}^{n} y_i}{n} \qquad (2.2)$$

2. Find the nodes which are at less than d_0 (distance from the centroid).

3. Weights are calculated using centroid for all the nodes as

$$w_i = \begin{cases} 1 & if \quad d_{iC} \\ \frac{d_{iC^2}}{d_{0^2}} & if \quad d_{iC} \geq d_0 \end{cases} \qquad (2.3)$$

ii. Cluster Head Selection Algorithm

LEACH forms clusters by using a distributed algorithm, where nodes make autonomous decisions without any centralized control. The mathematical model adopted for this work was performed by Heinzelmann, et al (2002) who designed a cluster formation algorithm such that during each round, CHs are chosen randomly without recourse to the available energy of the sensor and/or its distance to the BS. In our proposed model, CHs are chosen based on the energy of the node and its distance to the BS relative to that of other nodes in the cluster.

Hence, a node is eligible to become a CH if its energy content is higher than the average energy of the nodes in the cluster. If two nodes have the same energy value compared to the average energy, then the node closest to the BS is selected as the CH instead. This method also saves unnecessary overhead associated with frequent CH selection at the beginning of every round because CH node(s) after a given round could be re-selected as the CH for the next round if it satisfies the aforementioned conditions thereby saving overhead cost and energy.

iii. Energy of the Sensor Node

The energy consumption of the sensor node can be evaluated using any of these energy models:

1. Radio energy model and
2. Computation energy model.

In the radio energy model, energy is consumed for the circuit and for transmitting the signal. For fair comparison with previous protocols, the simple model shown in Figure 2 for the radio hardware energy dissipation is considered, where the transmitter dissipates energy to run the radio electronics and the power amplifier, and the receiver dissipates energy to run the radio electronics. It is clear from the first-order energy transfer model (Figure 2) that the energy consumption of data receiving and data fusion are less than that for data transmission, especially over long distances (Dilip, et al. 2011).

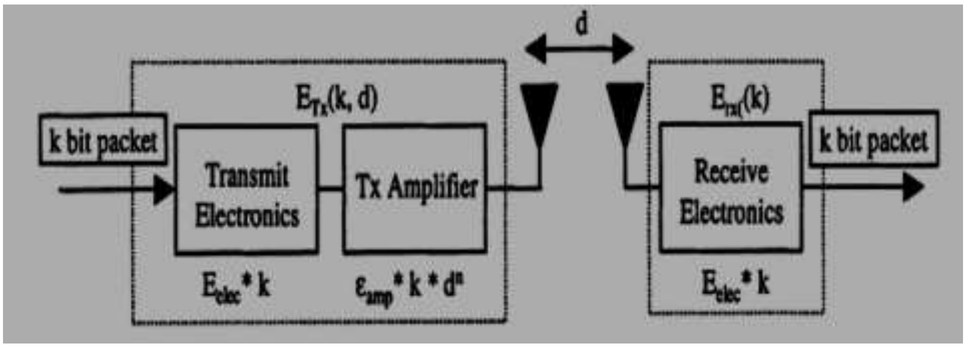

Figure 2. Radio Energy Dissipation Model

The radio energy model per bit in transmitting M number of bits is given as

$$E_{radio} = (P_{sig} + P_{tot\ circuit})T_{on} \quad (2.4)$$

Where;

P_{sig} is power consumed while transmitting the signal; $P_{tot\ circuit}$ is power consumed by the circuit and T_{on} is duration for which the transceiver is ON

The power required for transmitting the signal is expressed as follows

$$P_{sig} = \left(\frac{4\pi}{\lambda}\right) d^n \left(\frac{P_r}{G_r G_t}\right) \quad (2.5)$$

Where λ is the wavelength; d is the distance; n is the path loss component; P_r is the received power; G_r is the antenna gain of the receiver and G_t is the antenna gain of the transmitter.

The power consumed by total circuit is given by

$$P_{tot} = P_{pa} + P_{circuit} \quad (2.6)$$

Computation energy model deals with the energy consumed during the encoding and decoding process of various ECC. Consider E_{enc} is the energy consumed during the encoding and E_{dec} the energy consumed during decoding, thus computational energy model per bit is given as:

$$E_{com} = \frac{E_{enc} + E_{dec}}{M} \quad (2.7)$$

The energy consumption model used in this work was adopted from Chouhan, Bose, and Balakrishnan (2009). The sensor node energy per bit which is the addition of the computation energy model and the radio energy model is given as

$$E_{node} = \frac{(1+\alpha)P_{sig}T_{on} + P_{circuit}T_{on}\frac{N}{K} + ME_{com}\frac{N}{K}}{M} \quad (2.8)$$

iv. Energy of the Network

In cases like turbo codes where the transmitter energy is reduced considerably with the increase in the complexity of the decoder, we consider that the decoding is done at the BS where there is no scarcity of energy (Zahra and Shima, 2012). The energy consumed by the overall sensor network is given by

$$E_{total} = E_{enc} + E_{tx} + E_{rx} \quad (2.9)$$

Where E_{total} is the total energy of the network; E_{enc} is the encoding energy of the node; E_{tx} is the transmitting energy of all the sensor nodes; E_{rx} is the receiving energy of all the nodes. Hence, the total energy is given as

$$E_{total} = E_{enc} + \sum_{t=1}^{m} ME_{tx} + \sum_{t=1}^{m-1} ME_{rx} \quad (2.10)$$

Where M is the total number of bits that has been transmitted; energy consumed for a single bit transmission from the node; energy consumed for a single bit reception by the node.

vi. Proposed E-LEACH Algorithm

The sensors that make up the network, upon deployment, possess the same amount of energy. The first stage of network operation is grouping of the nodes into clusters. For the first round of network operation, CHs are chosen randomly since all the nodes have same energy content. Selection of CHs in subsequent rounds is based purely on the available residual energy of the nodes that form a cluster and its distance to the BS. The BS computes the ratio of the nodes' energy content and its distance to the BS. The nodes with higher average value become selected as the CH for that round of data transmission. The CH nodes then announces its state to the other normal nodes(NNs) that form that cluster and sends a TDMA schedule to the nodes so each will transmit information when it has the channel (depending on its time slot). The NNs, having transmitted their data packets to the CH nodes, switch to an idle or sleep mode to save energy. The CHs fuse the received packets and forwards same to the BS. The CHs have data processing and storage capabilities. For the proposed scheme, multi-hop CH to CH transmission is employed to further balance energy consumption in the network. Here, a CH that is distant from the BS chooses to forward its aggregated data packet to a neighboring CH closer to the BS node.

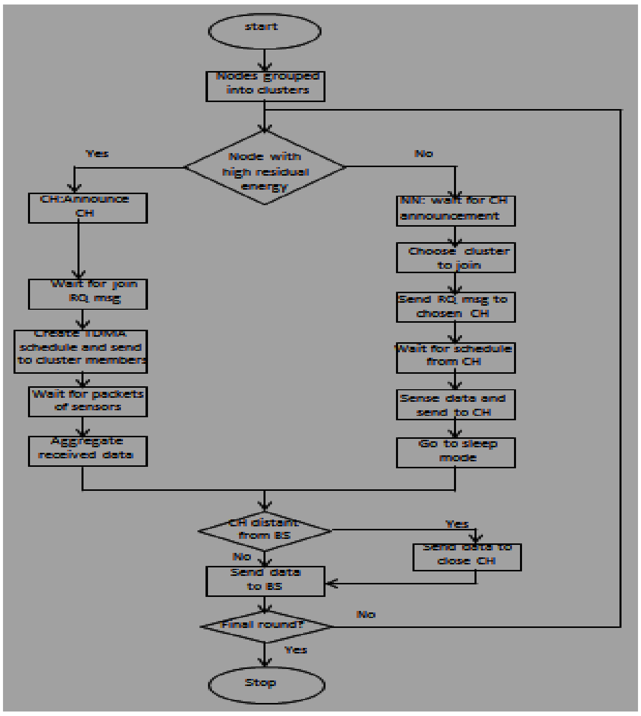

Figure 3 Operation flowchart of the E-LEACH Protocol per Round

III. RESULTS AND DISCUSSION

The performance of E-LEACH is analyzed through parameters such as energy of sensor nodes, number of data packets transmitted to the BS (i.e. throughput) and the number of dead nodes after carrying out series of rounds of data transfer. Network simulations were carried out in MATLAB environment. Obtained results show that our proposed E-LEACH performs better considering the aforementioned metrics. Our proposed scheme showed improvements on the conventional LEACH scheme as well as recent variants such as MODLEACH, MODLEACHHT and MODLEACHST as carried out by Mahmoud, D. et al (2013) along with BEC-LEACH as carried out by Avadhesh, et al (2013).

Table 1. Network Parameters

Network Parameters	Value
Network size	100x100 m^2
Initial energy of sensor nodes	0.5J
Packet size	4000bits
Transceiver idle state energy consumption	50nJ/bits
Data aggregation/fusion energy consumption	5nJ/bit/report
Amplification energy (cluster to BS) $d \geq d_0$	E_{fs} = 10 pJ/bit/m^2
Amplification energy (cluster to BS) $d \leq d_0$	E_{mp} = 0.0013pJ/bit/m^2
Amplification energy (intra cluster comm.) $d \geq d_1$	$E_{fs}/10 = E_{fs1}$
Amplification energy (intra cluster comm.) $d \leq d_1$	$E_{mp}/10 = E_{mp1}$

i. Data Packet(s) Transmitted to Base Station per Number of Rounds (Throughput)

The proposed E-LEACH protocol shows an improvement of 68.75% on LEACH, 53.13% on MODLEACH, 31.25% on MODLEACHHT though a deficit of 36% when compared to MODLEACHST (figure 4) This is due to the focus on number of delivered packets in the network at the expense of lifetime of the network. Hence**,** the proposed method offers better performance whilst conserving energy.

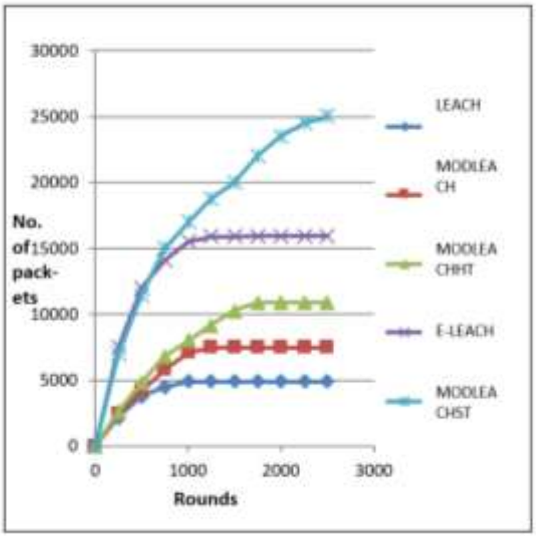

Figure 4. Performance Evaluations between Proposed E LEACH scheme and LEACH, MODLEACH, MODLEACHST, and MODLEACHHT based on Throughput

ii. Number of Dead Sensor Nodes

The last node dies after 2000 rounds for the proposed E-LEACH model unlike 850 rounds in LEACH (57.5% improvement), 1100 rounds in MODLEACH (45% improvement), and 1650 rounds in MODLEACHHT (17.5% improvement) respectively. Thus, other WSN employing LEACH, MODLEACH, MODLEACHHT would go offline before those employing the proposed scheme. The result is shown in figure 5.

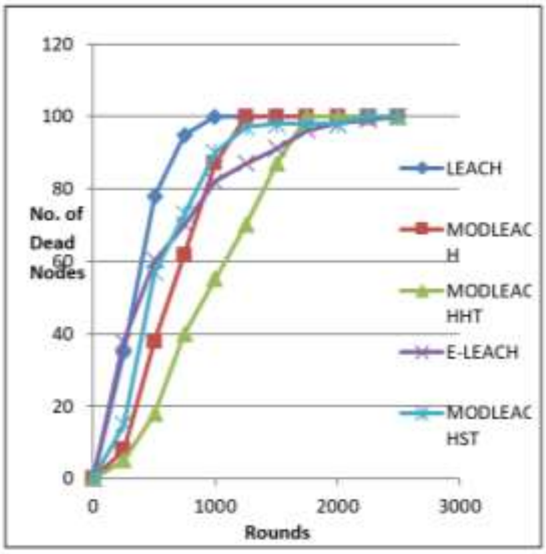

Figure 5. Performance Evaluations between Proposed E-LEACH, LEACH, MODLEACH, MODLEACHST and MODLEACHHT based on Number of Dead Nodes

iii. Energy Consumed by WSN

The residual energy for the proposed E-LEACH in WSN under study gets exhausted after operating for over 1500 rounds. Whereas, that of LEACH gets exhausted in 900 rounds (40% improvement) and BEC-LEACH gets exhausted in 930 rounds (38% improvement). This shows that the proposed model in this work prolongs the lifetime of the sensor network when compared with other techniques.

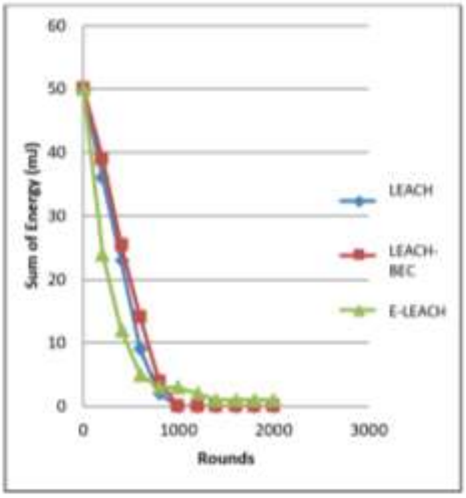

Figure 6. Performance Evaluation between Proposed Model (E-LEACH) with LEACH and LEACH-BEC in terms of Energy Consumed per Round

IV. CONCLUSION

In this work, we give a brief insight on the evolving cluster based routing in WSN and how it affects the performance of the network. We also proposed the Enhanced LEACH (E-LEACH), a new and improved variant of LEACH which could be employed in other routing protocols to further enhance the network system performance

After examining the obtained results, it is shown that the proposed scheme greatly improve the performance parameters of number of packets sent over the network per number of rounds as well as the number of dead sensor nodes and energy content of the system. Here, a WSN model made of 100 nodes deployed in an area of 100*100 m^2 with up to 2500 iteration (rounds) of data transmission was considered.

It can be inferred that using a deterministic CH selection method is far more advantageous compared to employing a probabilistic approach as was the case in LEACH. Here, the CHs are chosen based on the available energy of each node in the cluster as well as the distance of the node to the BS. If the energy of a given node is higher than the average energy of the sensors that make up that cluster, it is chosen as the CH for the next round of data transmission while considering the distance of the node and surrounding nodes' distance to the BS. In the future, we intend to apply optimization schemes to further improve our obtained results and perform a load/cost analysis of E-LEACH for the development of stable, cost efficient WSNs.

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