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A smart power saving protocol for IoT with wireless energy harvesting technique

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Abstract

Internet of things (IoT) is the wireless network of physical devices that are capable of sensing the environment. In order to prolong the network lifetime of the IoT nodes called sensor nodes, an effective energy consumption protocols to adapt the wireless sensor network. This paper explores in depth the energy harvesting techniques, and proposes a cluster algorithm with energy harvesting technique to improve energy and throughput of the network. The proposed algorithm implements the creation of clusters with cluster-head selection protocol and we have reduced the number of iteration required for electing the cluster head. HEED algorithm has been enhanced with an energy harvesting algorithm using wireless charging technique. Proposed algorithm is to select the appropriate channel in the multi-channel system. Simulation results shows that the proposed algorithm has better adaptability to ubiquitous environments than existing clustering algorithm in prolonging the network lifetime.

Keywords Ubiquitous network · Clustering technique · CS-HEED · Energy harvesting · Wireless power transfer · Cluster head selection · IoT · Wireless body area network

1 Introduction

Firstly, we illustrate the clustering technique for wireless sensor networks (WSNs). We clarify the challenges of applying such a technique for internet of things (IoT). And we discuss about the need of energy harvesting technique. Finally, we brief about the proposed solution and structure of this paper.

1.1 WSN clustering technique

WSNs are networks composed of wireless distributed devices which has the capability to sense the environment called as sensors [1]. These sensor nodes are deployed in remote area to analyze the environment. Sensor node has limited energy typically a battery with no energy refilling techniques. Large number of sensor nodes constitute WSNs requires extended life time to ensure long services. These nodes send valuable information to the base station (BS) [2]. In order to ensure a prolong life time of the sensor nodes, clustering techniques have been introduced. A clustering technique groups the sensor nodes into separate clusters as shown in Fig. 1. These clusters communicate through the Cluster Group Head node (CGH) [3]. CGH is the node in each cluster which gathers information from all sensor nodes from a cluster, assemble them and transmit to the next CGH or BS. Energy consumption is less for sensor node since it communicates with the CGH node in the network rather than communicating the BS. Figure 1 shows the four CGH nodes from four clusters which communicates to each other and the final CGH will communicate with BS. This approach minimizes the energy consumption but the CGH node should possess large energy residue. The routing scheme between CGH nodes can be either single hop or multi-hop which depends on various factors.

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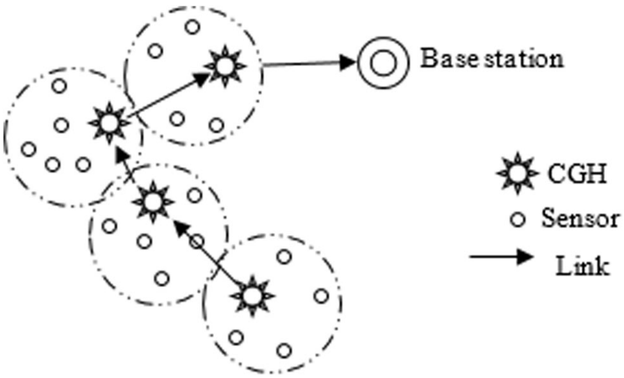


Fig. 1 SN clustering technique

1.2 Ubiquitous network

Ubiquitous network known as pervasive networking is the distribution of communications infrastructure and wireless technologies throughout the environment to enable the continuous connectivity [4]. Ubiquitous networking is the underlying combination of wired and wireless technologies that support communications among the various systems involved. The IoT, one prominent element of ubiquitous computing, involves in embedding computational capabilities into everyday objects throughout the environment and connecting to them to each other. IoT environments include automated, often industrial, facilities as well as user spaces, such as homes and workplaces. Wireless body area network (WBAN) contains sensor nodes which may embedded inside the body or may be surface mounted on the body [5]. Implanted sensor nodes require more effort to recharge or replace the battery since it is embedded inside human body. Thus, we require an energy harvesting technique to recharge these sensor nodes and an effective clustering technique to lower the power usage.

1.3 Wireless power transmission

We used wireless power transmission (WPT) technique to recharge the CGH nodes in the network. The nodes that are capable of transmitting power in the network is known as power transmission node (PTN) [6]. These nodes are scattered in the network to support the CGH node and avoid them to die sooner in the network. WPT is useful to power the devices where interconnecting the wires are inconvenient or not possible. Since sensor nodes are embedded inside the human body in WBAN, the wireless power transmission plays vital role to recharge the sensor node easily. Several intrusion attacks in WBAN focus on power depleting technique such as sleep depreciation attack which doesn't allow sensor nodes to fall to sleep state.

This paper proposes a clustering algorithm over hybrid energy efficient distributed clustering (HEED) [7] and energy harvesting technique using wireless power transmission. HEED is designed to select the cluster head in a field according to the amount of energy that is distributed in relation with the Neighbour node. This paper proposes a technique to identify the CGH node in the cluster considering wireless energy transmission in IoT [8] and proposes energy harvesting technique to deploy PTN in the network. Finally, a deep performance analysis of the proposed model compared with HEED technique.

2 Related works

Various previous works focus on selecting cluster head, lowering the energy consumption and enhancing energy harvesting techniques. Cluster head node are randomly selected in low-energy adaptive clustering hierarchy (LEACH) [9]. Randomly selected CGH node will inform all the sensor node in the network. Sensor node decide to join the CGH for data transmission. This random selection scheme often use node that has low energy residual. This result in the wastage of energy during CGH election process. Hybrid energy-efficient distributed (HEED) [10] uses high residual node as cluster head through iteration of process. In this iteration for electing cluster head, CGH nodes are classified as 'elected' and 'tentative' nodes. Tentative nodes can be selected randomly. The probability of becoming CGH for tentative node increases during iteration process. When a sensor node gains the probability value to the threshold value 1, the node will elect itself as CGH. In each iteration, the probability doubles the value and becomes the final node. The nodes which are not covered by any CGH node will be elected automatically. This scheme guarantees that the probability of selecting two sensor nodes as CGH, within same communication area is rare. Thus, the CGH will be evenly distributed over the network. The major disadvantage over HEED is that it consumes more energy during iteration process. In this paper, we propose a technique to lower the iteration process.

Most of the energy efficient protocol designed for heterogeneous networks [11] are based on clustering techniques which is effective for energy saving in WSNs. Due radio communication characteristics, the network cannot evolve equally for each node in expanding energy, with random events such as short-term link failure and morphological characteristics of the field. According to initial energy, Smaragdakis et al. proposed a SEP scheme for a two-level heterogeneous WSN [12]. Stability period is enhanced in this approach, which was defined as time interval before the death of first sensor node. This approach focuses only on two types of nodes, so it is difficult for widely used multi-level heterogeneous wireless sensor nodes. Distributed.

A distributed energy efficient clustering algorithm (DEEC) [13] is proposed by Zhu et al., for multi-level and two-level energy heterogeneous WSNs. In this technique, the cluster heads were selected using the probability derived from the ratio between the residual energy of each node and the average energy of the network. These nodes with high initial and residual energy had more chances of the becoming cluster heads compared to nodes with low energy. Each node needed to possess global knowledge of the network along with its initial and residual energy in the DEEC protocol. This increases the computational overhead over the cluster head in the network. Centralized clustering algorithm (CSS) was proposed based on PEGASIS [14]. Base station lies in the centre of the network and other sensor node align themselves with level number based on the signal strength received from BS. Hierarchical structure is created based on the level and cluster head is elected one for each level. This cluster head is responsible for transferring data to the base station from each levels. This approach had a serious drawback since the nodes near BS will die soon.

Most existing studies are for traditional WSNs and limited work was shown on highly diverse IoT systems. Very few clustering algorithms focus on multi communication interfaces in ubiquitous network. We have proposed an energy efficient technique with a ranking system in communication interface selection.

3 Motivation

Based on existing works over clustering techniques and energy harvesting techniques, we can see that three challenges need to be addressed in ubiquitous network. One, iteration procedure consumes more energy to elect the sensor node as CGH. The iteration count should be reduced. Two, a multiple communication interface should be considered to adopt with the IoT system and make it consume less energy during transmission. Third, an effective energy harvesting technique to improve node lifetime in the network.

4 Context aware smart HEED formation (CS-HEED)

4.1 Cluster group head selection

Let us consider a probabilistic deployment of sensor node in WSN with total of N nodes, denoted by S_1, S_2, …, S_N with one sink node at the edge of the square area. The position of each sensor node will not change and have unique identity.

$N \in [S_1, S_2, \ldots, S_N]$

The sensor node has the ability to adjust the transmission power freely. The initial energy of the sensor node is denoted by E_{Initial} which lies between the interval, such as [E_{MIN}, E_{MAX}] in which E_{MIN} is the minimum and E_{MAX} is the maximum energy.

$$E_{INITIAL} \geq E_{MIN} \tag{1}$$

$$E_{INITIAL} \geq E_{MAX} \tag{2}$$

$$E_{INITIAL} = \delta E_{MIN}, \quad \text{where } \delta \geq 1 \tag{3}$$

Therefore, the total energy of the WSN can be determined as E_{TOTAL}.

$$E_{TOTAL} = \sum\nolimits_{I=1}^{N} \delta E_{MIN} \tag{4}$$

Threshold function depends on the application of the heterogeneous network with different energy models [15]. CGH is selected based on the availability of energy resource above the threshold value and availability of the node to participate in the network. If the node has not been CGH for the last 1/τ rounds, the threshold value will be a probabilistic random number.

$$\begin{aligned} T_{(i)} = {} & \frac{\tau}{1 - \tau_{opt}\left(C_r {}^{1}\!/_{\tau}\right)} \\ & \times \left[\frac{E_R(i)}{E_{INITIAL}(i)} + \left(\eta div \frac{1}{\tau}\right)\left(1 - \frac{E_R(i)}{E_{INITIAL}(i)}\right)\right], \\ & \text{if } i \in {}'S_{CGH} \end{aligned} \tag{5}$$

where C_{r} denotes the total number of current round and ${}'S_{CGH}$ denotes the set of nodes that are not being selected for CGH in recent (C_r 1/τ) rounds. To improve the coverage ratio, the probability value for selecting CGH node is conducted randomly to ensure that all nodes with threshold values participate as CGH. For a ubiquitous network, the threshold function should be improved to be adaptive to the nodes with different initial energy.

4.2 Energy harvesting technique

In ubiquitous network, cluster of nodes form groups with CGH as a relay node. CGH node helps the network node to shorten their transmission distance to save energy consumption. When a node satisfies threshold energy with Eq. (5), depending upon the energy of the node, CGH node is selected. To avoid CGH run out of power, a new round begin and a new cluster structure should be built in the network. In ubiquitous network, the initial energy of each node is not uniform, and CGH selection should consider the initial energy and the energy harvesting possibility.

CGH should lie within the range of wireless charging area to charge up the node when it drains up below threshold value ($T_{(i)}$).

Various technique is used in wireless charging technique (WCT) depending upon the range between the transmitter and receiver, amount of power transferred and operating frequency. Far field (FF) [16] and Near field (NF) [17] are the two types of wireless charging technique with the differentiation stated in Table 1.

FF is based on the concept of electromagnetic radiation such as microwave and laser according to the operating frequency. NF can be categorized as magnetic induction and electric induction. Energy transfer in magnetic induction depends on the mutual coupling between the coils which is known as inductive power transfer [18]. In electric induction, energy is transferred through the electric field between the plates of the capacitor, known as capacitive power transfer.

The power transfer efficiency is deduced as

$$P_{transfer} = \frac{\omega^2 M^2 R_1}{(\omega^2 M^2)(R_1 + R_{ac}) + (R_s + R_{1ac})(R_1 + R_{2ac})^2} \tag{6}$$

where M is the mutual coupling, R_{1ac} and R_{2ac} are the series resistance of the primary and secondary coil, R_s and R_1 are the load and source residence respectively and ω is the resonance frequency.

4.3 Energy model

A radio energy model for radio energy dissipation was proposed by Heinzelman [9]. Transmitter dissipated energy to run the radio electronics and the power amplifier, and the receiver dissipated energy to run the radio electronics

$$E_{Transmitter} = \begin{cases} \beta M_{fs} D^2 + \beta E_{Elec}, & D < D_0 \\ \beta M_{mp} D^4 + \beta E_{Elec}, & D \geq D_0 \end{cases} \tag{7}$$

$$E_{Rx(\beta,d)} = \beta E_{Elec} \tag{8}$$

where $E_{Transmitter}$ denotes the amount of energy to transmit β bit message over distance D, E_{Rx} denotes the amount of energy to receive the message, M_{fs} is the free space model of transmitter amplifier, and M_{mp} is the multipath model of the transmitter amplifier. E_{Elec} is the electrical energy depends on factors such as the digital coding, modulation, filtering, and spreading of the signal.

Table 1 Difference between far field and near field in WCT

WCT	FF	NF
Phenomenon	Coupled mode theory	Induction theory
Range	Long	Short
Frequency	Mega Hertz	Kilo Hertz
Efficiency	Low	High

From Eqs. (6) and (7), we can identify that the power transmitted per unit time from WCT should be equal of higher than the energy consumed for transmitter if there is a continuous transfer of data. Power reserving capacity should be high so that the random selection of CGH will be reduced. We do not consider the energy consumption due to the data aggregation for CGH node. The total energy consumption of the cluster can be determined as follows.

$$E_{Cluster} = E_{CGH} + E_{BS} + E_{receive} \tag{9}$$

where E_{CGH} denotes the energy consumption for the data transmission by all nodes to the CGH, E_{BS} denotes the energy consumed during the data transfer CGH to the base station and $E_{receive}$ refers to the energy consumed by CGH while receiving data.

Using first order radio model, E_{CGH} is given by:

$$E_{CGH} = \int_0^r \beta\pi\vartheta\left(E_{Elec} r^2 + \frac{1}{2}(M_{fs} r^4)\right) \tag{10}$$

where r denotes radius of the CGH and ϑ is the node density range. Sensor nodes in WBAN have limited power capacity and requires to lower the energy consumption mechanism. A directional antenna model can improve the multiplexing rate of the network spatial coverage, increase the coverage area, and cost less energy consumption, etc. [19, 20]. Omnidirectional antenna results in the decrease in efficiency over the transmission period. Using Eq. (7) the E_{BS} can be derived as

$$E_{BS} = \beta E_{Elec} + \beta M_{mp} D^4 \tag{11}$$

We consider that the CGH communicates with other node using directional mode in which θ represents the conversion factor, then Eq. (11) becomes

$$E_{BS} = \beta E_{Elec} + \theta\beta M_{mp} D^4 \tag{12}$$

Applying energy consumption Eq. (7) for the consumption of energy due to receiving messages from its member nodes is equal to:

$$E_{receive} = \beta E_{Elec}(\pi r^2 \vartheta - 1) \tag{13}$$

Applying Eq. (10), (12) and (13) in the Eq. (9), the average energy consumed by each node in a network is derived as

$$E_{Cluster} = \left(\int_0^r \beta\pi\vartheta\left(E_{Elec} r^2 + \frac{1}{2}(M_{fs} r^4)\right) + \right) + \left(\beta E_{Elec} + \theta\beta M_{mp} D^4\right) + \beta E_{Elec}(\pi r^2 \vartheta - 1) \tag{14}$$

$$E_{Cluster} = \frac{\beta E_{Elec}(\pi r^2\vartheta - 1) + \beta E_{Elec} + \theta\beta M_{mp}D^4 + \beta\pi\vartheta\left(E_{Elec}r^2 + \frac{1}{2}\left(M_{fs}r^4\right)\right)}{\pi r^2\vartheta} \tag{15}$$

According to [21], we can get the optimal cluster number C_N where N is the sensor nodes that are distributed randomly in M × M sensor field as follows:

$$C_N = \sqrt{\frac{N}{2\pi}} \times \sqrt{\frac{M_{fs}}{M_{mp}}} \times \frac{M}{D^2} \tag{16}$$

Thus the overall estimated value for the entire network lifetime is:

$$RT = \frac{\mathrm{E}_{TOTAL}}{C_N \, * \, E_{Cluster}} \tag{17}$$

Assuming that energy of each node is consumed uniformly in every round, then the average energy can be estimated as

$$E_{Average} = \frac{1}{N}E_{TOTAL}(1 - rt/RT) \tag{18}$$

Equation (18) shows the average energy consumed by each node in the network. So, it is necessary to maintain the energy of the network through energy harvesting technique to avoid CGH to run out of energy.

4.4 Data transmission and power transfer

From Eqs. (6) and (18), the power transferred thorough wireless charging mode should provide equals or more than the average power required for the cluster.

$$P_{transfer} \geq E_{Average} \tag{19}$$

As discussed in Eq. (6), the data transmission consumes power with direct propositional to the distance. CGH should be chosen close to the transmission node and the power node should be close to the CGH. When CGH transmit the data to the base station from the sender node, the threshold value from Eq. (5) will be evaluated. Wireless power transfer from the PTN starts when the CGH power drop from the threshold base line. Due to the mobile nature of the node, the distance between the CGH and PTN should be maintained within the power transfer range. If the distance is larger, then CGH selection technique is evaluated to identify the next CGH node.

5 Energy harvesting CS-HEED algorithm

A node in the network has different time periods which is divided into a self-organizing and data manipulating stages. Self-organizing refers to the time taken to involve in the CGH selection process and sleep duration analysis when it is in idle state. Data manipulation includes the sending or receiving of data packets from CGH node and to act as relay node when it is selected as CGH. We have discussed about various factors to determine the CGH node. But each node location in the network will also contribute more on the efficiency. Many PTN can be identified in the network and the selection process for CGH may be confusing at the stage. Location of CGH should be considered in the selection process of the CGH node.

The three-main objective of context aware—WT are to (1) reduce the iteration for electing the CGH node (2) reduce power consumption for ubiquitous system (3) improve node lifetime using wireless power transfer. In this paper, context aware—WT focus more on reduction of power consumption to prolong the lifetime of the sensor node. Following section elaborates the objectives and shows how the proposed model fulfills it.

5.1 Improved iteration for CGH election

The initial probability that a cluster node elects as CGH is

$$P_{CGH} = C_{Prob} \times \frac{E_{residual}}{E_{max}} \tag{20}$$

$\mathrm{C_{Prob}}$ denotes the initial CGH probability which is 5% in HEED algorithm. $\mathrm{E_{max}}$ is the initial energy and $\mathrm{E_{residual}}$ is the residual energy of the sensor node. If a sensor node is not covered by any CGHs, it will elect itself as a tentative CGH. A random generated number is smaller than the value of PCGH. After each iteration, PCGH is increased twice with the maximum value is 1. Once $\mathrm{P_{CGH}}$ reaches 1, a tentative node will declare itself as a final CGH. If a sensor is not covered by any final CGHs, it will declare itself as a final CGH when $\mathrm{P_{CGH}} = 1$. A node will terminate the iteration process when its $\mathrm{P_{CGH}} = 1$. Since $\mathrm{P_{CGH}}$ starts from 5%, a high energy sensor still needs at least 6 iterations to have a chance to declare itself as a final CGH. When residual energy of the node decreases, it needs more iterations to terminate the CGH election process.

We have proposed:

Considering local density in HEED algorithm, Eq. (20) becomes

$$P_{CGH} = C_{Prob} \times \frac{E_{residual}}{E_{max}} \times min\left(\frac{N_d}{D_{avg}}, 1\right) \tag{21}$$

where $\mathrm{N_d}$ is the degree of the node and $\mathrm{D_{avg}}$ is the average density of the network.

$$D_{avg} = \pi R^2 \times \frac{Num_{sensors}}{Area} \tag{22}$$

NumSensors is the total number of sensor nodes in the network, R is the default communication range of the sensors and Area represents the area of the sensing field.

We consider the threshold factor in Eq. (5) to determine the CGH node, so Eq. (21) becomes,

$$P_{CGH} = C_{Prob} \times \frac{E_{residual}}{E_{\max}} \times min\left(\frac{N_d}{D_{avg}}, 1\right) \times T_{(i)} \tag{23}$$

We proposed to keep the CGH node nearby the PTN node, the probability to elect CGH also depends on the nodes that falls within the power transmission range. Priority of electing CGH is higher for the nodes that are in the power transmission range. Equation (21) becomes

$$P_{range} = \begin{cases} \frac{D_{node}}{PEN_{range}} & if \quad D_{node} \le PEN_{range} \\ 1 & if \quad D_{node} = 0 \end{cases} \tag{24}$$

$$P_{CGH} = C_{Prob} \times \frac{E_{residual}}{E_{\max}} \times min\left(\frac{N_d}{D_{avg}}, 1\right) \times T_{(i)} \times P_{range} \tag{25}$$

To reduce the number of iteration, we separate the Eq. (25) into five parts:

1. $C1 = C_{Prob}$
2. $C2 = \frac{E_{residual}}{E_{\max}}$
3. $\mathrm{C4} = T_{(i)}$
4. $\mathrm{C5} = P_{\mathrm{range}}$

C_{Prob} is set to optimal CGH ration to 5% in HEED algorithm. We have considered C4 and C5 to also determine P_{CGH}. After each iteration, the value of C2 and C3 are doubled in HEED. CGH node will not perform in the election when C2 or C3 reaches to 1. By separating the probability, we aim to decrease the number of iteration to elect CGH node in the network. Table 2 shows the proposed condition in which a CGH node remains as CGH and elects itself depending upon the given condition. C4 is the mandatory condition in which CGH should have higher than threshold value. So we consider the CGH status to be 'Not Elected' if the C4 value is 0.

Table 2 CGH self-election table

C1	C2	C3	C4	C5	CGH status
1	1	1	1	1	Elected
0	1	1	1	1	Elected
1	0	1	1	1	Elected
1	1	0	1	1	Elected
1	1	1	1	0	Tentative
0	0	1	1	1	Tentative
1	0	0	1	1	Not Elected
1	1	0	1	0	Elected
0	0	0	1	1	Elected
1	0	0	1	0	Not Elected
0	0	1	1	0	Not Elected
0	0	0	1	0	Tentative

If all conditions are true, the sensor node will elect itself to be a CGH node directly without executing the iteration of election process. In proposed model, each sensor node has the same probability to become tentative status. C1 and C4 remains same for each iteration whereas in HEED, this value doubles to make many tentative nodes. Tentative nodes will not be elected when it discovers a lower cost CGH in its communication range. The number of nodes with elected state participate in the polling and C5 plays major role in the election. Node with C5 higher value is considered for CGH since it gets the power transmitted during data transmission process. So the election for CGH is straight forward which is directly proportional to the C5 value. If a node with higher degree than the average, it is always elected in the high-density area are allowed to drain off the power fully. In proposed technique, we have considered the node which is very near to the PTN to recharge the CGH when the data transmission occurs.

5.2 Reduce power consumption for ubiquitous system

Many communication interfaces are available in the ubiquitous network with IoT devices, includes Bluetooth, Wifi, LTE, Zigbee etc. The mentioned communication interfaces have their own characteristics such as frequency, energy consumption, transmission range and data rate. These characteristics affects the network relay, throughput, lifetime and throughput. Table 3 shows the list of some popular communication technologies. LTE and Wifi are used for long range and energy consumable techniques whereas Zigbee and Bluetooth are used for shorter range. Compared to all, Zigbee has low energy consumption that ensure working of nodes for years without recharging.

Multiple communication techniques are available for the sensor node to communicate with the CGH node. Selecting the appropriate communication technique plays a major role in reducing power consumption while transferring data. Normally sensor nodes choose the suitable communication interfaces according to the data transmission requirements. Proposed technique will select only one communication interface and one CGH for transmitting the data to base station. The communication interface is selected based on the availability of the interfaces. Today sensor nodes in IoT has the capability to switch over interfaces. Existing works lacks the flexibility and ignores the diversity of sensor nodes.

In this paper, we assume that all sensor nodes are capable of multi-in multi-out interfaces (MIMO). Proposed

Table 3 Different communication interfaces

Communication technique	Data rate	Transmission range	Energy consumption
ZigBee	250 kpbs	10–100 m	Low years
Bluetooth	1 Mbps	10 m	Low days
LTE	10 Mbps	< 15 km	23 dBm
Wifi	54 Mbps	30 m	15–25 dBm

model consider volume of traffic to determine which communication interface should be used. We consider three types of data packets to be transmitted. Heavy traffic is termed for the data packets with high volume of traffic such as video streaming, medium traffic is for data packets with medium sized traffic such as big files and lower traffic for data packets with very low volume of data packets such as temperature information updates from sensor nodes.

Proposed model will have rank parameter to determine the communication technique. The proposed technique describes the priority of each communication interfaces. Lower traffic will use all transmission interfaces for data transfer. If medium or higher traffic is used, we consider the following ranking technique to determine the communication interface.

$$Rank_i = \frac{DR_{NAI}}{(DE_{NAI})^2} \tag{26}$$

$\mathrm{DR}_{\mathrm{NAI}}$ denotes the data rate requirement for ith network access interface (NAI) and DENAI is the energy consumption for ith NAI. If transmitting low traffic data, all transmission techniques are available. If medium or high-volume data is transferred, only interface with are allowed.

Proposed algorithm maintains Table 4 to determine which communication interface is to be selected. Energy consumption, data rate and transmission range are used as parameter to select the interface. These values are derived from the overall ratio of their high-end values. $\mathrm{Rank}_{\mathrm{i}}$ will be identified for high and medium traffic and consume Table 3 to identify the communication interface. If rank fall over many communication interface value, the selection process will be based on the low consumption value. By using this technique, we have created a framework to effectively identify the communication interface to reduce energy consumption during data transmission.

5.3 Improve node lifetime using wireless power transfer

Equation (18) shows the average energy consumed by each node in the network in which it mainly depends on the estimated value of the node life time (RT). It is necessary to maintain the threshold value of the CGH node to avoid the draining out of power. PTN nodes are distributed randomly in the network to boost the energy in the network. It is necessary to consider the distribution of PTN node in such a way that all CGH nodes receives the energy. Consider PTN nodes are mobile in nature that can travel to the CGH node to supply power. This approach is used by [22] technique where drones are used to power the CGH node. But it will not work out if the number of CGH node is larger in the network. We already proposed to minimize the iteration of CGH, which will minimize the CGH node change in the network. In Eq. (6), we considered the power transmitted to select the CGH node. SO, while electing the CGH node, the node near the range of PTN will be elected automatically. Some nodes that are not covered within PTN range will be selected with it satisfies other parameter in Eq. (25). These nodes do not get power transmitted from other PTN. We propose to have partially movable PTN that can recharge the CGH node in the network which is not in the range. This will avoid the energy consumption required for PTN to navigate to the CGH node.

6 Performance analysis

The proposed model will be evaluated in ns2 simulation [23–26]. In this section, the experimental analysis is presented. The performance of the energy harvesting technique is related to the parameter settings in the simulation. If broadcast packet all has low traffic, the high and medium traffic broadcast will significantly undermine the

Table 4 Normalized value for communication interfaces

Communication means	Energy consumption	Data rate	Transmission range	Ranki
ZigBee	0.3	0.5	0.4	0–0.3
Bluetooth	0.8	0.3	0.3	0.2–0.25
LTE	0.6	0.8	0.7	0.3–1
Wifi	0.65	0.5	0.4	0.6–1

performance. Also, node density will affect the impact of the broadcast. We will compare our result with HEED. 450 nodes are deployed in a (0,0) → (200,200) field with base station at (50,100).

In our simulation, we assume four communication interfaces are available as shown in Table 3. We consider using the network access interfaces (NAI) instead of direct usage of the interface. We considered low, medium and high traffic volume to mention the interface in the simulation. The main reason for this temptation is to make the algorithm scalable for new communication interface. Table 4 will be used to identify the grade for the interface for new technologies.

6.1 Energy consumption

Figure 2 shows the relationship between the number of cluster heads and total energy consumption in each round. From the experimental results, we can observe that the CGH node starts with high energy and drops to an average level in each iteration. The increase in the energy is due to the deployment of PTN node in the network to charge the energy when the CGH drops below threshold level. A lower surge in the energy consumption is due to the missing of PTN near the CGH node to transfer the power. These nodes are used up to the threshold level and iteration for electing CGH is executed to determine the next CGH node.

6.2 Active nodes

A sensor node is considered as active if the residual energy is not equal to zero and it can able to communicate with the other nodes in the network. Active nodes can die quickly due to improper balancing technique. Sometimes CGH node dies and the sensor nodes are not able to find a CGH node in that range. HEED algorithm lacks in the consumption of energy in iteration process and dies soon. Figure 3 shows the comparative analysis of active nodes in the network. Proposed CS-HEED and EH-CS-HEED are plotted as a comparative result with HEED. It shows that the proposed CS-HEED consumes less energy compared to HEED and has more active nodes in the network. EH-CS-HEED perform well depends on placement of PTN in the network.

6.3 Nodes distribution

Figure 4 a show the distribution of sensor node in the network using HEED and figure b using CS-HEED techniques. HEED performs more iteration compared to CS-HEED to achieve this segregation in the network. CGH nodes are elected with the equation for the proposed model to minimize the energy consumption. Next section shows the iteration performed to achieve this distribution of sensor node.

6.4 Iterations to elect CGH

Reducing the number of iteration in the network can reduce (1) the number of broadcast packets and (2) the clustering delay. The comparison of iteration between HEED and EH-CS-HEED is shown in Fig. 4a, b. By separating the P_{CGH} into five different parts, the number of iteration has significantly reduced in proposed EH-CS-HEED network. At the end, in HEED, the number of iteration suddenly drops to zero because there is no sensor node is alive in the network. When the battery of the sensor node is high, it requires 6–15 iterations for HEED to elect the CGH. When the battery is low, it takes about 20 iterations to identify the CGH. The iteration has increased significantly in proposed EH-CS-HEED since the energy harvesting PTN lies next to the CGH node as shown in Fig. 5.

Fig. 2 Number of CGH versus energy consumption

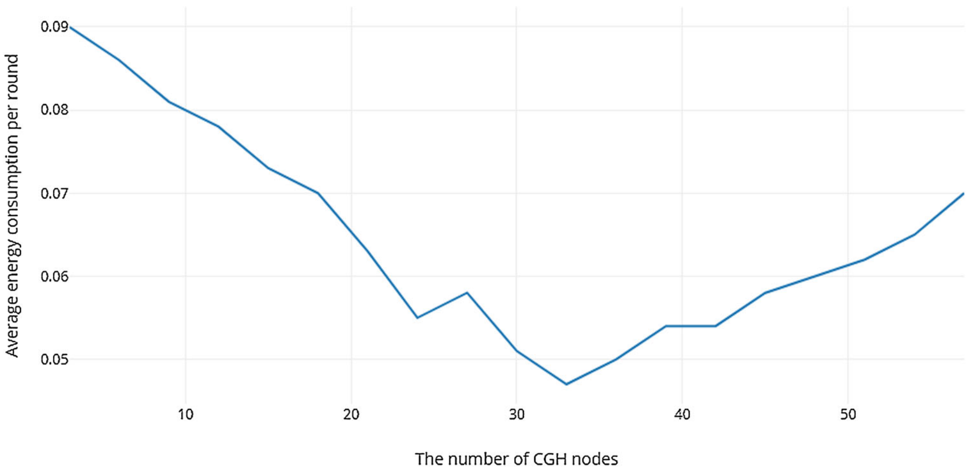


Fig. 3 Number of active nodes over time

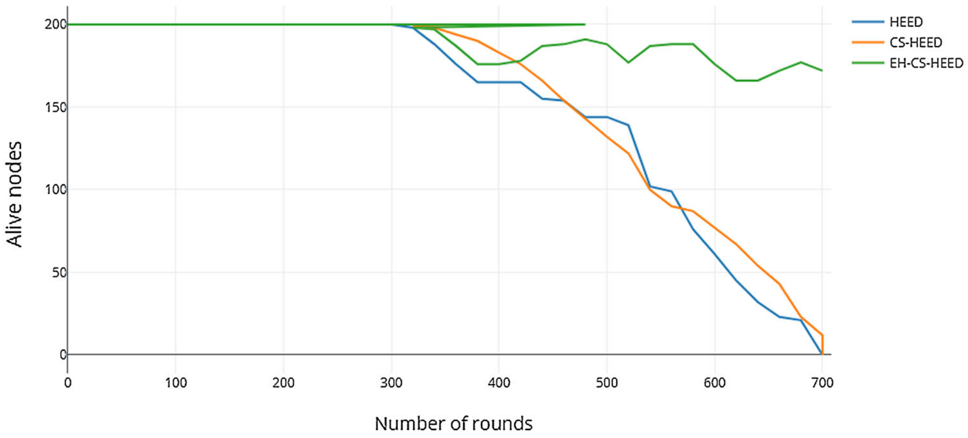


Fig. 4 **a** Sensor distribution after 450 rounds in HEED, **b** sensor distribution after 450 rounds in EH-CS-HEED

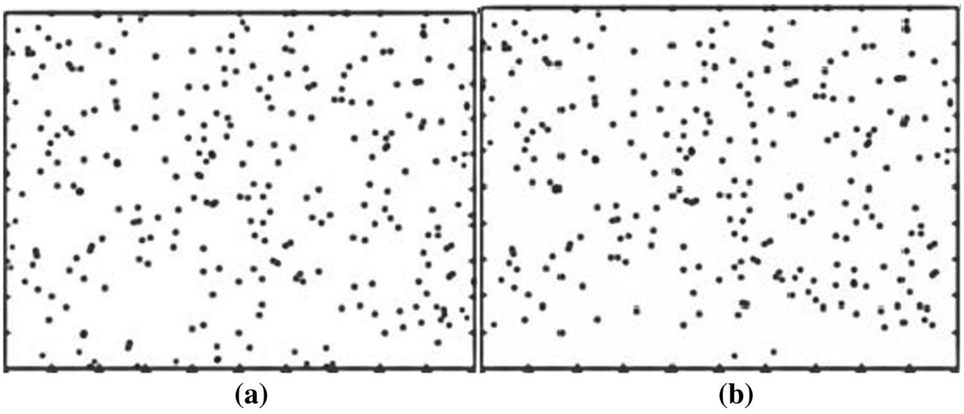
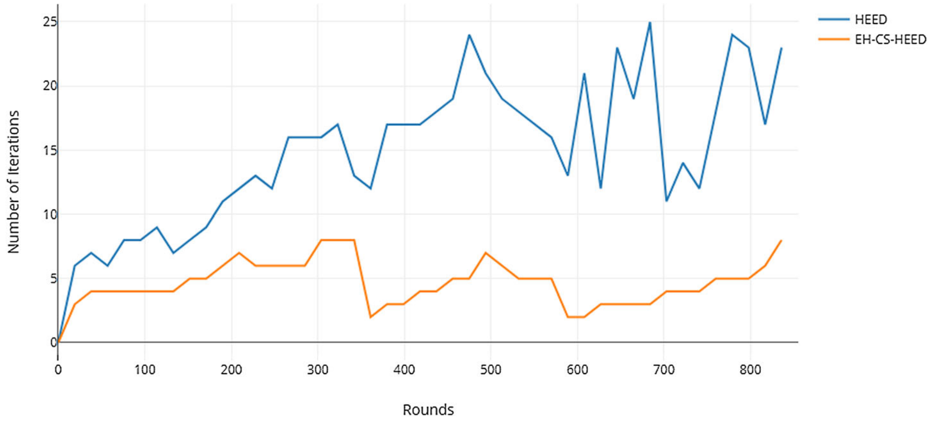

(a) (b)

Fig. 5 Number of iteration versus rounds



In Fig. 6, HEED started to lose coverage around 230 rounds but the sensor node started to die from round 150–230 but the network coverage is not affected. But in a long run, proposed EH-CS-HEED can provide better coverage than HEED.

The stabilization period is very short in HEED and thus the sensor node dies in a fixed rate. Our algorithm without energy harvesting improves the lifetime of sensor nodes by 18.23% compared to HEED. If the energy harvesting technique is considered, almost 76.34% improvement can be seen compared to HEED. Figure 7 shows the total data packets consumed by BS in each round. The proposed technique sends more data compared to HEED which improves quality of services.

Fig. 6 Number of alive nodes vs rounds

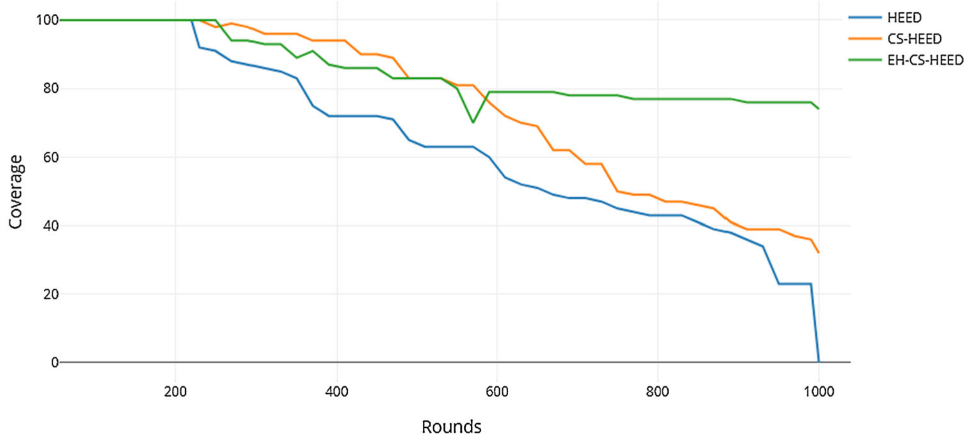
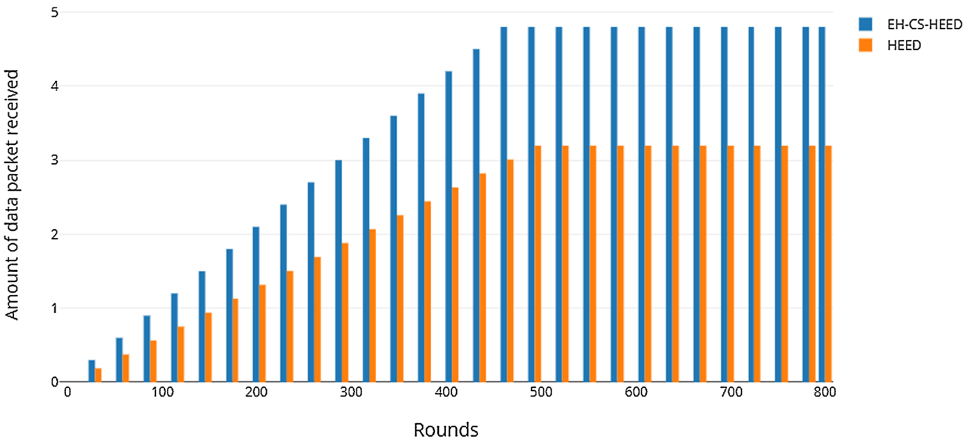


Fig. 7 Number of messages received by base station over time



7 Conclusion and future work

HEED clustering technique is enhanced by separating the iteration parameters and adding energy harvesting techniques. Clustering technique normally overlook the importance of network coverage when evaluating the performance, firstly we have proposed a method to minimize the iteration process. This effectively lowers the energy consumed during the iteration process to elect CGH node. We have proposed Context-Aware Smart—HEED algorithm to realize the energy consumption and to reduce the iteration process. We have considered the wireless power transmission technique to induce energy in the network. CGH node receives power from the PTN and avoids the chance of running out of energy. Proposed Energy Harvesting Context-Aware—HEED implements the wireless charging technique to recharge the sensor nodes. This technique is helpful for sensor node in WBAN, since the nodes are embedded inside human body [27]. Multiple communication interfaces are considered in this paper to support IoT system and to enhance the power consumption during the data transmission. The sensor nodes deployed in IoT systems are capable of having multiple communication interfaces and we have considered this paper to support for new communication interface. Our proposed algorithm identifies the correct communication interface to communicate with the CGH node or to BS. The experimental results have shown that EH-CS-HEED can better maintain the number of alive nodes and the network coverage compared with HEED. There are several perspectives that our proposed algorithm can be further advanced to support ubiquitous network. IoT devices in the network are assumed to have communication interfaces with known range of transmission. There is a possibility that high range transmission devices can be expected in future that consumes less energy. User utility has the highest priority when selecting CGHs and communication interfaces. However, in real systems, energy consumption and user utility should be balanced well. In some specific circumstance, user utility may be sacrificed to gain more energy efficiency.

References

1. Hosni, I., Hamdi, N.: Distributed cooperative spectrum sensing with wireless sensor network cluster architecture for smart grid communications. Int. J. Sens. Netw. (IJSNET) **24**(2), 118–124 (2017)
2. Rani, S., Talwar, R., Malhotra, J., Ahmed, S.H., Sarkar, M., Song, H.: A novel scheme for an energy efficient internet of things based on wireless sensor networks. Sensors **15**, 28603–28626 (2015)
3. Mishra, B.K., Nayak, N.R., Rath, A.K.: Assessment of basic clustering techniques using teaching-learning-based optimisation. Int. J. Knowl. Eng. Soft Data Paradig. **5**(2), 106–122 (2016)
4. Talpur, M.S.H., Bhuiyan, M.Z.A., Wang, G.: Shared-node IoT network architecture with ubiquitous homomorphic encryption for healthcare monitoring. Int. J. Embed. Syst. **7**(1), 43–54 (2015)
5. Al-Busaidi, A.M., Khriji, L.: Wearable wireless medical sensors toward standards, safety and intelligence. Int. J. Biomed. Eng. Technol. **14**(2), 119–147 (2014)
6. Fan, Z.: Dynamic transmission power switch for fast data collection in duty-cycled sensor networks. Int. J. Ad Hoc Ubiquitous Comput. **24**(3), 173–182 (2017)
7. El-Din, A.E., Ramadan, R.A.: Smart secure HEED for WSN'. Int. J. Sens. Netw. **16**(1), 48–60 (2014)
8. Singla, C., Kaushal, S.: An efficient game theoretic based computation offloading framework for network optimisation in mobile cloud IoT systems. Int. J. Adv. Intell. Paradig. **9**(2/3), 186–203 (2017)
9. Heinzelman, W., Chandrakasan, A., Balakrishnan, H.: Energy-efficient communication protocol for wireless microsensor networks. In: Proceedings of the 33rd Hawaii International Conference on System Sciences, Maui, Hawaii, 4–7 January 2000
10. Younis, O., Fahmy, S.: HEED: a hybrid, energy-efficient, distributed clustering approach for ad hoc sensor networks. IEEE Trans. Mobile. Comput. **3**, 366–379 (2004)
11. Smaragdakis, G., Matta, I., Bestavros, A.: SEP: a stable election protocol for clustered heterogeneous wireless sensor networks. In: Proceedings of the Second International Workshop on Sensor and Actor Network Protocols and Applications, Boston, MA, 22–24 August 2004
12. Handy, M.J., Haase, M., Timmermann, D.: Low energy adaptive clustering hierarchy with deterministic cluster-head selection. In: Proceedings of the 4th International Workshop on Mobile and Wireless Communications Network, Stockholm, Sweden, 9–10 September 2002, pp. 368–372
13. Zhu, Q., Wang, M., Qing, L.: Design of a distributed energy-efficient clustering algorithm for heterogeneous wireless sensor networks. Comput. Commun. **12**, 2230–2237 (2006)
14. Ding, P., Holliday, J., Celik, A.: Distributed energy-efficient hierarchical clustering for wireless sensor networks. In: Proceedings of the First IEEE International Conference on Distributed Computing in Sensor Systems, Marina del Rey, CA, 30 June–1 July 2005, pp. 322–339
15. Yasotha, B., Sasikala, T.: Intrusion detection system for mitigating attacks using energy monitoring in wireless sensor networks. Int. J. Mobile Netw. Des. Innov. **6**(4), 219–227 (2016)
16. Pais, S.C.: The high energy electromagnetic field generator. Int. J. Space Sci. Eng. **3**(4), 312–317 (2015)
17. Recebli, Z., Gedik, E., Selimli, S.: Electrical field effect on three-dimensional magnetohydrodynamic pipe flow: a CFD study. Prog. Comput. Fluid Dyn. Int. J. **16**(4), 261–270 (2016)
18. Angelopoulos, C.M., Nikoletseas, S., Raptis, T.P., Raptopoulos, C., Vasilakis, F.: Improving sensor network performance with wireless energy transfer. Int. J. Ad Hoc Ubiquitous Comput. **20**(3), 159–171 (2015)
19. Shu, W., Wang, W., Wang, Y.: A novel energy-efficient resource allocation algorithm based on immune lonal optimization for green cloud computing. EURASIP J. Wirel. Commun. Netw. **64**, 1–9 (2014)
20. Liu, J., Sun, Q., Li, S.: Topology control algorithm based on directional antenna in wireless ad hoc networks. J. Northeast. Univ. (Nat. Sci.) **33**, 1257–1260 (2012)
21. Halke, R., Kulkarni, V.A.: En-LEACH routing protocol for wireless sensor network. Int. J. Eng. Res. Appl. **2**, 2099–2102 (2012)
22. Rozman, M., Fernando, M., Adebisi, B., Rabie, K.M., Kharel, R., Ikpehai, A., Gacanin, H.: Combined conformal strongly-coupled magnetic resonance for efficient wireless power transfer. Wirel. Power Transf. **10**(4), 498 (2016)
23. Ns-2 network simulator. http://www.isi.edu/nsnam/ns/2008.282
24. CMU Monarch BPensions to NS-2. http://www.monarch.cs.cmu.edu/cmu-ns.html2008.283
25. Marc Greis' Tutorial for the UCB/LBNL/VINT Network Simulator "ns"284. http://web.uct.ac.za/depts/commnetwork/tutorial_ns_full.pdf2008.285
26. Installing OLSR on NS-2. http://masimum.inf.um.es/um-olsr/html12008
27. Shin, J., Suh, C.: CREEC: chain routing with even energy consumption. J. Commun. Netw. **13**, 17–25 (2011)

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