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Comparative Cluster Based Routing Protocols Investigations for Distributed Wireless Networks

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Abstract

Wireless sensor networks technology has become a vast field of research due to its wider sphere impacting our daily lives. This paper presents elementary work to address network load effect over energy efficiency through heterogeneous distributed energy efficient routing protocols. Since clustering is one of the major factors for energy optimization in routing protocols. So, we focus our research work on clustering based heterogeneous routing protocols for comparative analysis in wireless sensor networks. We included network workload scaling metric to address performance based aspects. Moreover, performance evaluation metrics for energy consumption like dead node count, alive node count, throughput, and cluster-head count are also evaluated. Finally, simulation analysis has been done to prove validity of our proposal. This work seems to be a bench mark for wireless sensor network system designer towards distributed energy efficient routing protocols.

Keywords

Clustering, Count, Heterogeneity, Node, Routing Protocol, Scalability, WSN

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1. Introduction

At present wireless sensor networks have become a novel and influential tool for diverse fields such as sensing, data gathering, tracking and wide range of monitoring [1]. Application domain [2] of WSNs associated with environmental monitoring, security and surveillance, precision agriculture, and industrial usage etc. Such a network consists of set of large micro sensors deployed randomly in harsh environment to perform some sensing task. Due to probability of working in harsh and inaccessible environment, batteries of sensor nodes cannot be charge and substitute further [3]. That's why energy consumption becomes a key limitation in WSNs. Since each node has limited capacity but summation of entire network's energy performs the designated task in WSNs. Collaboration power of WSNs can be achieved naively via routing protocols to ensure multi hop communication. In routing protocols, clustering remains one of the novel ways for energy optimization [4]. In clustering, nodes arrange themselves into local clusters electing one node as a cluster-head. Initially, non cluster-head nodes transmit data to the cluster-head node. Next, two functions namely data aggregation and data fusion are performed at cluster-head node to eliminate redundant information. Finally, data is forwarded to the remote base station. Clustering approach in routing protocols is significant way to reduce energy consumption. WSNs can be broadly classified namely homogeneous and heterogeneous sensor networks based on their nodes capacity [5]. Nodes are of same capacity deployed in randomly distributed environment is treated as homogeneous WSNs. In contrary with different nodes capacity on the basis of their bandwidth, data rates are called heterogeneous wireless sensor networks. Clustering with heterogeneity in routing protocols is most practically applicable concept to deal with

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energy consumption challenge in WSNs. In this paper, we included low energy adaptive clustering hierarchical protocol (LEACH) [5], stable election protocol (SEP) [6], distributed energy efficient clustering routing protocol (DEEC) [7], developed distributed energy-efficient clustering protocol (DDEEC) [8], enhanced distributed energy efficient clustering protocol (EDEEC) [9], and threshold distributed energy efficient clustering routing protocol (TDEEC) [10] for heterogeneous WSNs. In LEACH protocol, cluster-head selection idea is backbone for energy optimization. Cluster-heads are local base stations to maintain energy load for all the nodes. LEACH is able to achieve factor of eight reductions in energy dissipation with tradition routing protocols [5]. In SEP protocol, cluster-head selection is based on weighted election probabilities in each node. SEP always prolongs the stability period but only achieve two-level heterogeneity [6]. In DEEC protocol, cluster-head selection is probability is the ratio of residual energy of node to average energy of network. Multilevel heterogeneity is achieved in DEEC [7]. In DDEEC protocol, key idea for cluster head selection is based on dynamic behaviour probability [8]. EDEEC protocol performs better than SEP with more stability period [9]. EDEEC also achieve multilevel heterogeneity. In TDEEC protocol, cluster-head selection process achieves better results due to change in threshold value [10-11]. This paper presents comparative evaluation of heterogeneous routing protocols based on network lifetime and energy consumption aspects. Verma et al. [12] contributed towards scalability issue in AODV routing protocol for wireless sensor networks. Data dissemination based investigations over sensor node distribution strategies have been reported in references [13-14]. Sensors augmentation influence over trust and reputation models has been reported in reference [15].

The layout plan for this paper is as follows. Section II defines related work on explorative distributed routing protocols. In section III, we define cluster-head selection phase for each routing protocol for comparative analysis. In section IV detail experimental setup with performance measurement parameters are defined. Simulation results are shown with evaluation parameters in section V. Finally, conclusion and future direction are defined in section VI.

2. Related Work to Distributed Routing Protocols

Usages of heterogeneous routing protocols [16] are increasing day by day. This is due to routing protocols are one of efficient and realistic way to address energy consumption aspects. In this section we have included network model and energy consumption model.

2.1. Network Model

We have taken network model in consistent pattern of DEEC routing protocol. N numbers of sensor nodes randomly distributed over M×M square region. Network model can be extended in terms of heterogeneity. In this model, all the sensor nodes always have data to transmit to a base station. In such type of network model, heterogeneity can be achieved up to multilevel.

In case of two-level heterogeneity, two types of sensor nodes present in the network. One is normal node with initial energy E_0 and second is advance node with initial energy $(1+a) \times E_0$. Advance nodes have a time more energy than normal nodes. If fraction of m number of sensor nodes are advanced nodes in that case $(1-m) \times N$ normal nodes are present in the network. Total energy of the two level heterogeneous networks can be calculated using equation (1),

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

In case of three-level heterogeneity, three types of nodes present in the network. Node types included normal node, advanced node, and super node with initial energy E_0, $(1+a) \times E_0$, $(1+b) \times E_0$ respectively. Super node has b time more energy than advance node. In that case, total energy of the network can be calculated as,

$$E_{Total} = N(1-m)E_0 + Nm(1-m_0)(1+a)E_0 Nm_0(1b)E_0$$

$$E_{Total} = NE_0\big(1 + m(a + m_0 \times b)\big) \quad (2)$$

In case of multi-level heterogeneity, there are multiple nodes are present with different energy capacity. Range of energy lies between E_0 to $E_0\,(1+a_{max})$, where E_0 is minimum range, and $E_0\,(1+a_{max})$ is maximum range with a_{max} determine value of maximum energy. In case of multilevel heterogeneity, total energy of the network can be calculated as,

$$E_{Total} = \sum_{i=1}^{N} E_0\,(1 + a_{max}) = E_0\,(N + \sum_{i=1}^{N} a_{max}) \quad (3)$$

2.2. Energy Consumption Model

We take energy consumption model in consistent pattern of distributed energy efficient clustering algorithm with improved coverage [4]. We have included transmission energy, receiving energy and energy consumption and dissipation in one round in this model. Energy consumption included E_{elec} (depending on factors such as digital coding, modulation, filtering and spreading of the signal). Energy dissipation included both free space (d^2 power loss) and multipath (d^4 power loss) fading channel models. These losses depend on the distance d between transmitter and receiver. Thus, to transmit l bit message from transmitter to receiver with distance d, energy expands

$$E_{TX}(l,d) = \begin{cases} lE_{elec} + l\epsilon_{fs}d^2, & d < d_0 \\ lE_{elec} + l\epsilon_{mp}d^4, & d \geq d_0 \end{cases} \quad (4)$$

As well, for receiving l bit message between sensor nodes, energy expands

$$E_{RX}(l) = lE_{elec} \quad (5)$$

Total energy consumption in the network during a round is calculated as:

$$E_{round} = l(2NE_{elec} + NE_{DA} + k\varepsilon_{mp}d^4{}_{toBS} + N\varepsilon_{fs}d^2{}_{toCH}) \quad (6)$$

3. Cluster-Head Selection Process

In this paper, we evaluated clustered based heterogeneous routing protocols. In these protocols, selection of cluster-head procedure is different which is responsible for better performance. We included cluster-head selection phase for each routing protocol as described below.

3.1. Low Energy Adaptive Clustering Hierarchy (LEACH)

In LEACH protocol, initially group of sensor nodes make single cluster and no cluster-head present in network. Here, optimal election probability (P) to be a cluster-head is predefined. Before cluster-head selection, firstly residual energy is checked for satisfying criteria. Random value is selected and compared with threshold value i.e. (p/1-p × mod (r, round (1/p))). Estimated random value is less than threshold value than that node becomes a cluster-head for current round. For next round, other nodes have chance to be a cluster head node except elected nodes. When cluster-head selection process is over, co-ordinates are assigned to cluster-head node. Distance between cluster-head node to sink node is calculated. After that ID is assigned to cluster-head node. Residual energy of each node is calculated based on free space loss and multi path losses for each round. This process is repeated for every node. Lastly, cluster-head count is calculated.

3.2. Stable Election Protocol (SEP)

Stable Election Protocol follows the consistent pattern of LEACH protocol for cluster-head selection. Election probability to be a cluster-head for each node is predefined. Threshold value is used to compare with estimated random value. Thus, those nodes satisfying the required criteria selected as cluster-head for current round. This process is repeated for all the active nodes until nodes are inactive.

3.3. Distributed Energy Efficient Clustering Protocol (DEEC)

In DEEC Protocol, Initially no cluster-head is present, group of sensor nodes make single cluster. Average energy (E_a) of the network will be checked for each node. Probability to be a cluster-head (p(i)) is calculated for every node using equation given below.

$$E_a = E_t \times (1 - r / r_{max}) / n \quad (7)$$

$$p(i) = P \times n \times (1 + a) \times E(i) / (n + A) \times E_a \quad (8)$$

For election of cluster head node, residual energy will be checked for minimum value. A random value is taken between 0 and 1 and compare with threshold value i.e. $(p(i)/1 - p(i) \times \mathrm{mod}(r, \mathrm{round}(1 / p(i))))$. If random value is less than threshold value for a node that node will selected as cluster-head. DEEC followed cluster-head selection strategy is shown in figure 1.

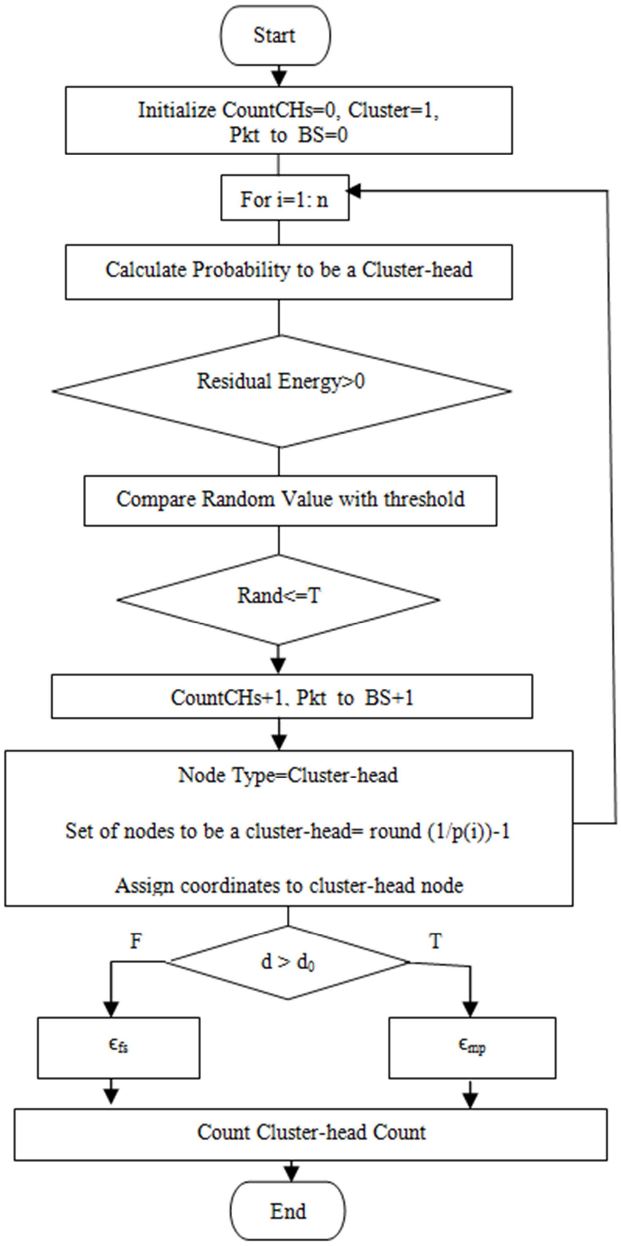

Figure 1. Cluster-head selection procedure flow chart.

3.4. Developed Distributed Energy Efficient Clustering Protocol (DDEEC)

DDEEC routing protocol follows consistent pattern of DEEC in cluster-head selection phase. We have seen disparity present in cluster-head selection probability. Probability to be a cluster-head can be calculated based on energy based heterogeneity. Energy heterogeneity can be implemented such as (initial energy) $\leq 0.7 \times E_0$ Then probability to be a cluster-head can be calculated using equation (9).

$$p(i) = C(1 + S(i).A)PE(i)/(1 + (S(i).A \times m_7)) \times E_a \quad (9)$$

If (Initial Energy $\leq E_0$) Then Probability to be a cluster-head can be calculated using equation (10).

$$p(i) = P \times E(i)/(1 + (S(i).A \times m_7)) \times E_a \quad (10)$$

If (Initial Energy $> E_0$) Then Probability to be a cluster-head can be calculated using equation (11).

$$p(i) = (1 + S(i).A)PE(i)/(1 + (S(i).A \times m_7)) \times E_a \quad (11)$$

After calculating probabilities, estimated random value is compared with threshold value. DDEEC protocol follows consistent pattern of DEEC for further processing. Lastly, cluster heads are calculated.

3.5. Enhanced Distributed Energy Efficient Clustering Protocol (EDEEC)

EDEEC Protocol followed consistent pattern of DEEC protocol for cluster-head selection procedure. Differentiation is present in terms of node heterogeneity. In this protocol residual energy is calculated for normal node, advanced node, and super node. Probability to be a cluster-head selection is based on nodes heterogeneity such as if (Initial Energy <= 0) Then probability to be a cluster-head can be calculated using equation (12).

$$p(i) = P \times E(i)/(1 + m \times (a + m_0 b)) \times E_a \quad (12)$$

If (Initial Energy <= E_0 × (1+a)) Then probability to be a cluster-head for advanced node can be calculated using equation (13).

$$p(i) = P(1 + a)E(i)/(1 + m(a + m_0 b)) \times E_a \quad (13)$$

If (Initial Energy <= E_0 × (1+b)) Then cluster-head selection probability for super node can be calculated using equation (14).

$$p(i) = P(1 + b)E(i)/(1 + m(a + m_0 b)) \times E_a \quad (14)$$

Furthermore, a random value is chosen and compared with threshold value i.e. $(p(i)/1 - p(i) \times \text{mod}(r, \text{round}(1/p(i))))$ for cluster-head selection. After completion of cluster-head selection various operations are performed for further processing. Residual energy also calculated based on two types of losses namely free space loss and multipath loss. For each round, those nodes satisfying required criteria selected as cluster-head.

3.6. Threshold Distributed Energy Efficient Clustering Protocol (TDEEC)

TDEEC protocol also followed consistent pattern of DEEC routing protocol for cluster-head selection phase. Cluster-head selection probability is calculated based on nodes heterogeneity level. In this protocol, residual energy will be Calculated for normal node, advanced node, and super node before cluster-head selection procedure. But threshold value is modified such that $(p(i) \times E(i) \times k)/(1 - p(i)) \times r \times \text{mod}(1, p(i)) \times E_a$. This value can be compared with random variable, if smaller value then random value is found node will be selected as cluster-head node.

4. Detail Setup

In this section, we deployed investigational framework to analyze different heterogeneous routing protocols. For simulation setup, we have taken N number of sensor nodes randomly distributed over M×M square region. We have included energy consumption parameters like $E_{elec}, \in_{fs}, \in_{mp}$, and E_{DA} etc for network load analysis. Figure 2 shows network model with 100 nodes that are spread over 100m×100m region. We have taken base station is in centre of the sensing region for simplicity purpose.

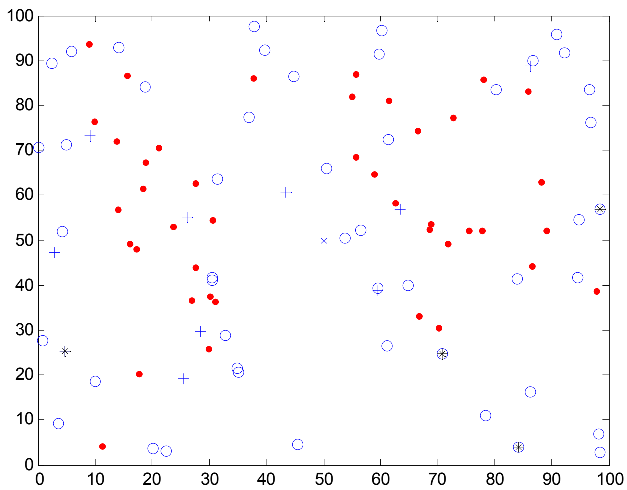

Figure 2. Experimental Simulation Setup.

In experimental simulation scenario, (o) oval represents normal nodes, (+) represents advance nodes, and (×) represents sink node. In this setup, red marks denote number of dead node after some iteration. Simulation is based on various fixed and scalable parameters. In table 1, we have included energy and network parameters.

Table 1. Simulation Parameters.

Parameters	Value
E_{elec}	5 nJ/bit
ϵ_{fs}	10 pJ/ bit/m^2
ϵ_{mp}	0.0013 pJ/bit/m^4
E_0	0.5 J
E_{DA}	5 nJ/bit/message
d_0	70 m
Message Size	4000 bits
P_{opt}	0.1
a	1.5
m	0.5
Network Load	100, 200, 300, 400, 500
Network Size	100×100
Number of Rounds	10000

5. Results

We used MATLAB over windows platform to evaluate the performance based on network load and energy constraints. Performance investigation is basically evaluating energy consumption and dissipation aspects through five parameters namely: DNC, ANC, PTBS, PTCH, and CHC. This section shows effect of network load over such as LEACH, SEP, DEEC, DDEEC, EDEEC, and TDEEC routing protocols. Network load can be defined as number of sensor nodes present in the network. Network life time can be defined as counting of number of rounds until all alive nodes are dead in the network. Dead node count is defined as counting of number of rounds showing number of inactive nodes present in the network. Alive Node Count is defined as counting of number of rounds until all alive nodes become dead. Packets send to Base Station is defined as data packets need to send from cluster-head node to the base station. Packets send to Cluster head is defined as number of data packets send between non cluster-head nodes to the cluster-head nodes. Cluster-head count calculates number of cluster-head present per round.

Figure 3 presents performance based evaluations for 100 nodes. This figure divided into four subplots. In which x-axis represents number of rounds and y-axis represents number of nodes, packet size, and number of cluster-heads respectively. First and second sub plots represent network life time through dead node count and alive node count. In third and fourth subplots, we represent energy consumption through packets send to base station and cluster-head count. We analyzed network lifetime is less in LEACH and SEP protocols. In EDEEC and TDEEC routing protocols network lifetime is more and energy consumption is less.

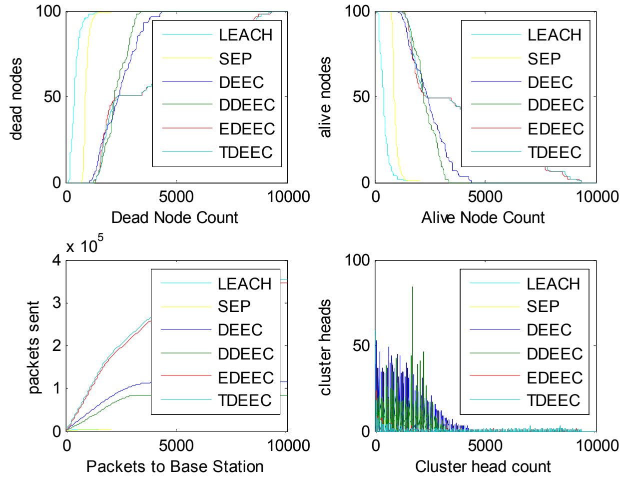

Figure 3. Performance based evaluations for 100 nodes.

Figure 4 presents performance based evaluation for 200 nodes. This figure shows, how network load affect energy parameters. First and second subplots shows network lifetime may decreases as network load increases. This is due to more number of data packets send to base station resulting in increment of cluster-head count. In this case, we analyzed LEACH, and SEP protocols are more affected in terms of energy consumption.

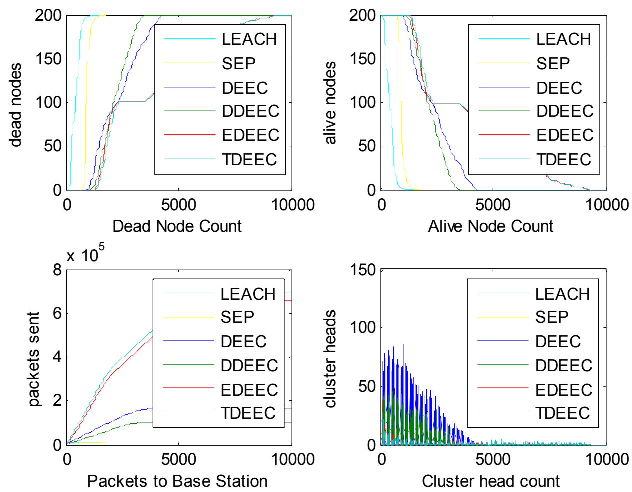

Figure 4. Performance based evaluations for 200 nodes.

Figure 5 represents performance based evaluation for 300 nodes. We have evaluated routing protocols affected through network load based scalability in term of energy consumption. Performance of LEACH and SEP protocols is less in term of network lifetime. Other routing protocols like EDEEC and TDEEC perform better.

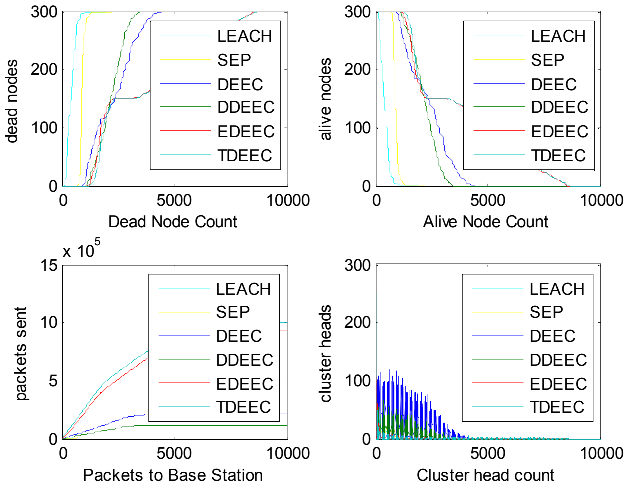

Figure 5. Performance based evaluations for 300 nodes.

Figure 6 represents performance based evaluation for 400 nodes. In this figure first subplot shows, stability period and network lifetime have decreased. Remaining three subplots show energy consumption and throughput have increased. We have analyzed, two routing protocols such as LEACH and SEP have more influenced with network load while DEEC and its variants perform well in this aspect.

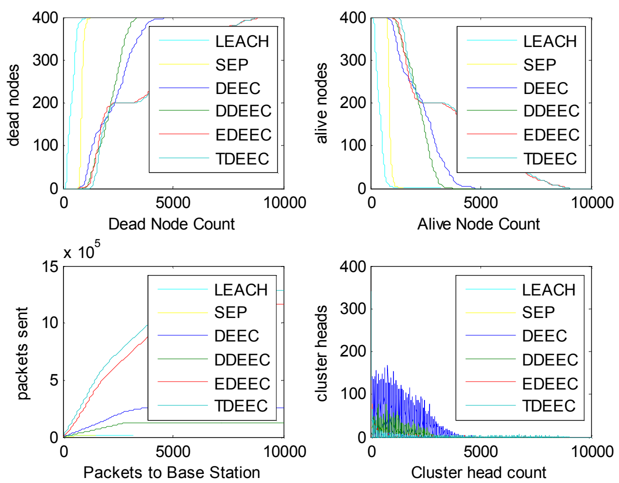

Figure 6. Performance based evaluations for 400 nodes.

Figure 7 represents performance based evaluation for 500 nodes. First subplot shows all nodes are dead earlier with fewer rounds. Network lifetime also decreased in alive node count with more network load. Moreover, packets send to base station and cluster-head count increased with more network load. As cluster-head count increases in each round, energy consumption is more. We analyzed in DDEEC protocol, energy consumption is more due to more number of cluster-heads present per round. Network lifetime is more in EDEEC and TDEEC routing protocols due to less number heads.

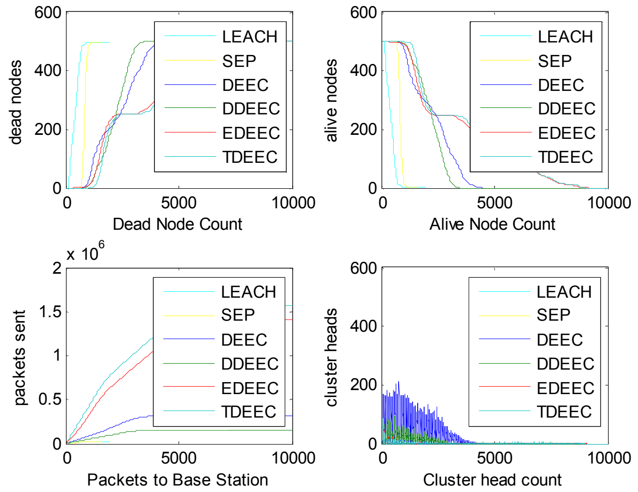

Figure 7. Performance based evaluations for 500 nodes.

Table 2 represents performance evaluation of six heterogeneous routing protocols name as Low Energy Adaptive Clustering Hierarchy (LEACH) protocol, Stable Election Protocol (SEP), Distributed Energy Efficient Clustering Routing protocol (DEEC), Developed Distributed Energy Efficient Clustering Protocol (DDEEC), Enhanced Distributed Energy Efficient Clustering Routing Protocol (EDEEC), and Threshold Distributed Energy Efficient clustering protocol (TDEEC). This performance evaluation is based on five parameters name as dead node count, alive node count; packets send to base station, packets send to cluster-head, and cluster-head count.

Table 2. Network load based comparison analysis.

Network Load	100	200	300	400	500
LEACH					
First Dead	447	418	413	394	336
Tenth Dead	555	577	537	534	537
All Dead	1473	1229	1207	1143	1004
Pkts_to_CH	38033	76241	112208	147873	187711
Pkts_to_BS	4515	8714	12765	16929	21311
SEP					
First Dead	880	792	746	694	650
Tenth Dead	924	848	794	751	687
All Dead	2051	1765	1588	1491	1628
Pkts_to_CH	87009	175825	256902	332166	400149
Pkts_to_BS	47009	9454	13727	17681	21274
DEEC					

Network Load	100	200	300	400	500
First Dead	1099	920	877	790	771
Tenth Dead	1437	1257	1183	1121	1112
All Dead	4385	4347	4649	4751	4498
Pkts_to_CH	135143	302875	472046	638267	822924
Pkts_to_BS	70669	74798	97014	110861	125397
DDEEC					
First Dead	1286	1129	1099	955	828
Tenth Dead	1628	1443	1383	1331	1310
All Dead	3386	3613	3540	3753	3460
Pkts_to_CH	117479	102090	434461	611217	767509
Pkts_to_BS	96484	84210	92389	101720	114275
EDEEC					
First Dead	1320	1276	1234	1072	1016
Tenth Dead	1565	1555	1438	1360	1324
All Dead	9330	9285	9101	9069	9206
Pkts_to_CH	27792	72270	120953	166802	215152
Pkts_to_BS	344647	662373	985421	1288726	1630301
TDEEC					
First Dead	1322	1287	1279	1200	1057
Tenth Dead	1597	1555	1571	1545	1510
All Dead	9376	9354	9105	9050	9041
Pkts_to_CH	8340	17760	26664	33886	41002
Pkts_to_BS	461777	916188	1385712	1856488	2310656

6. Conclusion and Future Direction

This paper presented comparative analysis of six distributed energy efficient clustered routing protocols. We have evaluated network lifetime and energy consumption issues over network load parameter. We have analyzed that network load affects stability period and network lifetime. This is due to increment in energy consumption and decrement in stability period. We have analyzed that LEACH protocol gives low performance for heterogeneous environment. In SEP protocol, stability time improves than the LEACH protocol. In DEEC protocol along with its variants, both stability period and network lifetime increases.

In the future, this work can be extended to performance affecting parameters such as network size, fraction of energy enhancement, and security aspects etc.

Appendix

Variable Name	Description
E_{elec}	Energy dissipated per bit to run transmitter or receiver
ϵ_{fs}	Amplifier energy factor for free space channel model
ϵ_{mp}	Amplifier energy factor for multipath fading channel model
E_0	Initial energy for sensor node
E_{DA}	Energy consumption in data aggregation operation
d_0	Maximum distance between sensor node to sink node
d_{toCH}	Distance between sensor node to cluster-head
d_{toBS}	Distance between cluster-head to base station
P	Probability to be a cluster-head (Initially)
p(i)	Probability to be a cluster-head for each node
R	Number of rounds
m	Number of advanced node
a	Energy enhancement of advanced node
E_a	Average energy of the network
E_t	Total Energy of Network
E(i)	Residual energy of each node
K	Optimal number of cluster
r_{max}	Maximum number of round
r	Current Round

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