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# Energy Efficient Clustering Protocols In Wireless Sensor Networks

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***Abstract***—Wireless Sensor Networks (WSNs) is a broad area of research which is getting more and more relevant nowadays.The use of wireless sensor networks (WSNs) has grown enormously in the last decades; however, WSNs being battery operated, the performance and applications of these networks are highly constrained. In many applications, energy replenishment through human intervention is not possible. Different clustering protocols are used to increase the efficiency and lifetime of the sensor network. The performance comparison was done with Distributed Energy Efficient Clustering (DEEC), Developed Distributed Energy Efficient Clustering (DDEEC), Enhanced Distributed Energy Efficient Clustering (EDEEC) and Threshold Distributed Energy Efficient Clustering (TDEEC) protocols.

***Keywords***—*Wireless Sensor Ntworks, routing protocols, energy efficiency, cluster based routing*

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## I. Introduction

The wireless sensor networks (WSNs) contain hundreds or thousands of sensor nodes equipped with sensing, computing and communication abilities. Advancements in wireless communications, low-power electronics, battery technology, and power harvesting capabilities have enabled the development of low cost WSNs. The flexibility, self organisation, low cost and rapid deployment of wireless sensor networks are ideal characteristics to many new and exciting ubiquitous application areas such as military applications, environmental applications, medical applications, etc. However, WSNs are inherently energy constrained because they are equipped with small battery and once this battery fails, replacement or replenishment in most of the cases are quite difficult. Thus, energy saving of sensor nodes is a major design issue. To prolong the network's lifetime, minimization of energy consumption should be implemented at all layers of the networkprotocol stack starting from the physical to the application layer[1].

A sensor node is made up of four basic components as shown in figure: a sensing unit, a processing unit, a transceiver unit and a power unit.They may also have application dependent additional components such as a location findingsystem, a power generator and a mobilizer.

Sensing units are usually composed of two subunits: sensors and analog to digital converters (ADCs). Processing unit is responsible for collecting data from various sources, process it and stores it. The central process unit of sensor node determines energy consumption and computational capabilities of a node. It consists of micro controllers, timer/clock, operating system and memory. A transceiver unit connects the node to the network. One of the most important components of a sensor node is the power unit. Power units may be supported by a power scavenging unit such as solar cells. There are also other subunits, which are application dependent[1].

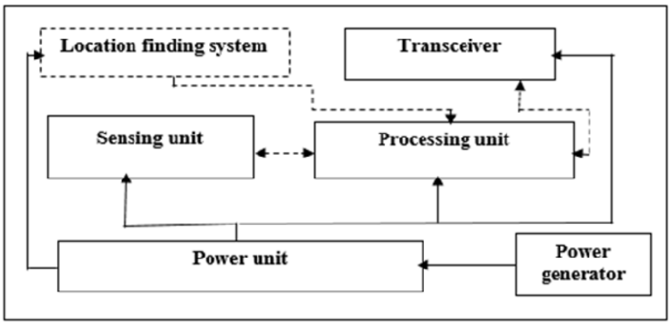


Fig 1: The components of a sensor node

The protocol stack consists of the application layer, transport layer, network layer, data link layer, physical layer, power management plane, mobility management plane, and task management plane. Protocol stack combines power and routing awareness, integrates data with networking protocols, communicates power efficiently through the wireless medium, and promotes cooperative efforts of sensor nodes.

A sensor node either communicates among its peers to collect the sensed data or sends (receives) the data to (from) a base station. A base station connects the sensor networks to another network. Usually nodes in WSN are power constrained due to limited battery, it is also not possible to recharge or replace battery of already deployed nodes and nodes might be placed where they can't be accessed. Nodes may be present far away from BS so direct communication is not feasible due to limited battery as direct communication requires high energy.

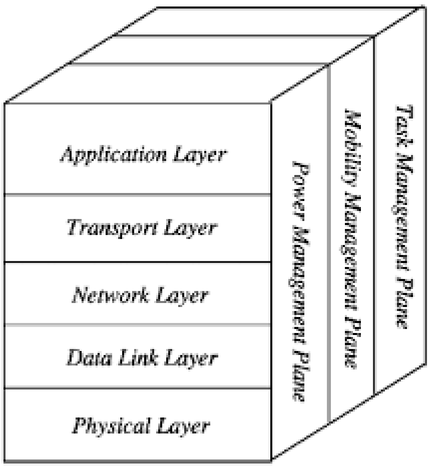


Fig 2: The sensor networks protocol stack

Clustering is the key technique for decreasing battery consumption in which members of the cluster select a Cluster Head (CH). Clustering can be done in two types of networks i.e homogeneous and heterogeneous networks. Nodes having same energy level are called homogenous network and nodes having different energy levels called heterogeneous network. Stable Election Protocol (SEP), Distributed Energy-Efficient Clustering (DEEC), Developed DEEC (DDEEC), Enhanced DEEC (EDEEC) and Threshold DEEC (TDEEC) are algorithms designed for heterogeneous WSN. DEEC, DDEEC, EDEEC and TDEEC are designed for multilevel heterogeneous networks and can also perform efficiently in two level heterogeneous scenarios. Three level heterogeneous networks contain normal, advanced and super nodes whereas super nodes have highest energy level as compared to normal and advanced nodes[2].

# I. DISTRIBUTED ENERGY EFFICIENT CLUSTERING PROTOCOLS

In many critical applications WSNs are very useful such as military surveillance, environmental, traffic, temperature, pressure, vibration monitoring and disaster areas. To achieve fault tolerance, WSN consists of hundreds or even thousands of sensors randomly deployed inside the area of interest. All the nodes have to send their data towards BS often called as sink. Usually nodes in WSN are power constrained due to limited battery, it is also not possible to recharge or replace battery of already deployed nodes and nodes might be placed where they can't be accessed. Nodes may be present far away from BS so direct communication is not feasible due to limited battery as direct communication requires high energy. Clustering is the key technique for decreasing battery consumption in which members of the cluster select a Cluster Head (CH). All the nodes belonging to cluster send their data to CH, where, CH aggregates data and sends the aggregated data to BS[2].

Energy consumption for aggregation of data is much less as compared to energy used in data transmission. Clustering can be done in two types of networks i.e homogenous and heterogeneous networks. Nodes having same energy level are called homogenous network and nodes having different energy levels called heterogeneous network. Low-Energy Adaptive Clustering Hierarchy (LEACH), Power Efficient Gathering in Sensor Information Systems (PEGASIS), Hybrid Energy Efficient Distributed clustering (HEED) are algorithms designed for homogenous WSN under consideration so these protocols do not work efficiently under heterogeneous scenarios because these algorithms are unable to treat nodes differently in terms of their energy. Whereas, Stable Election Protocol (SEP), Distributed Energy-Efficient Clustering (DEEC), Developed DEEC (DDEEC), Enhanced DEEC (EDEEC) and Threshold DEEC (TDEEC) are algorithms designed for heterogeneous WSN. SEP is designed for two level heterogeneous networks, so it can't work efficiently in three or multilevel heterogeneous network. SEP considers only normal and advanced nodes where normal nodes have low energy level and advanced nodes have high energy. DEEC, DDEEC, EDEEC and TDEEC are designed for multilevel heterogeneous networks and can also perform efficiently in two level heterogeneous scenarios[3].

## *A. DEEC*

DEEC (Distributed Energy Efficient Clustering) is cluster-based algorithmin which cluster heads are selected on the basis of probability of ratio of residualenergy and average energy of the network. In this algorithm, node having moreenergy has more chances to be a cluster head. It prolongs the lifetime of thenetwork. The DEEC upholds the distributed property while it can be implementedon the multi-level heterogeneous wireless sensor network.

DEEC is designed to deal with nodes of heterogeneous WSNs. For CH selection, DEEC uses initial and residual energy level of nodes. CH selection criteriain DEEC is based on energy level of nodes. In WSNs, nodes with high energy aremore probable to become CH than nodes with low energy. In DEEC protocol allnodes use the initial and residual energy level to define the cluster heads. DEECestimate the ideal value of network lifetime to compute the reference energy thateach node should expend during each round DEEC does not require any globalknowledge of energy at every election round. Unlike SEP and LEACH, DEECcanperform well in multi-level Heterogeneous wireless network.Advanced nodesalways penalize in the DEEC, particularly when their residual energy reduced andbecome in the range of the normal nodes. In this position, the advanced nodes die rapidly than the others[3].

*B. DDEEC*

DDEEC (Developed DEEC) uses same method for estimation of average energy in the network and CH selectionalgorithm based on residual energy as implemented in DEEC. Difference between DEEC and DDEEC is centered in expression that defines probability for normal nodes and advanced nodes to be a cluster head.Nodes with more residual energy at round r are more probable to becomeCH, so, in this way nodes having higher energy values or advanced nodes willbecome CH more often as compared to the nodes with lower energy or normalnodes. A point comes in a network where advanced nodes having same residualenergy like normal nodes. Although, after this point DEEC continues to punishthe advanced nodes so this is not optimal way for energy distribution because bydoing so, advanced nodes are continuously a CH and they die more quickly thannormal nodes[4].When energy level of advanced and normal nodes falls down to the limit ofthreshold residual energy then both type of nodes use same probability to become cluster head. Therefore, CH selection is balanced and more efficient[4].

*C. EDEEC*

EDEEC(Enhanced DEEC) uses concept of three level heterogeneous network.EDEEC scheme is based on DEEC with addition of super nodes. It contains threetypes of nodes normal, advanced and super nodes based on initial energy. EDEECis adaptive energy aware protocol which dynamically changes the probability ofnodes to become a CH in a balanced and efficient way to distribute equal amountof energy between sensor nodes. Cluster head algorithm is broken into rounds.At each round node decides whether to become a cluster head based on thresholdcalculated by the suggested percentage of cluster heads for the network and thenumber of times the node has been a cluster head so far. This decision is madeby the nodes by choosing the random number between 0 and 1. If the number isless than a threshold the node becomes a cluster head for the current round.

*D. TDEEC*

TDEEC (Threshold DEEC) uses same mechanism for CH selection and average energy estimation as proposed in DEEC. At each round, nodes decide whether to become a CH or not by choosing a random number between 0 and 1. If number is less than threshold then nodes decide to become a CH for the given round. In TDEEC, threshold value is adjusted and based upon that value a node decides whether to become a CH or not by introducing residual energy and average energy of that round with respect to optimum number of CHs. TDEEC implements the same strategy for estimating the energy in the network as proposed in DEEC. In TDEECapproach we have adjusted the value of the threshold, according to whicha node decides to be a cluster head or not, based on ratio of residual energy and average energy of that round in respect to the optimum number of cluster heads.So that only nodes having a more energy becomes the cluster head[4].

## III. ENERGY DISSIPATION MODEL

Energy model for the radio hardware energy dissipation where the transmitterdissipates energy to run the radio electronics and the power amplifier, and thereceiver dissipates energy to run the radio electronics is shown in Figure.

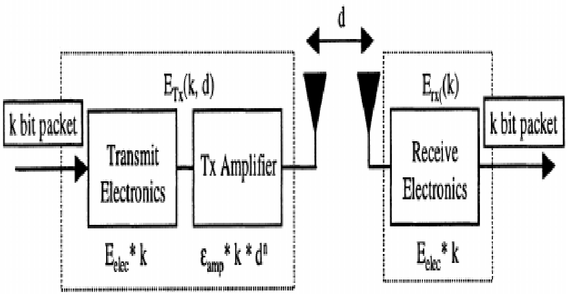


Fig 3: Radio Energy Dissipation Model

Here both the free space ($d^2$power loss) and the multipath fading ($d^4$Here both the free space ($d^2$power loss) and the multipath fading ($d^4$ power loss) channel models were used, depending on the distance between the transmitter and receiver. Power control can be used to invert this loss by appropriately setting the power amplifier if the distance is less than a threshold ($d_0$), the free space model is used; otherwise, the multipath model is used.

Value of threshold distance $d_0$ is given by

$$d_0 = E_{fs} / E_{amp} \quad (1)$$

The electronics energy, $E_{elec}$, depends on factors such as the digital coding, modulation, filtering, and spreading of the signal, whereas the amplifierenergy,$E_{fs} . d^2$ or$E_{amp} . d^4$, depends on the distance to the receiver and the acceptable bit error rate.[4]

## III. NETWORK MODEL

N number of nodes placed in a square region of dimension M x M. Heterogeneous WSNs contain two, three or multi types of nodes with respect to their energy levels and are termed as two, three and multi level heterogeneous WSNs respectively.

*A. Two Level Heterogeneous WSNs Model*

Two level heterogeneous WSNs contain two energy level of nodes, normal and advanced nodes. Where,$E_0$ is the energy level of normal node and $E_0$.(1+α) is the energy level of advanced nodes containing α times more energy as compared to normal nodes. If N is the total number of nodes then Nm is the number of advanced nodes where m refers to the fraction of advanced nodes and N(1 - m) is the number of normal nodes. The total initial energy of the network is the sum of energies of normal and advanced nodes. The two level heterogeneous WSNs contain am times more energy as compared to homogeneous WSNs[5].

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

*B. Three Level Heterogeneous WSNs Model*

Three level heterogeneous WSNs contain three different energy levels of nodesi.e normal, advanced and super nodes. Normal nodes contain energy of $E_0$, the advanced nodes of fraction m are having α times extra energy than normal nodes equal to $E_0$ .(1+α) whereas, super nodes of fraction $m_0$ are having a factor of b times more energy than normal nodes so their energy is equal to $E_0$ .(1+b). As N is the total number of nodes in the network, then $Nmm_0$ is total number ofsuper nodes and Nm(1-$m_0$) is total number of advanced nodes. The total initial energy of three level heterogeneous wireless sensor network is therefore given by:

$$E_{total} = N(1-m)E_0 + Nm(1-m_0)(1+a)E_0 + Nm_0E_0\,(1+b) \quad (3)$$

$$E_{total} = NE_0\left(1+m(a+m_0b)\right) \quad (4)$$

The three level heterogeneous WSNs contain (α+$m_0b$) times more energy as compared to homogeneous WSNs.[5][6] .

*C. Multilevel Heterogeneous WSNs Model*

Multi level heterogeneous WSN is a network that contains nodes of multiple energy levels. The initial energy of nodes is distributed over the close set [$E_0$,$E_0$(1+$\alpha_{max}$)], where $E_0$ is the lower bound and$\alpha_{max}$ is the value of maximal energy. Initially, node $S_i$ is equipped with initial energy of $E_0$. (1+$\alpha_i$), which is $\alpha_i$times more energy than the lower bound$E_0$.

CH nodes consume more energy as compared to member nodes so after some rounds energy level of all the nodes becomes different as compared to each other. Therefore, heterogeneity is introduced in homogeneous WSNs and the networks that contain heterogeneity are more important than homogeneous networks.[7]

## IV. RESULTS AND DISCUSSION

Performance parameters used for evaluation of clustering protocols for heterogeneous WSNs are lifetime of heterogeneous WSNs, number of nodes alive duringrounds and data packets sent to BS. These parameters depict stability period, instability period, energy consumption, data sent to the BS, and data received by BS and lifetime of WSNs. Stability period is period from start of network until the death of first node whereas instability period is period from the death of first node until last one.

We evaluated the system performance through simulationsin MATLAB. In the sensor network , 20 percent advanced nodes are deployed with 1.5 timesmore energy than normal nodes and 30 percent super nodes are deployed with 3 times more energy than the normal nodes. Base Station is placed at center of the network field.For simplicity consider all the nodes are either fixed or micro mobile. In heterogeneous wireless sensor networks, the radio parameters mentioned in the table are used for different protocols deployed in wireless sensor networks andsimulate the performance for three level heterogeneous wireless sensor networks.

TABLE 1. Simulation Parameters

| Parameters | Value |
|---|---|
| Network Field | 100m, 100m |
| Number of nodes | 100 |
| Initial Energy | 0.5J |
| Data aggregation Energy | 5nJ/bit |
| Amplification energy for short distance | 10 pJ/bit/$m^2$ |
| Amplification energy for long distance | 0.0013 pJ/bit/$m^4$ |
| Probability of cluster head | 0.1 |

Parameter m refers to fraction of advanced nodes containing extra amount ofenergy a in network whereas, mo is a factor that refers to fraction of super nodes containing extra amount of energy b in the network.

Figure 4 represents the number of nodes dead during the lifetime of the network. It is clear that by introducing super nodes lifetime increases. From the figure it is clear that, as the number of rounds increases the number of dead nodesalso increases. As the number of rounds increases the first node dies for DEECprotocol. EDEEC and TDEEC protocols perform better than DDEEC and DEEC.

The first node for DEEC, DDEEC, EDEEC and TDEEC dies at 1000, 1450,1500 and 1540 rounds respectively. All nodes are dead at 3670, 4590, 9980 and9980 respectively. It is obvious from the results of all protocols that in terms ofnodes dead during round, TDEEC and EDEEC performs best of all. DDEEC performs better than DEEC and DEEC has least performance than all the protocols.

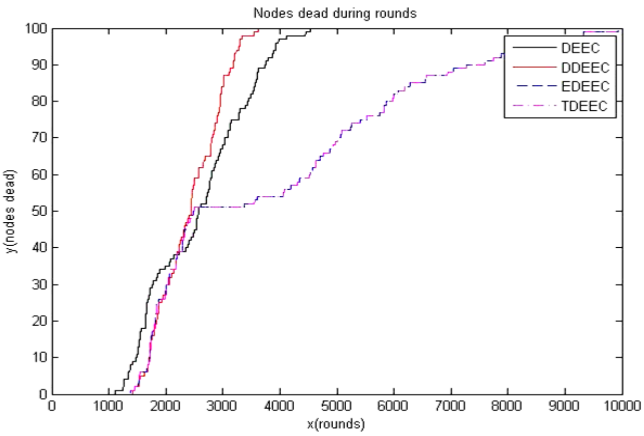


Fig 4: Nodes dead during rounds

Figure 5 represent the number of nodes alive during the lifetime of the network.The number of nodes alive in TDEEC is quite larger than EDEEC becausein TDEEC the formula of threshold used by nodes for cluster head selection is modified by including residual energy and average energy of that round. So nodeshaving high energy become cluster heads.

The first node for DEEC, DDEEC, EDEEC and TDEEC dies at 1000, 1450,1500 and 1540 rounds respectively. All nodes are dead at 3670, 4590, 9980 and9980 respectively. It is obvious from the results of all protocols that in terms ofnodes alive during round, TDEEC and EDEEC performs best of all. DDEEC performs better than DEEC and DEEC has least performance than all the protocols.

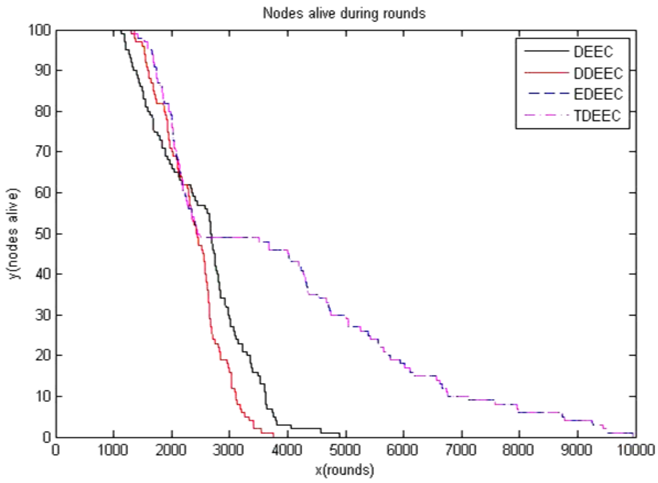


Fig 5: Nodes alive during rounds

Figure 6 represent the number of packets send to BS during the lifetime ofthe network. The packets send to BS for EDEEC and TDEEC are almost samebecause the probability equations for normal, advanced and super nodes is samein both of them. In DEEC protocol packets send to BS is more when comparedwith DDEEC protocol.

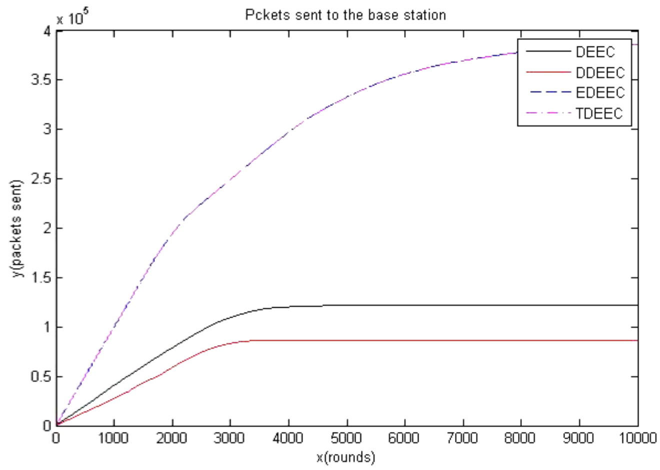


Fig 6: Packets send to BS during rounds

Simulations prove that EDEEC and TDEEC perform well in all scenarios.TDEECand EDEEC has best performance in terms of number of nodes alive during round and the packets send to BS during rounds. DEEC has worst performance than allother protocols.

## V. CONCLUSION

Wireless sensor network is a combination of wireless communication and sensor nodes. The energy saving is a challenging issue in the wireless sensor networks. The network should be energy efficient with stability and longer lifetime. To increase energy efficiency and extend the lifetime of sensor node, new and efficientenergy saving schemes must be developed. Many algorithms are recently proposed to increase stability and lifetime of heterogeneous WSNs. DEEC, E-DEEC, T-DEEC and DDEEC are the different protocols used in heterogeneous wirelesssensor networks. Simulations prove that EDEEC and TDEEC perform well in allscenarios. The performance of DDEEC is better than DEEC but less than thatof TDEEC and EDEEC. DEEC has the least performance in all of the protocols.TDEEC and EDEEC has best performance in terms of stability period and lifetime.

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