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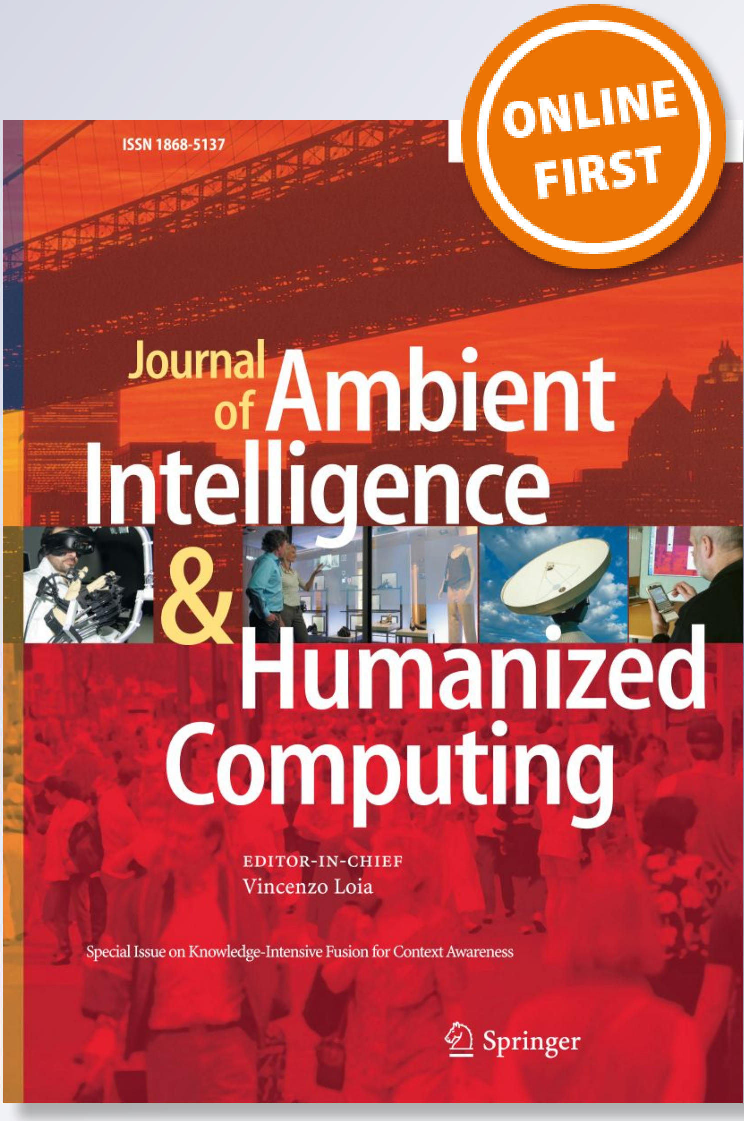

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ORIGINAL RESEARCH

I-DEEC: improved DEEC for blanket coverage in heterogeneous wireless sensor networks

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Abstract

Event critical applications demand blanket coverage. On the other hand, nodes closer to the base station are exploited as they have to spend additional energy in relaying data of far away nodes. This brings in the idea of implementing blanket coverage in heterogeneous wireless sensor networks. I-DEEC improvises distributed energy efficient clustering (DEEC) by deploying network nodes in two layers. Layer 1 strategically tessellate hexagons to deploy nodes as normal or super nodes based on distance from the base station, considering the high data requirement within hop distance around the base station. Layer 2 randomly deploys advanced nodes with condition that no two advanced nodes sense the same area. Further, it uses the sum of the ratio of node's distance to the base station along with residual energy ratio to calculate the possibility of a node to be selected as a cluster head, followed by the selection of the optimal percentage high possibility nodes as cluster heads. I-DEEC provisions blanket coverage by extending the stability period by reducing the ratio between initial energy of different types of nodes. I-DEEC revamps DEEC protocol in terms of network lifetime, percentage area coverage, throughput, and residual energy.

Keywords Blanket coverage · Heterogeneous network · Stability period · Initial energy · Hexagon covering

1 Introduction

The deployment of sensor nodes in an application domain has one of the following objectives: improving percentage area coverage, intensifying connectivity, attaining energy efficiency, revamp network lifetime. Usually, there exist operational trade-offs among the above objectives (Abdollahzadeh and Navimipour 2016). This implies that deployment of nodes in a sensor field requires consideration of the amount of initial energy to be given to the nodes being deployed, energy dissipation by the node based on responsibilities assigned to it, sensing area coverage, network lifetime and many more.

Amount of area covered by a deployment implies to the percentage of the sum of the area enclosed by circular sensing coverage of each node to the total area of sensing field under consideration. Application domains like dense forest, underwater (Priyadarshini and Sivakumar 2019), glaciers or remote international border locations where constant physical presence is a vigorous assignment due to the extremes of nature. The physical phenomenon to be sensed in such domains can be a forest fire, human intrusion, seismic activity, ice-melting, avalanches, and crevasses, etc. In such applications, events take place randomly at any point within the area of interest and each occurrence of the event is crucial. Detecting such events requires complete coverage at all times called Blanket coverage (Sharma et al. 2016).

Along with random and strategic deployment, another deployment strategy evolving in recent years is self- deployment (Abdollahzadeh and Navimipour 2016; Sharma et al. 2016). In this approach, randomly air-dropped nodes reposition themselves to scatter in the network so as to provide better coverage and avoid redundancy. Such node mobility in energy-constrained network with the aim to reposition post-deployment has to face various challenges including uneven terrain, vegetation or bushes which may hurdle node movement. Moreover considering reachability of the above domains to strategically position nodes at a certain moment of time on the cost of battery power utilization, concludes static and strategic deployment as more suitable for provisioning blanket coverage.

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1.1 Contribution

This paper improves DEEC (Qing et al. 2006) by node deployment in the terms of two layers, where layer 1 strategically deploys normal nodes and super nodes using hexagon packing which confirms 1-coverage or 100% area coverage till the death of the first node. While layer 2 extends this percentage area coverage by deploying additional advanced nodes in a random fashion such that no new advanced node lies in the sensing range of the existing advanced node. Considering hop distance as the distance from the base station where nodes have to consume more energy relaying data of far away nodes to the base station. The idea behind the deployment of super nodes in layer 1 is to provide additional energy to nodes within hop distance to the base station, in order to meet additional energy requirement. I-DEEC also increases the stability period of the network by providing additional energy to normal nodes and reducing the initial energy ratio between the nodes. Further, I-DEEC improvises the efficiency by using the ratio of node's distance to the base station and average distance to base station, in addition to residual energy ratio for calculation of possibility of a node to be eligible to be Cluster Head, followed by the selection of p_{opt} highest possibility nodes as CH for current round.

1.2 Paper organization

Section 2 details the work done in the current literature domain in two sections, one for strategic deployment, another for energy efficiency of a heterogeneous wireless sensor network, followed by identification of the literature gap. Section 3 explains I-DEEC in subsections as suppositions, network deployment, node energy distribution, clustering hierarchy followed by data transmission and quality of service parameters. Section 4 details the mathematical values of various simulation parameters and presents different simulation analysis. Section 5 concludes the paper.

2 Literature review

Considering a sensing field of size 100×100 meters with the aim to maximize percentage area covered for the same for a considerable period of time. Sensor nodes usually provide circular coverage within its sensing range. Geometrically, the area of interest is a square and sensing range of a sensor is a circle. It implies that the underlying problem is to accommodate equal-sized circles inside a square such that the complete area of the square is covered.

Packing circles in different regular shapes like a plane or a sphere have been a trendy research problem but covering is the exact interest for the current domain. The packing of regular shape such as circle inside another shape say square implies to filling in maximum circles inside the square without any overlapping, but, covering aims to filling the complete square irrespective of overlapping among circles.

Two classical problems of discrete geometry have been addresses as (Tarnai and Gaspar 1995). First, packing of 'n' equal non-overlapping circles in the unit square such that diameter is as large as possible. Second, covering a unit square by 'n' equal circles such that radius is smallest possible. The solution covered the square with 10 equal circles, based on 'cooling technique' and theory of rigidity. Likewise, (Melissen and Schuur 2000) presented optimal thinnest covering of square with up to seven circles. This followed (Nurmela et al. 2000) a computational method to obtain good coverings of a square with equal circles. It used the quasi-Newton method with BFGS secant update to maximize the covered area by moving the circles. Their best covering for square used up to 30 circles. (Chakrabarty et al. 2002) advocated a linear model for complete coverage of the 3-d field of interest. The model for k-coverage, minimized node deployment cost using two types of sensors. Further, this exemplary could be hypothesized for n-sensor types.

Considering absence of analytical model (Li and Mohapatra 2005) to characterize the energy hole problem for a many-to-one sensor network, presented a mathematical model and characterized the energy hole problem. The model deployed a set of high energy assisting nodes on the top of already deployed nodes forming a relay layer to alleviate the energy hole problem. Another techniques being employed to alleviate energy hole problem in wireless sensor networks is based on immune clone selection for power control (Zhao et al. 2019).

Considering the same sensing and communication range, (Wang et al. 2008) the planned sensor deployment using grid approximation could be costly. They proposed a deployment approach applicable to various shapes considering possible obstacles but didn't talk about the network lifetime of such deployment.

A circular corona based multihop sensor field with non-uniform node distribution and continual reporting leads to unbalanced energy depletion among nodes (Wu et al. 2008). For balanced energy consumption, the number of nodes from outer to inner coronas should be increased in geometric progression except the outer most.

Another solution to handle area coverage problem (Liu et al. 2009) used intra-cluster coverage, which decided a node's probability to be cluster head based on the ratio of its the residual energy and average residual energy of all the neighbors in its cluster range.

For facilitation of focused on partial coverage, (Andersen and Tirthapura 2009) minimized the number of nodes still facilitated a higher degree of coverage. Considering it as a set-cover problem with k multiplicity to compute lower bound using the above model.

Critical-square grid coverage was introduced by (Chieh et al. 2011) while studying the computational complexity of node deployment using the least number of nodes at grid points of critical square grid cells and classified it as NP-Complete. It used binary sensing model on the sensor field split into square cells forming grid followed by node placement on the center of a grid cell.

The character of surveillance by sensor network aims to maximize the area covered with an optimum number of sensor nodes, yet minimizing redundancy. 1-coverage helps to avoid redundancy saving constrained battery energy (Rebai et al. 2015).

Now, moving towards the scene of the development of energy-efficient protocols for a heterogeneous network. SEP (Smaragdakis et al. 2004) used advanced nodes in addition to normal nodes for uniform deployment scenario. The time elapsed from initial deployment until the death of the first node (stability period) was similar as in homogeneous network. Even the first nodes to dies were normal nodes.

DEEC (Qing et al. 2006) reduced energy consumption, increased scalability and network lifetime for a heterogeneous network. It determined cluster head based on probability which is a ratio of the residual energy of each node and the average energy of nodes in the network. This ward off the necessity of each node to know the global network knowledge by estimating the ideal value of the network lifetime as a reference of energy consumption per round by a node.

S-EECP and M-EECP (Kumar 2014) maximized the lifetime of a cluster-based heterogeneous wireless sensor network. S-EECP used single hop to transmit data directly to BS through CH selected based on weighted probability from the ratio of the residual energy of each node and the average energy of the network but this consumed high amount energy from nodes far away from the BS. So, M-EECP solved this single source shortest problem using a greedy approach to find the shortest path from each CH to BS.

Algorithm 1: Node deployment for layer-1

Input : Field dimensions (anti-clockwise): [(0,0),(m,0),(m,m),(0,m)],
Top left corner of the field:(0,m), Sensing radius of nodes say 'rad'
Output: Location of the node, Type of node

Deploy first sensor at (0,m-$\frac{rad}{2}$) `/* deploying from top left corner (left-right, top-down) */`
Set edge=0 `/* flag */`
while *there exist an uncovered area* **do**
  Row-wise: Repeat till new sensor location(a,b) is not outside field
  (a,b)=(x+$\sqrt{3}$ rad, y) `/* sensors are` $\sqrt{3}$`rad distance apart row-wise */`
  if *(a,b) is outside the field but within* $\frac{rad}{2}$ `/* end of row */`
  then
    bring (a,b) on boundary i.e. (m,b)
  end
  `/* move to next column */`
  Column-wise: (a,b)=(x,y-$\frac{3\times rad}{2}$) `/* ( */`
  rows are $\frac{3\times rad}{2}$ distance apart)
  if *edge==0* **then**
    (a,b)=(0+$\frac{\sqrt{3}\times rad}{2}$,y)
    edge=1
  else
    (a,b)=(0,y)
    edge=0
  end
  if *(a,b) is outside field but within* $\frac{rad}{2}$ **then**
    bring it on boundary i.e. (a,0)
  end
end
hop_distance=$\frac{1}{3}\times m$
for *each node (a,b))* **do**
  if *(a,b) lies within hop_distance of BS* **then**
    node is super node
  else
    node is normal node
  end
end

In order to reduce energy consumption in DEEC protocol, (Singh et al. 2017; Singh and Malik 2017a) modeled a single parameter to characterize heterogeneous sensor network. This enriched and executed DEEC on the proposed model for 1, 2 and 3 levels of heterogeneity as hetDEEC-1, hetDEEC-2, and hetDEEC-3. While (Singh and Malik 2017b) works to improvise network energy for SEP protocol in heterogeneous sensor networks. Further (Singh 2019) comes up with a node deployment strategy which canvas all the target points using flexible sensing lengths in grid established wireless sensor networks. Then, (Singh 2017) implements primary and secondary parameters on a multi-level heterogeneous network to improve network lifetime further.

On the similar grounds, in order to achieve energy efficiency in resource constrained wireless sensor networks, different strategies have been adopted in order to reduce the data among communicating entities (Srivastava et al. 2019; Anuradha and Srivatsa 2019; Bhola et al. 2019; Gupta and Sharma 2019).

2.1 Literature gap

The above study leads to the identification of the following gaps in the literature:

- No consideration for the distance of a node to the BS which is an important energy consumption parameter during data communication.
- The requirement of the necessity of global knowledge can be mitigated further.
- Stability period can be extended further to provide better results in terms of blanket coverage.

3 I-DEEC

3.1 Suppositions

- Nodes under consideration are static, homogeneous in terms of capabilities and priorities but heterogeneous in terms of fixed initial battery capacity.
- The communication channel is symmetric for a given signal to noise ratio.
- Precise locations are not known among nodes, only relative locations are known based on received signal strength indicator (RSSI).
- Binary sensing model has been taken into consideration i.e. the event is sensed only if present inside the sensing range.
- The sensing range is fixed for the nodes while the transmission range is dependent on the distance of the receiver, considering each node can transmit directly to BS.
- Time taken to transfer data from nodes to the base station is known as round or delay in propagation.
- Energy consumption of node is based on the character of assignment (i.e., cluster member, cluster head or relay node) based on the distance between transmitter and receiver.
- The radio model is the same as that considered in Heinzelman et al. (2002).

3.2 Network deployment

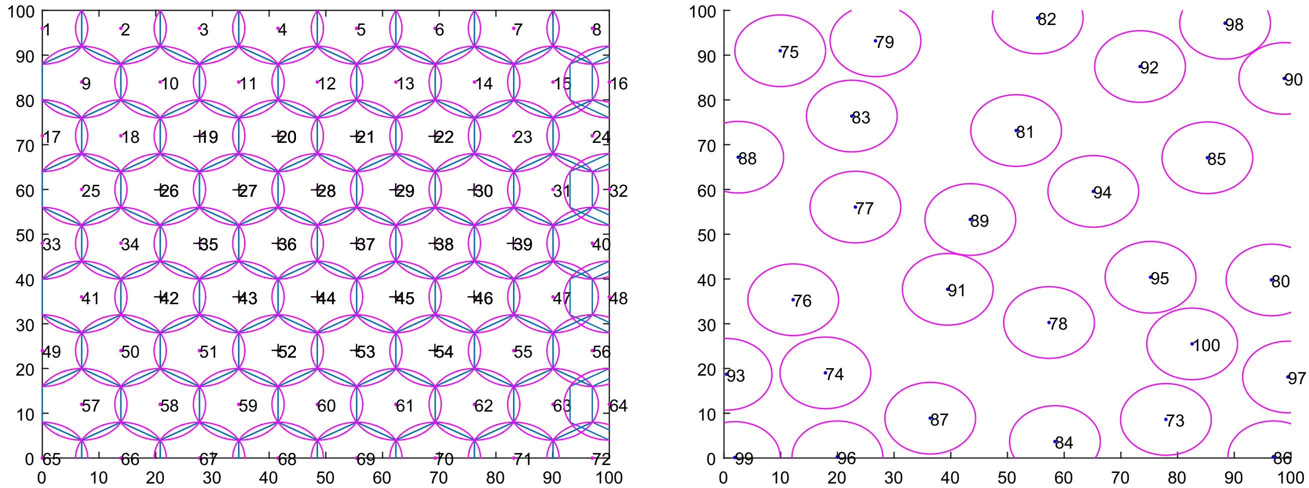
The current area of interest is a square field whose area extends to $m \times m$ meters where $m = 100$. The base station is present at the center of the field. The network consists of $n = 100$ nodes at three energy levels, i.e., normal nodes, advanced nodes and super nodes which have initial energy levels in increasing order respectively.

The network coverage model has depicted the problem of field coverage in terms of a unit disk graph, where the aim is to cover the area of interest with unit disks of certain unit size (modeled as a sensor with certain sensing range). The network nodes have been deployed in as two layers, i.e., layer 1 and layer 2 as shown in Fig. 1.

Layer 1 tessellate the plane with hexagons such that the entire area is covered. The circumcircle of these hexagons is assumed to be circular sensing range of sensors with nodes positioned at circumcenter or center of the hexagon. The energy level of nodes in this layer have been declared as normal nodes and super nodes, i.e. nodes around the base station have been initialized with a high amount of initial energy due to additional responsibility of relaying data of nodes far away from the base station.

Layer 2 deploys advanced nodes such that no advanced node lies in the sensing range of existing advanced nodes. This is so because random deployment often plots the sensors within each other's sensing range which repeatedly provides the information which is already available, covers only small section of the field, i.e., too little information is retrieved, that too in duplicate. Further, the idea behind the random deployment of layer 2 nodes is to cover a larger section of the field after the death of layer 1 nodes. Accordingly, layer 1 deployment ensures 100% area coverage i.e. 1-coverage till the death of the first node, while, layer 2 deployment ensures k-coverage still avoiding redundancy within the layer, where $k = 2$ for the current case. Further, the deployment of the above two layers has been described as under.

- Layer 1: This layer strategically deploys normal nodes and super nodes as in algorithm 1.



(a) Layer-1 strategic deployment

(b) Layer-2 random deployment

Fig. 1 Network deployment

The time complexity of the algorithm 1 is explained as under:

The *while* loop in line 3 will run $\frac{m}{\frac{3\times rad}{2}}$ times, i.e., $O(m)$ times, line 4 and 5 will run $\frac{m}{\sqrt{3}\times rad}$ times for every iteration of the *while* loop in line 3. So, the time complexity for line 3–23 will be $O(m^2)$. Now, line 26–30 will run for every node deployed in layer 1 and the number of nodes is of $O(m^2)$. Therefore, the time complexity of algorithm 1 will be $O(m^2)+O(m^2)$ which is equal to $O(m^2)$. Where m is the length of the side of the field and *rad* is the sensing radius of a node.

- Layer 2: Randomly deploys remaining nodes as advanced nodes with condition that no advanced node lies in the sensing range of another advanced node.

3.3 Energy distribution

In existing energy distribution (Smaragdakis et al. 2004; Qing et al. 2006; Singh et al. 2017) for a heterogeneous wireless sensor network, normal nodes are the first ones to die. Moreover, considering the additional obligation to relay data of far away nodes to the base station, the idea is to provide additional energy to nodes near the base station. Therefore, in layer 1, the nodes at approximately a hop distance to the base station are assigned as super nodes. Still, on simulation, we find that the normal nodes are the first ones to die.

On the other hand, network lifetime to provide blanket coverage may be defined as the time elapsed from the initial deployment till the death of first node (stability period) or till a particularly less percentage of nodes die. Accordingly, the aim is to arrange the energy distribution among the nodes such that the stability period could be increased.

Table 1 Network energy distribution

Normal node	
Energy per node:	E_o
Number of nodes:	q
Total:	$q \times E_o$
Super node	
Energy per node:	$E_o \times (1+\beta)$
Number of nodes:	s
Total:	$s \times E_o \times (1+\beta)$
Advanced node	
Energy per node:	$E_o \times (1+\alpha)$
Number of nodes:	$n-(q+s)$
Total:	$(n-(q+s)) \times E_o \times (1+\alpha)$

The current setup provides a higher amount of initial energy to normal nodes and the energy heterogeneity ratio between different types of nodes has been reduced (as compared to (Smaragdakis et al. 2004; Qing et al. 2006; Singh et al. 2017)). Detailed node and energy distribution is as under and summarised in Table 1.

For a given sensing range of nodes and size of the area of interest, say q + s nodes are utilized in deploying layer 1, which consists of normal and super nodes respectively. Then, for a total of n nodes, remaining $(n-(q+s))$ nodes are advanced nodes. While the number of super nodes is dependent on hop distance of a node to base station say s nodes, then the number of normal nodes is equal to q nodes.

Let the energy available with the normal node is E_o (Smaragdakis et al. 2004), While advanced node and super nodes are equipped with α and β times more energy than normal node respectively.

3.4 Clustering hierarchy

The necessity of global knowledge about the whole network at each node for cluster head selection using initial energy and residual energy was solved with DEEC which estimated an ideal value of network lifetime to use it as a reference at each node. This result could be further improvised by considering another important parameter i.e. distance of a node to the base station.

Residual energy is an influential parameter in cluster head selection. The node with higher residual energy must be more often selected as cluster head rather than a node with comparatively less residual energy. This is so because assignment as cluster head consumes a large amount of constrained battery power. Moreover, it is always a better option for a node to stay alive, keep sensing and forwarding information from its application domain rather than be a cluster head for few instances and die.

Likewise, distance of a node to the base station may also be used as a parameter for cluster head selection. This implies to the idea of assigning the nodes around the base station to be cluster head more often rather than the nodes far away from BS. This is so because nodes near the base station will consume less energy to transmit the data to BS, thus consuming less energy as compared to the ones who are far away. Therefore, less energy node, but close to the base station can still be a better choice as compared to high energy node, far away from the base station.

This paper uses the ratio of a node's distance from the base station to average node distance from the base station in addition to the residual energy ratio for the process of cluster head selection. Each node computes its possibility to be cluster head as the sum of two probabilities based on residual energy and distance to the base station:

$$Possibility(i) = \frac{D_{iBS}}{D_{avg}} + \frac{E_{iResi}}{E_{avg}} \tag{1}$$

$$D_{avg} = \frac{\sum_{i=1}^{alive} D_{iBS}}{alive} \tag{2}$$

$$E_{avg} = \frac{\sum_{i=1}^{alive} E_{iResi}}{alive} \tag{3}$$

where D_{iBS} implies to the distance of ith node to base station and E_{iResi} is the residual energy of ith node, D_{avg} is the average node distance to the base station, E_{avg} is the average residual energy of the network and *alive* is the number of nodes which are still providing information to the base station.

Here, the base station computes the average distance of each node to BS along with the average residual energy of the network at the time of network initialization based on RSSI from nodes. Further, each dying node is reported to the BS, so that D_{avg} and E_{avg} may be computed accordingly at BS. The D_{avg} and E_{avg} are communicated in the network during the setup phase of next round and they also act as a reference at each node, thus mitigating the requirement of global knowledge about the whole network (i.e., distance to BS and residual energy) at the node level.

Later, P_{opt}% of highest possibility nodes are selected as the cluster head for the current epoch detailed as in algorithm 2:

Algorithm 2: Cluster Head selection

Input : Possibility of each node,
p_{opt} i.e. optimal number of CHs for each round
Output: Cluster heads for each round

if r mod $(\frac{1}{p_{opt}})$==0 **then**
    form set G arranging the possibilities in descending order /* Epoch starts */
end
count=0 /* Counter for number of CHs in a round */
while $count \leq p_{opt} \times alive$ **do**
    Select the first value as CH from G
    Remove node C from set G /* Avoids repeated assignment as CH */
    count=count+1
end

The time complexity of the algorithm 2 is explained as under:

For line 2, time complexity is $O(nlogn)$ (for sorting the elements in decreasing order) and *while* loop in line 5 will run for $O(n)$ times. Therefore, the total time complexity of algorithm 2 is $O(nlogn) + O(n)$ which is equal to $O(nlogn)$, where n is the total number of nodes alive at a particular round, P_{opt} is the optimal percentage of cluster heads per round, r is the current round number, G is the set of nodes who have not been cluster head in the current epoch.

Finally, the cluster formation takes place by the association of each non-CH node to a CH node.

3.5 Data transmission

After cluster formation, data transmission takes place. This includes information sensing at the node level, followed by forwarding at associated CH, which process and further forwards towards BS. If the CH under consideration is close enough to the base station, then data is forwarded to BS, else it is further forwarded to nearest CH and the process is repeated till the information reaches the base station.

3.6 Character of utility

The quality of service provided by the protocol for blanket coverage in the heterogeneous wireless sensor network has been specified in the terms of the following parameters:

- *Percentage area covered* - This is the most critical parameter in providing blanket coverage. This attributes to the percentage of the area from which deployed nodes could collect information based on their sensing range with respect to the total area of the field under consideration. Higher the percentage of covered area, better the quality of blanket coverage.
- *Stability period* - This accounts for the amount of time elapsed from the initial network deployment until the death of the first node.
- *Network lifetime* - In the current context, network lifetime may be specified as the amount of time elapsed till the death of the first node or till the death of a comparatively lower number of nodes. The aim of such deployment is to maximize the number of nodes which can serve a given area for a specific period of time.
- *Throughput* - This implies the number of processes executed per unit time, may be expressed as the number of packets sent to the CH and Number of packets sent to the base station.
- *Total residual energy* - This points to the sum of the total remaining energy in the network regardless of the node type. The total unused energy of the network per unit time expresses the amount of energy consumed to run the available setup for a given round.

4 Simulation outcomes

The proposed protocol has been simulated mathematically in MATLAB for the values in Table 2.

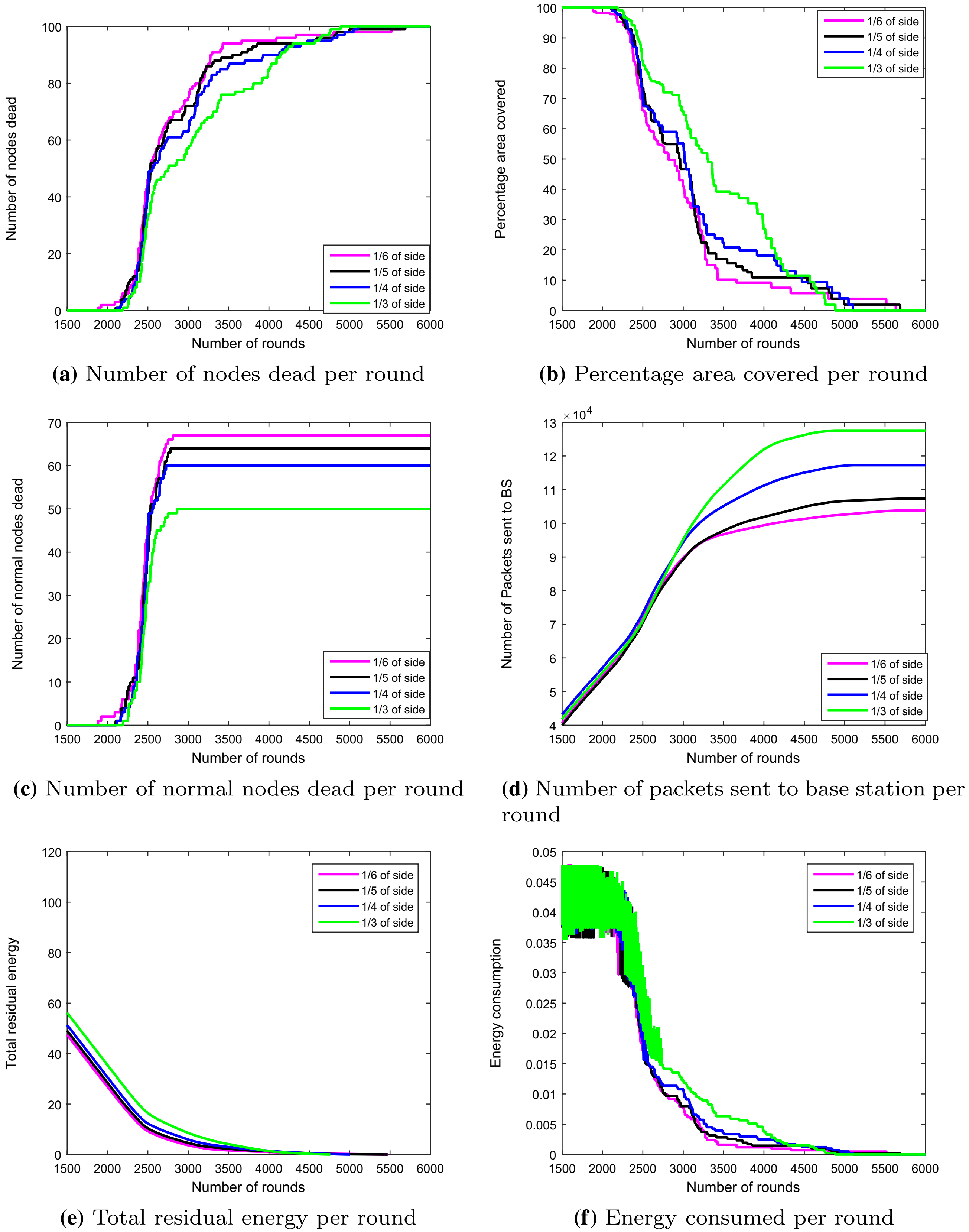
For a field size of 100×100 m, the work deploys a total of 100 nodes in two layers, where layer 1 consists of normal and super nodes and layer 2 consists of advanced nodes. The super nodes are deployed near the base station considering the higher energy requirement of nodes near the base station.

Starting with hop distance, i.e., distance from the base station within which the deployed node should be provided with additional energy as compared to a normal node. The current work uses the hop distance as the radius from the base station within the range from $\frac{1}{3}rd$ of the length of the side of the field to $\frac{1}{6}th$ of the length of the side of the field. Here, it is to be noted that the hop distance more than $\frac{1}{3}rd$ of the length of side shall increase the number of super nodes dramatically which shall increase the total energy of network as compared to others which won't be comparable to existing protocols. On the other hand, the hop distance less than $\frac{1}{6}th$ of the length of side shall reduce the number of super nodes to negligible, which leaves layer 1 nodes with normal nodes only.

Figure 2 presents the results of the comparison of hop distance for different network quality of service parameters. Increasing the hop distance increases the number of super

Table 2 Simulation parameters

Parameter	Value
Total number of nodes	100
Size of field	100×100 m
Base station location	(50, 50)
Initial energy of normal node	1 J
Additional energy with advanced node, α	0.25
Additional energy with super node, β	0.5
Transmitted packet size	4000 bits
Transmitter/receiver electronics, E_{elect}	50 nJ/bit
Transmitter amplifier energy for $d \le d_o$, E_{fs}	10 pJ/bit/m^2
Transmitter amplifier energy for $d > d_o$, E_{mp}	0.0013 pJ/bit/m^4
Data aggregation energy, E_{DA}	5 nJ/bit/signal
Supply voltage to sensor node, V_{sup}	2.7 volts
Time duration for sensing, T_{sens}	0.5 ms
Current for sensing, I_{sens}	25 mA
Sensing range for sensor	(7–8) m
Hop distance	($\frac{1}{3} - \frac{1}{6}$ of side of field)
Optimal percentage of CHs per round, p_{opt}	0.05



(a) Number of nodes dead per round

(b) Percentage area covered per round

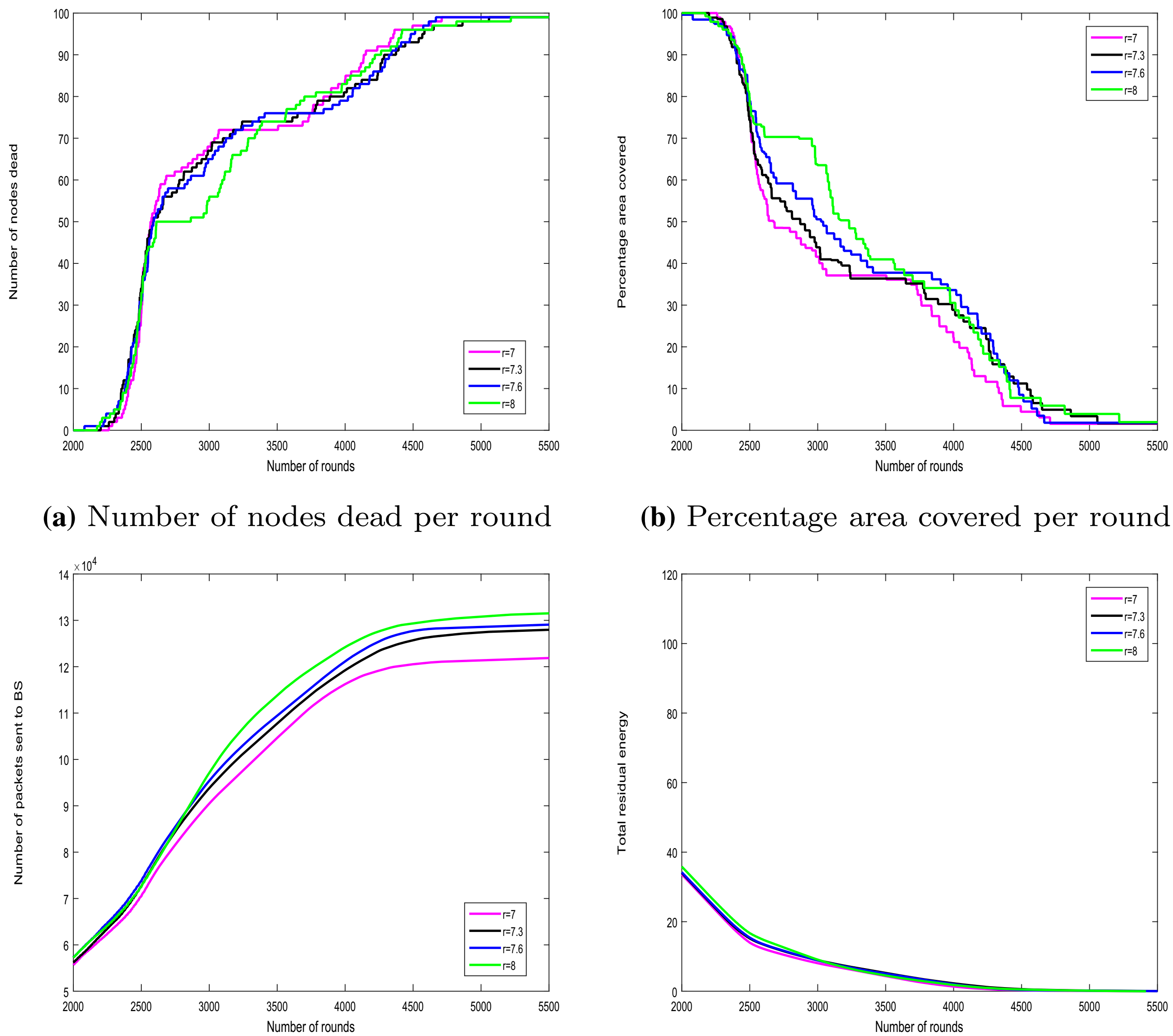
(c) Number of normal nodes dead per round

(d) Number of packets sent to base station per round

(e) Total residual energy per round

(f) Energy consumed per round

Fig. 2 Analysis on varying hop distance from base station



(a) Number of nodes dead per round **(b)** Percentage area covered per round

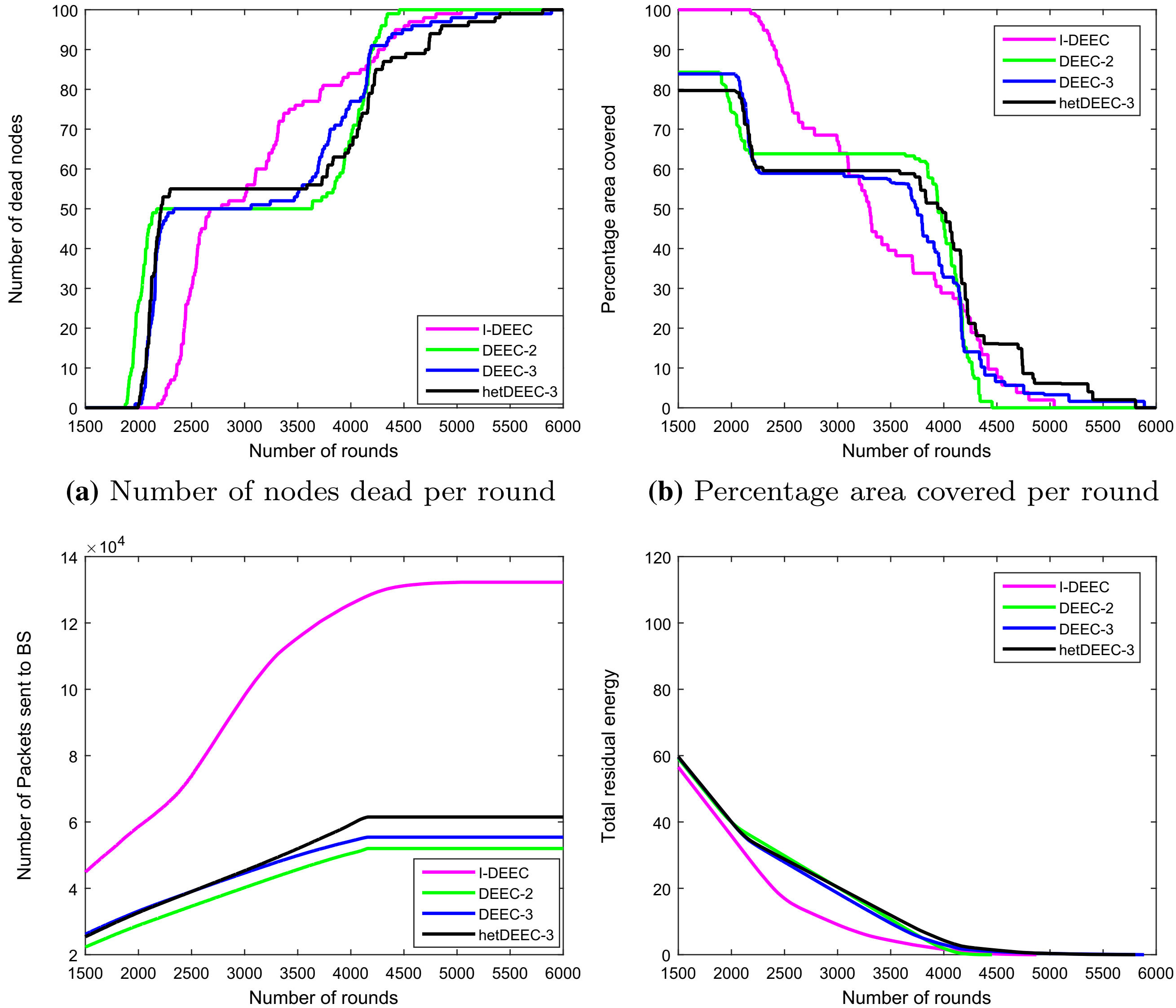
(c) Number of Packets sent to BS per round **(d)** Total residual energy per round

Fig. 3 Comparison on varying sensing radius of nodes

nodes around the base station, this allows a higher number of packets sent to the base station (Fig. 2d). For a higher amount of residual energy (Fig. 2e), the normal nodes still die almost in the same fashion, but this increases stability period (Fig. 2a) and provides a higher amount of percentage area coverage (Fig. 2b). Therefore, considering hop distance to be $\frac{1}{3}rd$ of the length of the side of the field due to the best performance among above.

Now, varying sensing radius of nodes within the range (rad = 7 to 8 m). Moreover, reducing the sensing radius beyond 7 will increase the number of nodes in layer 1 and a correspondingly negligible number of nodes in layer 2 (for the total of n = 100), which leaves the network with only two types of nodes as in layer 1. On the other hand, increasing sensing radius more than 8 will lead to not satisfying the redundancy condition in layer 2, thus not allow the deployment of all 100 nodes. Table 3 details the obtained number of layer 1 and layer 2 nodes for different sensing radii.

Figure 3 shows the behavior of network parameters for change in sensing radius of nodes. Figure 3a. illustrates results, for rad = 8 are more suitable for blanket coverage as more number of nodes are alive for a longer period of time, similar is revealed in Fig. 3b, providing a higher amount of percentage area covered. Further, the case for rad = 8 m sends the highest number of packets to the base station (Fig. 3c) for a similar amount of total unconsumed energy of the network (Fig. 3d).



(a) Number of nodes dead per round **(b)** Percentage area covered per round

(c) Number of Packets sent to BS per round **(d)** Total residual energy per round

Fig. 4 Comparison of I-DEEC with existing protocols

Table 3 Node distribution for different sensing radii of nodes

Sensing radius of nodes	Number of normal nodes	Number of advanced nodes	Number of super nodes
rad = 7	63	10	27
rad = 7.3	60	15	25
rad = 7.6	57	20	23
rad = 8.0	50	28	22

This follows the results obtained using I-DEEC as compared to existing protocols i.e. DEEC at 2 levels and 3 levels of hierarchy (Qing et al. 2006) along with hetDEEC3 (Singh et al. 2017) in Fig. 4.

Death pattern of nodes in existing three-level heterogeneous network show saturation at three levels, i.e., one before the death of normal nodes, second before the death of advanced nodes and third follows during the death of super nodes. Moreover, the length of the stability period is contributed by the death of the normal nodes. Blanket coverage requires a possible extension in the stability period and death of nodes at almost the same time instead of saturation gaps in different node types. Therefore, I-DEEC extends the stability period of the network by providing a comparatively higher amount of energy to normal nodes and reducing the ratio between the initial energy level of different types of nodes (Fig. 4a).

I-DEEC provides 100% area coverage until the death of the first node attributed by 1-coverage of layer 1 nodes. This percentage area coverage reduces with time due to the death of nodes which covered the area under their sensing range as shown in Fig. 4b.

Further, smart cluster head selection considering the ratio of the distance of the node to base station along with the residual energy of node, contributes to higher throughput in terms of number of packets sent to the base station due to more number of nodes alive per unit time as compared to existing protocols (Fig. 4c).

Figure 4d shows the rate of energy dissipation per round as the amount of energy consumed in dispensing data from nodes to the base station via one or more cluster head(s). All the network scenarios had the same amount of total energy during the phase of network initialization, thus they are comparable. Accordingly, I-DEEC is more energy efficient in terms of stability period, percentage area covered, throughput and total residual energy of the network.

5 Conclusion

Events can occur anywhere in an area of interest. Blanket coverage facilitates information from application domains where the occurrence of every single event is critical. This requires almost all nodes to keep providing information for the maximum period of time. For a heterogeneous wireless sensor network where initial energy is different for available nodes. I-DEEC strategically deploy nodes, provisions comparatively higher amount of initial energy to normal nodes and reduces the ratio between initial energy of different types of nodes. Further, it also considers the ratio of the distance of nodes to the base station along with the residual energy of the node for cluster head selection. Results from simulation experiments show that I-DEEC provides better performance in terms of stability period, lifetime, percentage area covered per unit time and throughput within the same amount of residual energy as that of compared protocols.

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