Energy Estimated Distributed Reactive Routing Algorithm in Wireless Sensor Network

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***Abstract*—A wireless sensor nodes have critical battery backup used for sensing environment, processing data, routing and transmitting sensed data to the sink or base station. Many research have been proposed to enhance the battery backup and lifetime of sensor network. Data transmission consumes more energy as compared to processing and sensing. So an efficient routing algorithms is required to save battery power. After deploying a wireless sensor network, it works up to remaining battery power. To efficiently optimize the battery backup, several energy efficient routing algorithms are available. In this paper, energy estimated distributed reactive routing (EEDRR) algorithm is proposed where sensor nodes use reactive method. For cluster head selection in wireless sensor network, EEDRR uses a ratio of remaining current energy to the initial energy. We compare the simulation results of proposed algorithm EEDRR with some modern algorithms such as DEEC, DDEEC, EDEEC and EDDEEC. Result presents that the performance of proposed algorithm have better energy efficiency and higher throughput as compared to other algorithms.**

***Keywords*— Wireless Sensor Networks, Clustering, Network Lifetime, Energy Efficiency, Stable Election, EEDRR.**

I. Introduction

Wireless sensor networks (WSNs) have become widespread technology and its application is rapidly growing. WSNs are generally group of power-constrained sensor nodes that sense the environment and send the data to the users. Sensors are responsible for sensing the environmental conditions, monitoring, collecting information and sending the data from source to the end user. The wireless sensor is the major component of Internet of things (IoT) devices, and it is extensively use in smart city development. The main focus in smart cities is the efficient energy management due to large numbers of growing customers. Energy management in smart city controls energy consumption of home appliances. Demand management is one of the method for customize energy utilization of customers. Modern sensor nodes are mostly used in many industrial, commercial and consumer applications, such as industrial process control and monitoring, healthcare applications, instrument health monitoring, traffic control system, agriculture, home automation and so on [1]. Sensor nodes are mostly power-constrained battery operated and limited storage space. This limitation break the WSN into a limited lifetime. Energy consumption of customer have to be minimized, in order to increase the network lifetime.

Several energy optimization techniques are available for energy management. Optimization based residential energy management schemes have been developed for energy management of appliances. For higher energy efficiency, major requirement is renovation. These renovation technologies mainly focus on the energy dependent, generation of renewable energy from efficient vehicles and buildings, high penetration and security and also avoids the greenhouse gas emissions [2][3]. A typical model of wireless sensor network is presented in Figure 1, all data from sensor nodes are collected into cluster head and send it to the base station, where user get this information through the Internet. Each sensor node in WSN is an electromechanical sensing device. The microelectronic mechanical systems (MEMS) [4] is a modern advanced technology today and MEMS with wireless communication technologies have developed small sized, low-power and low-cost multi-functional smart sensor nodes in a wireless sensor network (WSN) [5]. Earlier, application of wireless sensor networks were initiated by military such as battlefield surveillance, today the modern sensor networks are bi-directional and have self-controlling ability [6][7].

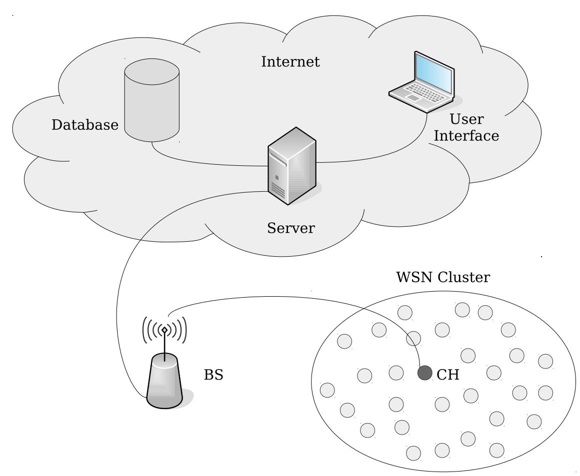

Fig. 1. Basic WSN Model

The WSN consists of hundreds to thousands sensor nodes, where each sensor node is connected to several sensor nodes. There are several components of each such sensor node: a radio transceiver, a microcontroller, an electronic circuit for interfacing to the sensors and a power source, an internal antenna or connection to an external antenna, typically a battery or an embedded form of energy source [8][9].

According to the type, size, functionality, applications and complexity of the individual sensor nodes, the cost of sensor nodes may vary. The multi-functional sensors have higher cost than the normal single functional sensor node [10]. Size and cost limitations on sensor nodes result in corresponding limits on resources such as processing speed, power backup, memory, computational speed, communications bandwidth, durability, efficiency and accuracy [11][12].

The geographical network arrangement and topology of the WSNs may vary from a simple star network to an advanced multi-hop wireless mesh and hybrid network [13]. The data transmission technique among the multiple hops of the sensor network may be routing or flooding. The cluster based techniques and protocols have been originally proposed for the wire line networks to resolve the scalability and expandability issues [14]. Practically, the battery recharge or replacement of sensor nodes are not possible once WSN is deployed. Hence, WSNs work without human involvement or manipulation so the lifetime enhancement of the network is prominent in any way. Various protocols and techniques were introduced and proposed for network lifetime enhancement [15].

II. Related Work

Hienzelman *et al.* introduced LEACH (Low Energy Adaptive Clustering Hierarchy) [16] as original clustering based routing protocol which is distributed in nature. At the beginning of each round each node generates a number between 0 and 1 on a random basis. The node, whose generated number is less than a threshold value, declare itself as CH for those round. LEACH [16] is basically a proactive routing protocol. The proactive routing protocols continuously try to send up-to-date sensed data to the base station in the WSN. In a network hundreds and thousands of sensor nodes dispersed randomly for even distribution of work load among nodes. These nodes sense data from the environment, transmit them to their associated cluster heads (CHs) which first receive, collect it and finally send its data packets to the base station (BS).

In the clusters of WSN, nodes send join request to their nearest cluster heads (CHs) based on the received signal strength. CHs send an acknowledgment message and TDMA time slot for data transmission as a reply. The major disadvantages of the protocol are unequal size of clusters in different rounds, no consideration of energy level of nodes in the CH selection process and single-hop transmission between the CH and the BS.

Hienzelman *et al.* extended LEACH and proposed LEACH-Centralized (LEACH-C) [17] protocol to overcome the limitations of LEACH. The number of CHs for each round is fixed in LEACH-C. This protocol reduces the overhead of CH selection from the nodes as it is centralized in nature. It offers better performance than LEACH but also suffers from problems such as single-hop transmission and centralized CH selection, which is not good for the large area network. A lot of successors of LEACH have been proposed for performance improvement.

In an environment, to distribute the burden or work among nodes, an improve network life clusters are formed. The sensor node devices are made to become CHs on turns. Nodes randomly elect themselves as CHs and it is done in a way that each node becomes CH once in the time period of $\frac{1}{P}$ round. CHs selection is done on probability basis, each sensor node produces a random number r inclusive of 0 and 1, if the generated value is less than this threshold computed by formula given in equation (1), and then this node becomes CH.

$$T_N = \begin{cases} \dfrac{P}{1 - P[r \ mod \ \frac{1}{P}]}, & \text{if } n \in G, \\ 0, & \text{otherwise.} \end{cases} \tag{1}$$

where,
T_N = Threshold
P = Desired change (probability) of being Cluster Head (CH)
r = Current round number
G = Set of nodes which are not became CH in $\frac{1}{P}$ round

Generally, each sensing node will become a CH in $\frac{1}{P}$ rounds by using threshold value.

Qing *et al.* introduced DEEC [18] as a distributed energy-efficient algorithm for clustering based heterogeneous wireless sensor networks. When the cluster-heads are selected by a probability based on the ratio between residual energy of each node and the average energy of the network. The round number of the rotating epoch for each node is different according to its initial and residual energy. DEEC accommodate the concept of rotating epoch of each node to its energy [18].

The nodes with high initial and residual energy will have more chances to be the cluster-heads than the low-energy nodes. Thus DEEC can prolong the network lifetime, especially the stability period, by heterogeneous aware clustering algorithm [18]. This choice penalizes always the advanced nodes, specially when their residual energy deplete and become in the range of the normal nodes. In this situation, the advanced nodes die quickly than the others [18].

DEEC uses the initial and residual energy level of the nodes to select the cluster-heads. To avoid that each node needs to know the global knowledge of the networks, DEEC estimates the ideal value of network life-time, which is use to compute the reference energy that each node should expend during a round [18].

Elbhiri *et al.* proposed DDEEC (Developed Distributed Energy-Efficient Clustering) [19] which is based on DEEC [18] 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 [18] and DDEEC [19] estimate the ideal value of network lifetime, which is use to compute the reference energy that each node should expend during each n round. Here, a network with N nodes, which are uniformly dispersed within a $M \times M$ square region.

The sensor network is configured into a clustering hierarchy, and the cluster-heads collect measurements information from cluster nodes and transmit the aggregated data to the base station directly. It is assumed that the base station is located at the center [19]. 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:

$$E_{total} = N(1-m)E_0 + NmE_0(1+a) = NE_0(1+am) \quad (2)$$

DDEEC Radio Model: On the first, for the purpose of this protocol it uses similar energy model and analysis as proposed in DEEC [18]. According to the radio energy dissipation model and in order to achieve an acceptable Signal-to-Noise Ratio (SNR) in transmitting an $L-bit$ message over a distance d, the energy expended by the radio is given by:

$$E_{TX}(L,d) = \begin{cases} LE_{elect} + LEfsd^2, & \text{if } d < d_0, \\ LE_{elect} + LEmpd^4, & \text{if } d \geq d_0 \end{cases} \quad (3)$$

where E_{elec} is the energy dissipated per bit to run the transmitter (E_{TX}) or the receiver circuit (E_{RX}). The E_{elec} depends on many factors such as the digital coding, the modulation, the filtering, and the spreading of the signal. Efs and Emp depend on the transmitter amplifier model used, and d is the distance between the sender and the receiver. For the experiments described here, both the free space (d^2 power loss) and the multi path fading (d^4 power loss) channel models were used, depending on the distance between the transmitter and the receiver. If the distance is less than a threshold, the free space (fs) model is used; otherwise, the multi path (mp) model is used. we have fixed the value of do like on DEEC at $d_0 = 70$.

Saini *et al.* introduced EDEEC (Enhanced Distributed Energy Efficient Clustering) [20] protocol for heterogeneous WSN. EDEEC [20] adds heterogeneity in the network by introducing the super nodes having energy more than normal and advanced nodes and respective probabilities. EDEEC [20] has better performance as compared to DEEC in terms of parameters used. It extends the lifetime and stability of the network. EDEEC [20] 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 [20] performs better than SEP with more stability and effective messages.

Properties of EDEEC Network: In the network model described in previous section some assumptions have been made for the sensor nodes as well as for the network. Hence the assumptions and properties of the network and sensor nodes are:

- Sensor Nodes are uniformly randomly deployed in the network.
- There is one Base Station which is located at the center of the sensing field.
- Nodes always have the data to send to the base station.
- Nodes are location-unaware, i.e. not equipped with GPS-capable antennae.
- All nodes have similar capabilities in terms of processing and communication and of equal significance. This motivates the need for extending the lifetime of every sensor.

Sensor nodes have heterogeneity in terms of energy and different energy levels. All nodes have different initial energy, some nodes are equipped with more energy than the normal nodes [20].

Javaid *et al.* introduced EDDEEC (Enhanced Developed Distributed Energy-Efficient Clustering) [21] as an energy-efficient distributed clustering 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 [21] 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:

$$E_{super} = Nmm_0E_0(1+b) \quad (4)$$

The total initial energy of advanced nodes is as follows:

$$E_{advanced} = Nm(1-m_0)E_0(1+a) \quad (5)$$

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

$$E_{normal} = N(1-m)E_0 \quad (6)$$

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

$$\begin{aligned} E_{total} &= E_{super} + E_{advanced} + E_{normal} \quad (7) \\ E_{total} &= NE_0(1+m(a+m_0b)) \quad (8) \end{aligned}$$

The three-level heterogeneous WSN has $m(a+m_0b)$ times more energy as compared to the homogeneous WSN [21]. 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 [21].

DEEC [18], DDEEC [19], EDEEC [20] and EDDEEC [21] protocols still use probability based cluster head (CH) selection. On probability based cluster head selection, low energy nodes may be selected as cluster head and high energy nodes may not be selected as cluster head. DEEC, DDEEC and EDEEC are proactive network routing protocols where nodes continuously transmit data to base station and transmission consumes more energy compared to sensing.

EDDEEC [21] is basically node heterogeneity aware protocols which improve network lifetime but the limitation of node heterogeneity is this that throughput is also increased which decrease lifetime of WSN. EDEEC and EDDEEC are prominent reactive network routing protocols where frequent data transmission is limited by threshold value [21].

Consumption of energy has been an issue in WSN, and it is one of major challenge because of limited battery power of sensor node. As a solution of this problem, Aghera *et al.* proposed MMR-LEACH [22] protocol which uses multi-tier concept with selecting two cluster-heads. In multi-tier concept, whole sensor network is partitioned into several layers of clusters. For the data transmission, another node selected as Vice Cluster Head (VCH) rather than Main Cluster Head (MCH). MCH is responsible for collecting, aggregating and transmitting data from sensor nodes to BS and selection of VCH based on residual energy. VCH is act as a mediator between lower layer MCH and BS for the transmission purpose. The lifetime of sensor network is exceeding by MMR-LEACH protocol in comparison to conventional routing protocols.

III. EEDRR (Proposed Protocol)

EEDRR (energy estimated distributed reactive routing) algorithm in Wireless Sensor Network is the proposed protocol. This 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 (9):

$$E_a(r) = \frac{1}{N} E_{total} \left(1 - \frac{r}{R}\right) \tag{9}$$

where,
R = the total rounds during the network lifetime. It is calculated by the equation 10.

$$R = \frac{E_{total}}{E_{round}} \tag{10}$$

where E_{round} is the energy dissipated in a network during a single round. Now $d_{to\ BS}$ and $d_{to\ CH}$ can be calculated as equation (11) and equation (12):

$$d_{to\ BS} = 0.765 \frac{M}{2} \tag{11}$$

$$d_{to\ CH} = \frac{M}{\sqrt{2\pi K}} \tag{12}$$

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 (13):

$$k_{opt} = \frac{\sqrt{N}}{\sqrt{2\pi}} \sqrt{\frac{\epsilon_{sf}}{\epsilon_{mp}}} \frac{M}{d^2_{to\ BS}} \tag{13}$$

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 (14):

$$Th(S_i) = \begin{cases} \dfrac{P_i}{1 - P_i \left(mod \left(r, \frac{1}{P_i} \right) \right)}, & \text{if } S_i \in G, \\ 0, & \text{otherwise} \end{cases} \tag{14}$$

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 EEDRR, 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 EEDRR is given below:

$$P_i = \begin{cases} \dfrac{P_{opt} E_i(r)}{(1 + m(a + m_0 b)) E_a(r)} \times \dfrac{E_0}{E_{res}}, \\ \dfrac{P_{opt}(1 + a) E_i(r)}{(1 + m(a + m_0 b)) E_a(r)} \times \dfrac{E_0}{E_{res}}, \\ \dfrac{P_{opt}(1 + b) E_i(r)}{(1 + m(a + m_0 b)) E_a(r)} \times \dfrac{E_0}{E_{res}}, \end{cases} \tag{15}$$

Equation (15) primarily illustrates the difference between DEEC [18], DDEEC [19], EDDEEC [21] and proposed protocol EEDRR 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, EEDRR punishes advanced as well as super nodes and EEDRR is only effective for repeatedly selecting the CH.

The limitation of EEDRR is that if threshold value is not reached, then the base station will not receive any information or data from sensor network and even all the sensor nodes of the network become dead, system will be ultimately unknown about these limitations. So, EEDRR is not useful for those types of applications where a sensed data is required frequently and continuously.

IV. Simulation, Performance Analysis and Result

Implementation and performance evaluation of the proposed protocol EEDRR, MATLAB was used. By the simulation results we can compare the performance of EEDRR with DEEC [18], DDEEC [19], EDEEC [20] and EDDEEC [21] protocols on the basis throughput and network lifetime.
In this MATLAB simulations following performance attributes are used:

1) Network Lifetime which is the number of alive nodes during each round.
2) Throughput which is the number of packets sent from cluster heads to the base station.

Certain initial parameter values are taken for simulation of DEEC [18], DDEEC [19], EDEEC [20] and EDDEEC [21], as well as the same parameter values for this proposed protocol EEDRR. Simulation results for DEEC [18], DDEEC [19], EDEEC [20] and EDDEEC [21] presented with three-level and multi-level heterogeneous WSNs using MATLAB. WSN consists of $N = 100$ nodes which are randomly deployed in a field of dimension $100\ m \times 100\ m$ with a centrally located BS. For simplicity, we consider that all nodes are either fixed or micro-mobile and ignore the energy loss due to collision and interference between signals of different nodes. For the evaluation of the protocols the used performance metrics are: network lifetime, and number of packets sent to the BS.

- **Network Lifetime:** It means the round number at which all nodes die or the number of rounds from network initialization till the death of all nodes.
- **Throughput:** It means the total number of packets that are directly sent to BS either from CHs or non-CH nodes.

The parameters used in simulations are given in table (I). Results along with discussions are provided in the following subsections. These are considering that initially the WSN

TABLE I
INITIAL PARAMETER SETTINGS

Parameters	Values
E_0	$0.50\ Joule$
E_{elect}	$60\ nJoule/bits$
l	$400\ bits$
ϵ_{fs}	$15\ nJoule/bits/m^2$
ϵ_{mp}	$0.0015\ pJoule/bits/m^4$
E_{DA}	$6\ nJoule/bits/signal$

consists of 200 sensor nodes, all sensor nodes are placed randomly in a region and a base station (BS) is located at the outside of that region.

A. Result Analysis of Network Lifetime

In figure 2, 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 EEDRR is shown in figure 3 as dashed dark blue curve. The graph in figure 2 for DEEC [18], DDEEC [19], EDEEC [20] and EDDEEC [21] represents the graph of nodes alive during each round (network lifetime). Again the proposed protocol EEDRR performs better as compared to other protocol as shown in the graph.

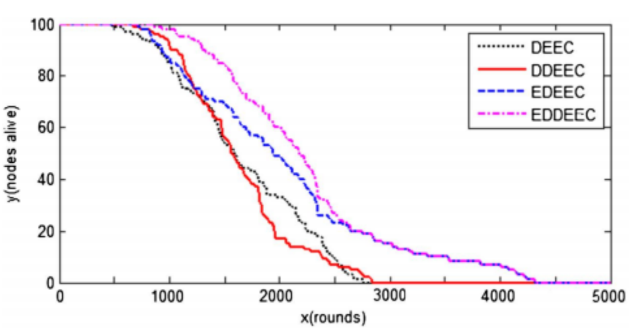

Fig. 2. Network Lifetime

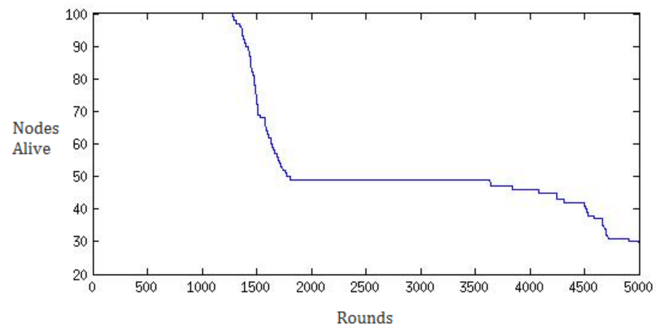

Fig. 3. Network Lifetime of Proposed Protocol EEDRR

B. Result Analysis of Throughput

The graph of figure 4 plots the data packets send to the base station (BS) or throughput. Again the same colored curve are used for DEEC [18], DDEEC [19], EDEEC [20] and EDDEEC [21] protocols. For performance evaluation of EEDRR in

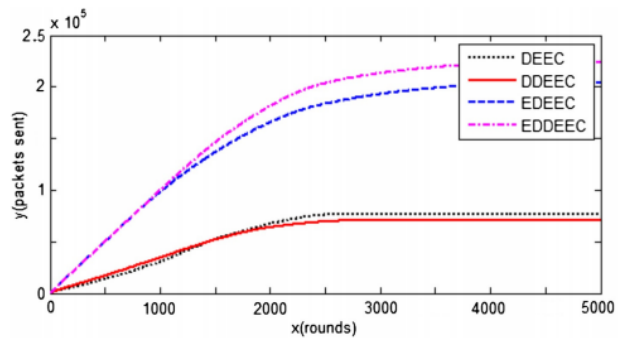

Fig. 4. Throughput

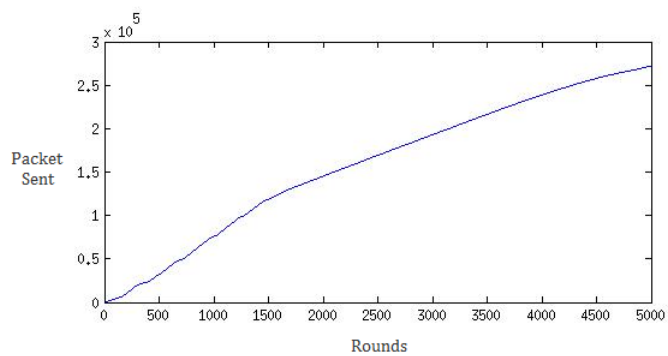

Fig. 5. Throughput of Proposed Protocol EEDRR

MATLAB, the same initial parameter values are considered and the next parameter values as used in DEEC [18], DDEEC [19], EDEEC [20] and EDDEEC [21]. As shown in figure 4 and 5, the proposed protocol EEDRR presents maximum throughput as compared to these protocols.

V. CONCLUSION AND FUTURE WORK

The proposed protocol “EEDRR (energy estimated distributed reactive routing) in Wireless Sensor Network” works as a reactive routing protocol which uses three different levels heterogeneity for sensor node. Whereas, LEACH, DEEC, DDEEC, EDEEC and EDDEEC use their own strategies for energy efficiency. EEDRR use the best features of EDDEEC with energy level calculation. EEDRR bring out high energy efficiency, greater network lifetime and highest throughput as presented in the simulation result, because of being reactive routing network protocol, energy level based cluster head selection, hard and soft threshold value and three levels of node heterogeneity. It can be concluded that the protocol EEDRR will perform well in small as well as large geographical networks and best suited for time critical applications, in comparison to DEEC, DDEEC, EDEEC and EDDEEC with the proposed EEDRR protocol. The strategy of the mobile base station can be introduced in EEDRR to perform the next level of advanced technology in future.

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