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Improved Distributed Energy Efficient Routing Technique for Lifetime Enhancement in Wireless Sensor Network

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Abstract: With the advancement of Internet of Things (IoT) and wireless sensor network (WSN), the researchers are working for innovative ideas and modern development. The network lifetime improvement is the most important task for wireless sensor network (WSN) because they are equipped with one time battery backup. Various energy efficient routing algorithms have been proposed to improve the network lifetime and these algorithms have their own advantages and limitations. This paper presents an innovative protocol for clustering of wireless sensor network to improve network lifetime and throughput. The simulation results present significant improvement over previous protocols with respect to network lifetime and throughput. Finally, paper is concluded with new ideas and future enhancement of proposed work.

Keywords: Wireless Sensor Networks, Energy Efficient Protocols, Clustering, Network Lifetime, Throughput.

1 Introduction

A WSN includes plenty of small low-cost, low-power and intelligent sensor nodes with one or more base stations (BS). Generally sensor nodes are statically deployed over the sensing area, but they can also be mobile and able to communicate with the environment [1, 2]. The objective of WSN is to monitor one or more characteristics of a particular area called "Area of interest" or "The sensing area" [3]. SNs work in a collaborative way to sense and gather the monitoring parameters, but also they can work autonomously. They are generally equipped with non-rechargeable batteries once deployed in the area of interest they keep operating until they consume their power. SNs can implement different functions including sensing the environment, communicating with neighbouring nodes, and in many cases performing basic computations on the data being collected which make WSNs excellent choice for many applications [4, 5]. Finding and maintaining routes in WSNs is important due to the energy restrictions and transmission range restrictions. Design of energy efficient routing protocol for WSN is of great challenge to prolong the network's lifespan [6–8].

Clustering has been considered to be one of the strategies to overcome the energy problems in WSNs. It partitions the sensing area into multiple clusters and in each cluster, a certain node will perform the task of a leader node, called a cluster head (CH). The role of CH is to communicate with the cluster members (CM), collect the data from CMs, aggregate the data, and send it to a central BS using a hierarchical routing protocol [9]. Thereby, clustering helps avoiding internal collisions by enabling SNs to communicate their data with their respective CH only, they do not have to share the communication channel with the nodes in other clusters [10]. The aggregation of data at CHs greatly reduces the energy consumption in the network by minimizing the total data messages to be transmitted to the BS. Soft computing based efficient radio resource and power management method for base station power optimization can be implemented to several types of modern base stations [11, 12]. Figure 1 shows the generalized view of WSNs, which consists of a BS, CHs and SNs deployed in a geographical region [13].

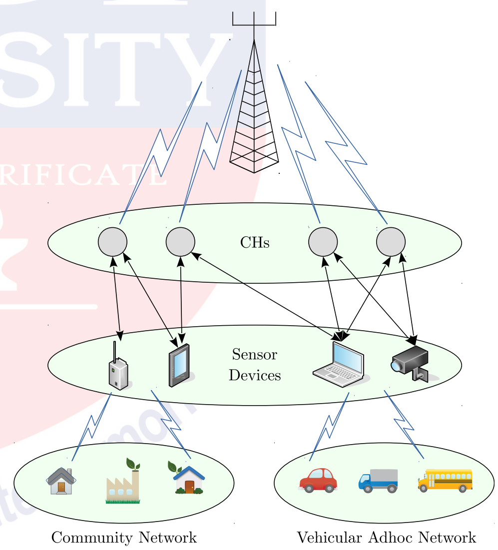

Figure 1: Generalized View of WSN

Once the clusters established, the communication between the nodes can be either intra-cluster or inter-cluster. Intra-cluster communication comprises the data exchanges between the CMs nodes and their respective CH. Inter-cluster communication includes transmission of the data between the CHs and the BS. Inter-cluster communication is an important aspect and essential feature of WSNs, a simple approach to communicate is a single hop-based approach, in which each CH sends data directly to the BS. Another method is a multi-hop based approach, in which intermediate nodes participate in data packets forwarding between the CH and the BS [14, 15].

1.1 Smart Sensors

The significant improvements in instruments and instrumentation systems are due to the integration of microsensors, nano-sensors, and smart sensors in measurement systems. The smart sensors have the ability to perform functions to increase the quality of the information gathered rather than passing only raw signals and they can communicate with other devices [16]. Among these functions: self-identification, self-testing, lookup tables, and calibration curves, all these functions are conducted by the integration of sensors with micro-controllers, microprocessor or logic circuits on the same chip and can be programmed externally. Figure 2 illustrate a general structure of a smart sensor.

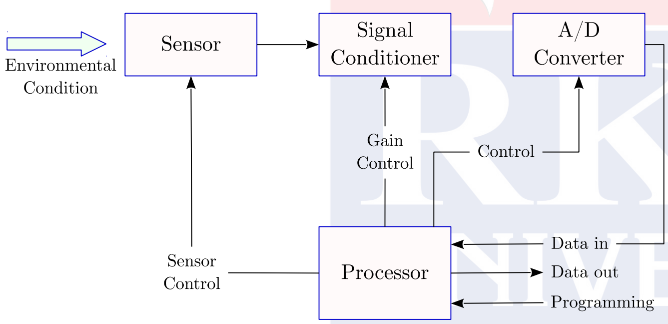

Figure 2: Smart Sensor Block Diagram

The global increasing use of smart sensors, such as in smart buildings [17, 18], smart meters [19], wearable devices [20] and many more systems made the Internet of Things (IoT) become possible [21]. Figure 3 shows the potential growth in millions worldwide for IoT sensor deployment [22].

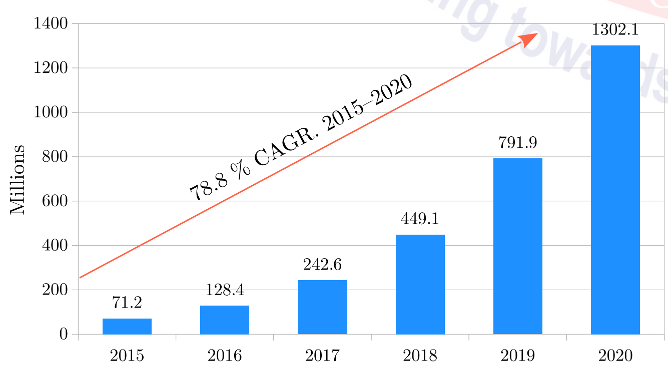

Figure 3: Potential Growth in Worldwide IoT Sensor Deployments

1.2 Path–Loss Model

Unlike wired channels that is predictable and stationary, wireless channels are random and suffer from propagation that depends on the transmission path between the receiver and the transmitter [23]. The path-loss estimation is based on the circuitry characteristics in the field of wireless communication networks. When signals are sent from a transmitter to a receiver circuitry, the path-loss is estimated as the function of the propagated signal of the transceiver. This is calculated as the reduction in power density that occurs as a radio wave propagates over a distance, and can be put as [24]:

$$\text{Max. Path–Loss} = \text{Transmit Power} - \text{Reciever Sensitivity} + \text{Gain} + \text{Losses} \quad (1)$$

The transmission path vary from simple line-of-sight to one that is severely obstructed by buildings or even mountains. Propagation is caused by several mechanisms including reflection, diffraction, and scattering, propagation models have focused on predicting the average signal strength received from the transmitter at a given distance, as well as the change of the signal strength in close spatial proximity to particular location. When there is a clear line-of-site between the transmitter and the receiver, they undergo free space propagation. The free space power received by an antenna which is separated from a radiating antenna by a distance (d) is given by Friis free space equation [25]:

$$P_r(d) = P_r G_t G_r \frac{\lambda^2}{(4\pi d)^2} \quad (2)$$

where, G_t and G_r are the transmitter and the receiver antenna gains respectively. λ is the wavelength, d is the distance between the transmitter and the receiver. P_t is the transmitted power and P_r is the received power (Figure 4). If the antenna gains not considered, path loss can be expressed as:

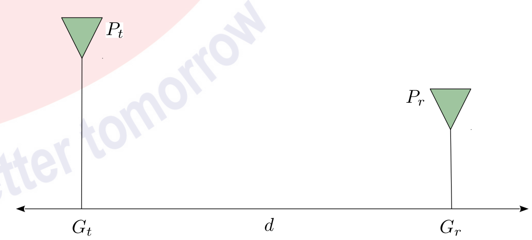

Figure 4: Friis Free Space Equation

$$P_r(d) = \frac{\lambda^2}{(4\pi d)^2} \quad (3)$$

With the free space model, the energy loss due to channel transmission is comparative to the square distance separation of the transmitter-receiver circuitry, which is estimated as $v = 2$ for a distance d. And for the multi-path model, it estimates this channel transmission loss as $v = 4$ for a distance d.

2 Literature Review

The main challenge of wireless sensor networks (WSNs) deployment is with the energy management, as sensor nodes (SNs) will mainly have limited source of energy. In order to achieve a robust result for data communication, it is important to allow SNs to work in a collaborative manner so as to achieve a collective objective [26].

Sensor networks can be classified into homogeneous and heterogeneous networks based on the nodes characteristics. In a homogeneous network, SNs have identical characteristics with respect to the various aspects of sensing, communication, and resource constraints. A heterogeneous network consists of nodes with different hardware capacities including battery functionality and different topologies are used which makes the network a very complex network. Since the dominant energy consuming process in a mote is communication, network lifetime is constrained by the communication costs and battery capacity. Therefore, prolonging the lifetime of a heterogeneous WSN requires the network routing protocol to consider the heterogeneity of the motes [27].

2.1 Low Energy–Adaptive Clustering Hierarchical Protocol (LEACH)

Heinzelman *et al.* proposed one of the first and most common cluster-based routing protocols in WSNs is LEACH [28], it was designed for homogeneous networks and succeed to prolong the network's lifetime to some extend compared to the flat-based routing protocols. LEACH does not require global information of the network; hence, it is completely distributed approach. Nodes in LEACH arrange themselves into single-level clustering structure, each cluster has one cluster head (CH) that collects the data from the cluster members (CMs), aggregate the received data, and send it to the base station (BS).

LEACH divides the operation time into rounds, each round is divided into two phases, namely the set-up phase and the steady-state phase which is always longer than the set-up phase to minimize the overhead. In the set-up phase, clusters are organized, while in the steady-state phase, data is delivered to the BS. During the set-up phase, when a node announces itself as a CH, it broadcasts an advertisement message to the other nodes with its location and waiting for joint request from members [29, 30]. Other nodes decide which cluster to join for this round based on the Received Signal Strength Indicator (RSSI) of the advertisement and send a joint request to its CH [31]. In order to equalize the energy load distribution among the CHs, SNs compete among themselves to be declared as CHs, the decision is based on the suggested percentage of CHs for the network and the number of times the node has been a CH so far. In each round, SNs choose a random number between 0 and 1, a successful candidate to become a CH in the current round is the node with random number less than the following threshold:

$$T(n) = \begin{cases} \dfrac{P}{1 - P \cdot \left[r \mod \dfrac{1}{P} \right]}, & \text{if } n \in G \\ 0, & \text{otherwise} \end{cases} \tag{4}$$

where P is the percentage of CHs (e.g. $P = 0.05$ which is equivalent to 5%), r is the current round and G is the set of nodes which have not been elected as a CH in the last (1/P) rounds, for calculation purposes, $\frac{1}{P}$ is rounded to the nearest integer. During the first round, $r = 0$ and each node has a probability P of becoming a CH. Nodes that are currently CHs in the first round cannot be CHs for the next $\frac{1}{P}$ rounds. After $\frac{1}{P} - 1$ rounds, $T = 1$ for any nodes that have not yet been CHs, and after $\frac{1}{P}$ rounds, all nodes are once again eligible to become CHs.

2.2 Distributed Energy-Efficient Clustering Protocol (DEEC)

Qing *et al.* [32] proposed the distributed energy-efficient clustering protocol (DEEC) to cope with the network energy-heterogeneity, following the thoughts of SEP [33], DEEC assumed there are nodes deployed with different energies in the network. The process of electing CHs in DEEC is based on the ratio between the residual energy of each node and the average energy of the network. The number of times for a certain node to become a CH differs according to the node initial and the residual energies. The researchers further estimated the ideal value of the network life time which is used to compute the reference energy that each node should spend during a round. They proposed a set of leading equations to ensure high energy nodes have more chances of being elected as CHs. They choose the probability P_i to become a CH as:

$$P_i = = p_{opt} \left[1 - \frac{E(r) - E_i(r)}{E(r)} \right] \tag{5}$$

$$P_i = p_{opt} = \frac{E_i(r)}{E(r)} \tag{6}$$

where $E_i(r)$ is the residual energy of node i at round r, p_{opt} is the initial probability of a node to become CH in a homogeneous setup as used in LEACH and $E(r)$ is the estimated average energy of the network at round r, which is calculated as:

$$E(r) = \frac{1}{n} E_{\text{total}} \left(1 - \frac{r}{R_{\max}} \right) \tag{7}$$

$$R_{\max} = \frac{E_{\text{total}}}{E_{\text{round}}} \tag{8}$$

where $R_{\max}$ is the maximum rounds of the network lifetime, n is the nodes number in the network, E_{total} is the total energy of the network at start of deployment, E_{round} is the total energy consumed by all nodes in each round. DEEC was able to further extend the network lifetime compared with the LEACH and SEP protocols by using this method of estimation. However, advanced nodes always penalize in DEEC, particularly when their residual energy reduced and become in the same range as the normal nodes causing the advanced nodes to die faster than the others nodes.

2.3 DDEEC (Developed Distributed Energy Efficient Clustering)

Elbhiri *et al.* [34] proposed developed distributed energy-efficient clustering (DDEEC) for heterogeneous wireless sensor networks. DDEEC is based on DEEC [32] scheme, where all nodes use the initial and residual energy level to define the cluster heads. To evade that each node needs to have the global knowledge of the networks, DEEC [32] and DDEEC [34] estimate the ideal value of network lifetime, which is use to compute the reference energy that each node should expend during each n round. In this section, we consider a network with N nodes, which are uniformly dispersed within a $M \times M$ square region. The network is organized into a clustering hierarchy, and the cluster-heads collect measurements information from cluster nodes and transmit the aggregated data to the base station directly. Moreover, we suppose that the network topology is fixed and no-varying on time. It is assumed that the base station is located at the center [34]. Furthermore, this condition show a two-level heterogeneous network, where we have two categories of nodes, a mN advanced nodes with initial energy $E_0(1+a)$ and $a(1-m)N$ normal nodes, where the initial energy is equal to E_0. The total initial energy of the heterogeneous networks is given by:

$$E_{total} = N(1-m)E_0 + NmE_0(1+a) = NE_0(1+am) \quad (9)$$

2.4 EDEEC (Enhanced Distributed Energy Efficient Clustering)

Saini *et al.* [35] proposed E-DEEC - enhanced distributed energy efficient clustering scheme for heterogeneous WSN. EDEEC adds heterogeneity in the network by introducing the super nodes having energy more than normal and advanced nodes and respective probabilities. EDEEC has better performance as compared to DEEC in terms of parameters used. It extends the lifetime and stability of the network. EDEEC for three types of nodes in prolonging the lifetime and stability of the network. Hence, it increases the heterogeneity and energy level of the network. Simulation results show that EDEEC performs better than SEP with more stability and effective messages.

2.5 EDDEEC (Enhanced Developed Distributed Energy Efficient Clustering)

Javaid *et al.* [36] proposed an energy-efficient distributed clustering (EDDEEC) algorithm for heterogeneous WSNs. Heterogeneous WSNs may contain two, three, or multitypes of nodes with respect to their energy levels and termed as two, three, or multi-level heterogeneous WSNs, respectively. EDDEEC considers three-level heterogeneous network that contains three different energy levels of nodes: normal, advanced, and super. Normal nodes have E_0 energy. Advanced nodes of fraction m have a times more energy than normal nodes, i.e., $E_0(1+a)$. Whereas, super nodes of fraction m_0 have b times more energy than the normal ones, it means, $E_0(1+b)$. As N is the number of nodes in the network, then Nmm_0 , $Nm(1-m_0)$, and $N(1-m)$ are the numbers of super, advanced, and normal nodes in the network, respectively. The total initial energy of super nodes in WSN is as follows:

$$E_{super} = Nmm_0E_0(1+b) \quad (10)$$

The total initial energy of advanced nodes is as follows:

$$E_{advanced} = Nm(1-m_0)E_0(1+a) \quad (11)$$

Similarly, the total initial energy of normal nodes in the network is calculated as follows:

$$E_{normal} = N(1-m)E_0 \quad (12)$$

The total initial energy of three-level heterogeneous WSNs is therefore calculated as:

$$E_{total} = NE_0(1+m(a+m_0b)) \quad (13)$$

The three-level heterogeneous WSN has $m(a+m_0b)$ times more energy as compared to the homogeneous WSN [36]. A homogeneous WSN also turns into heterogeneous after some rounds due to unequal energy consumption of nodes. CH nodes consume more energy, as compared to member nodes. After some rounds, the energy level of all nodes becomes different, as compared to each other. Therefore, a protocol which handles heterogeneity is more important than the homogeneous protocol [36].

3 Proposed Approach

This section presents an innovative concept in wireless sensor network which is the proposed algorithm. The proposed algorithm implements the idea of probabilities for CHs selection based on initial and residual energy of nodes as well as the average energy of the network. The average energy of r^{th} round from is given by Equation 14:

$$E_a(r) = \frac{1}{N}E_{total}\left(1-\frac{r}{R}\right) \quad (14)$$

where,
R = the total rounds during the network lifetime. It is

calculated by the Equation 15.

$$R = \frac{E_{total}}{E_{round}} \tag{15}$$

where E_r is the energy dissipated in a network during a single round and is calculated by Equation 16:

$$E_r = K\left(2NE_{elect} + NE_{DA} + l\epsilon_{mp}d^4_{to\ BS} + N\epsilon_{fs}d^4_{to\ CH}\right) \tag{16}$$

where,
K = The number of clusters,
E_{DA} = The data aggregation energy cost expended by CH,
$d_{to\ BS}$ = The average distance between the CH and the BS,
$d_{to\ CH}$ = The average distance between cluster members and the CH.
Now $d_{to\ BS}$ and $d_{to\ CH}$ can be calculated as Equation 17 and Equation 18:

$$d_{to\ BS} = 0.765\frac{M}{2} \tag{17}$$

$$d_{to\ CH} = \frac{M}{\sqrt{2\pi K}} \tag{18}$$

By taking the derivative of E_{round} with respect to k and equating to zero, we can find the optimal number of clusters k_{opt} and is calculated by Equation 19:

$$k_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}}\sqrt{\frac{\epsilon_{sf}}{\epsilon_{mp}}}\frac{M}{d^2_{to\ BS}} \tag{19}$$

At the start of each round, nodes decide on the basis of threshold whether to become CHs or not. The value of threshold is calculated by Equation 20:

$$Th(S_i) = \begin{cases} \dfrac{P_i}{1 - P_i\left(mod\left(r, \frac{1}{P_i}\right)\right)}, & \text{if } S_i \in G, \\ 0, & \text{otherwise} \end{cases} \tag{20}$$

where G is the set of nodes eligible to become CHs for round r and p is the desired probability of the CH. In real scenarios, WSNs have more than two types of heterogeneity. Therefore, in proposed protocol, we use the concept of three-level heterogeneity and characterize the nodes as: normal, advanced, and super. The probability for three types of nodes given by proposed protocol is given below:

$$P_i = \begin{cases} \dfrac{P_{opt}E_i(r)}{(1+m(a+m_0b))E_a(r)} \times \dfrac{E_{res}}{E_0}, & \text{if } S_i \text{ is the normal node,} \\ \dfrac{P_{opt}(1+a)E_i(r)}{(1+m(a+m_0b))E_a(r)} \times \dfrac{E_{res}}{E_0}, & \text{if } S_i \text{ is the normal node,} \\ \dfrac{P_{opt}(1+b)E_i(r)}{(1+m(a+m_0b))E_a(r)} \times \dfrac{E_{res}}{E_0}, & \text{if } S_i \text{ is the normal node,} \end{cases} \tag{21}$$

Equation 21 primarily illustrates the difference between DEEC [32], DDEEC [34], EDDEEC [36] and proposed protocol by defining probabilities for CH selection as DEEC, DDEEC, EDEEC and EDDEEC use probability based cluster head (CH) selection, however, the proposed protocol uses energy levels by using the ratio of E_0 (initial energy) to E_{res} (residual energy). It is the modification of of the existing EDDEEC protocol. The objective of this expression is to balance the energy consumption between nodes such that the stability period and network lifetime are increased. However, soon after few rounds, super and advanced nodes might have the same residual energy as that of the normals. At this point, DEEC punishes advanced nodes, proposed protocol punishes advanced as well as super nodes and proposed protocol is only effective for repeatedly selecting the CH.

4 Simulation Result

Result metrics used in the simulations are based on the following:

1. Number of the alive nodes during each round (network lifetime).
2. Number of packets sent from the cluster heads (CHs) to the base station (throughput).

4.1 Result Analysis of Nodes Alive Per Round (Network Lifetime)

In Figure 5, DEEC protocol is shown as the black curve, DDEEC protocol is shown as the red curve, EDEEC protocol is shown as dashed blue curve, EDDEEC is shown as magenta curve and the proposed protocol is shown in Figure 6 as a green curve. The graph of Figure 5 for DEEC [32], DDEEC [34], EDEEC [35] and EDDEEC [36] represents the graph of nodes alive during each round (network lifetime). The proposed protocol performs better as compared to other protocol as shown in the graph.

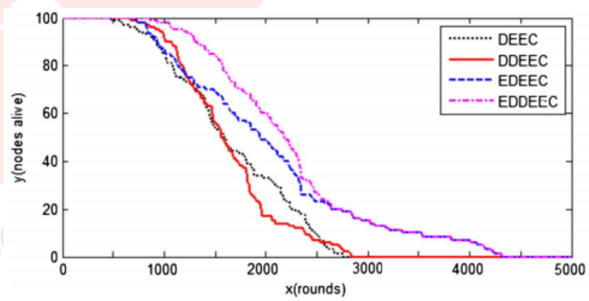

Figure 5: Network Lifetime of EDDEEC

4.2 Result Analysis of Throughput

The graph of Figure 7 plots the data packets send to the base station (BS) or throughput. Again the same colored curve are used for DEEC [32], DDEEC [34], EDEEC [35] and EDDEEC [36] protocols and the throughput of proposed protocol is shown in Figure 8 as a green curve. For performance evaluation of proposed protocol in MATLAB,

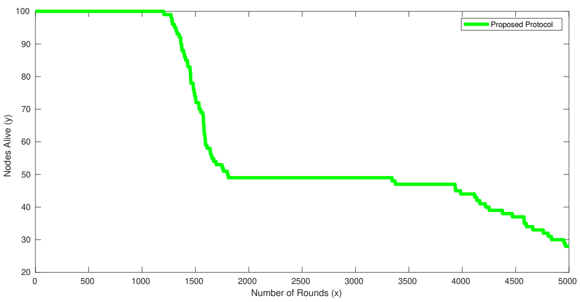

Figure 6: Network Lifetime of Proposed Protocol

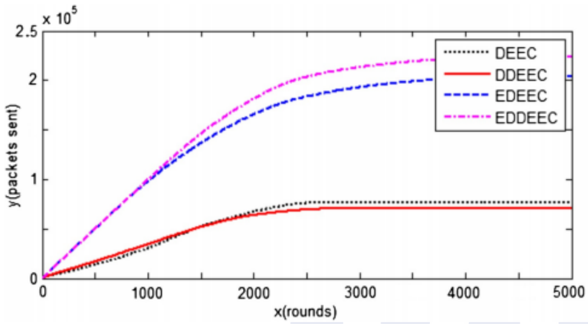

Figure 7: Throughput of EDDEEC

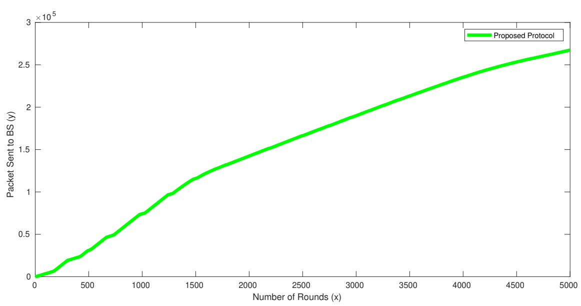

Figure 8: Throughput of Proposed Protocol

the same initial parameter values are considered and the next parameter values as used in DEEC [32], DDEEC [34], EDEEC [35] and EDDEEC [36]. As shown in Figure 7, the proposed protocol presents maximum throughput as compared to these protocols.

5 Conclusion

Presently there were so many algorithms protocols proposed for energy efficient routing to enhance the lifetime of the whole wireless sensor network. In this paper, an innovative protocol in WSN as a reactive network routing protocol are proposed with considering three different levels of sensor node heterogeneity. The proposed protocol combines the best features of EDDEEC protocol and energy level evaluation method. Due to the concept of energy level based cluster head selection, hard and soft threshold value, three levels of node heterogeneity and being reactive routing network proposed protocol produces increase in energy efficiency, enhanced lifetime of network and also maximum throughput as shown in the simulation result.

However, proposed protocol is not suitable where frequent information is received from wireless sensor network. The future direction will be to overcome this limitation in this protocol. Finally, in future, the concept and implementation of the mobile base station can be introduced in proposed protocol to perform the next level of advanced technology of wireless sensor network due to three levels of heterogeneity and being reactive routing network protocol, so it produces increased level in energy efficiency and enhanced network lifetime.

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