A Cellular-Assisted Mobile UE Cluster Head Selection Algorithm for Wireless Sensor Networks

Lianhai Shan[1], Yuling Ouyang[1], Zhi Yuan[1], Honglin Hu[1], and Zhenhong Li[2]

[1] Shanghai Research Center for Wireless Communications, Shanghai, P.R. China
Shanghai Institute of Microsystem and Information Technology,
Key Laboratory of Wireless Sensor Network & Communication,
Chinese Academy of Sciences, P.R. China
[2] Renesas Mobile Corporation, Shanghai, P.R. China
{lianhai.shan,yuling.ouyang,zhi.yuan,honglin.hu}@shrcwc.org,
zhenhong.li@renesasmobile.com

Abstract. Wireless sensor networks (WSN) have been applied in different areas, which consist of numerous autonomous sensor nodes with limited energy. Therefore, energy efficient algorithms and protocols have been one of the most challenging issues for WSNs. Many researchers have focused on developing energy efficient clustering algorithms for WSNs, but less research has concerned about the mobile user equipment (UE) acting as a cluster head (CH) for data transmission between cellular networks and WSNs. In this paper, we present a cellular-assisted mobile UE CH selection algorithm and describe particular procedure for the WSN system. Simulation results show that better system performance, in terms of system energy cost and WSNs life time, can be achieved in WSNs by using interactive optimization with cellular networks.

Keywords: WSN, cluster head, gateway_CH level, energy cost.

1 Introduction

With the continued requirement of information society development, wireless sensor networks (WSNs) generated an increasing interest from industrial and research perspectives. WSNs have played a vital role in our daily lives, i.e. e-Health care, environment monitoring, industrial metering, surveillance systems etc. WSN can be generally described as a network of intelligent sensing nodes, and can provide the detected results of the surrounding environment [1]. One great challenge is to create an organizational structure amongst these nodes. Since the fundamental advantage of WSNs can be deployed in Ad-Hoc manner, a typical deployment of large number sensor nodes is necessitated energy-awareness for the WSN network structures algorithms, as WSN are limited by the sensor nodes battery lifetime. There has been a large amount of research in creating WSN network structures (i.e. Flat or Hierarchical) [2]. In the hierarchical architecture, grouping sensor nodes into cluster has been widely pursued by the research community in order to achieve the network scalability objective. In each cluster, a sensor node is selected, termed as the cluster

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head (CH). Then, these cluster heads collect sensor data from other nodes in the vicinity and transmit the aggregated data to the gateway. The CH is responsible for not only the general request but also receiving the sensed data of other sensor nodes in the same cluster and routing (transmitting) these data to the gateway. Thus, the CHs have higher energy cost because all of the transmitting data packet will pass through them and be sent to the gateway [3]. And so, the cluster head selection is an important part for WSN network structures.

In the traditional selection methods, the random selection method is famous. Heinzelman [4] introduced a hierarchical clustering algorithm for sensor networks called Low Energy Adaptive Clustering Hierarchy (LEACH), which handles the distributed information from the clusters. LEACH randomly selects a few nodes and designates them as CH, and periodically rotates this function among the nodes to equally distribute the extra energy consumption. In paper [5], another system has improved upon LEACH: hierarchical Power-Efficient Gathering in Sensor Information Systems (PEGASIS) protocols in which the nodes form chains and the multi-hop method is used for transmission. In PEGASIS, each node communicates only with a close neighbor and takes turns transmitting to the gateway, thus reducing the amount of energy spending. In paper [6], Manjeshwar proposed a hierarchy protocols: TEEN (Threshold-sensitive Energy Efficient sensor Network protocol). In TEEN, the sensors constantly take readings from the environment, but the data are transmitted using a lower frequency. The cluster head will send two values including the triggering value and the minimum threshold value, to the cluster members indicating the value of the measured attribute and the granularity of the reports. In paper [7], it presented a protocol, HEED (Hybrid Energy-Efficient Distributed clustering), that periodically selects cluster heads according to a hybrid of the node residual energy and a secondary parameter, such as node proximity to its neighbors or node degree. HEED incurs low message overload, and achieves fairly uniform cluster head distribution across the network. The concept of dividing the geographical region to be covered into small zones has been presented implicitly as clustering in literature [8]. Any node can become a cluster head if it has the necessary functionality, such as processing and transmission power. In [9], the proposed weight-based distributed clustering algorithm takes into consideration the transmission power, mobility, and battery power of mobile nodes.

About the above clustering algorithms, the cluster formations and cluster heads selection algorithms partially focus on energy consumption for CH selection fairness, which is caused by data aggregation and data fusion. In current research, a controllably mobile infrastructure for low energy WSN is proposed in paper [10] and [11]. The WSN node will use the contention scheme to access the gateway. The mobile terminals are used as a cluster head to collect the data and transmit to the BS, which greatly decrease the traditional cluster head energy cost [12]. However, when the serving mobile user equipment (UE) gateway CH is leaving its responsible area, it won't tell each WSN node about its leaving. This will cause WSN nodes of this area contend transmission channel to access the other UE gateway CH again, which will bring out overload of the signaling between mobile gateway CH and WSN nodes. In this paper, we propose a weight level based distributed clustering algorithm for mobile UE gateway as a cluster head. In our algorithm, the UE gateway CH selection procedure is choosing the optimal UE under the help of BS in order to reduce the WSN system energy cost.

The major contributions of the paper lie in the following folds:

1. Proposed detailed parameters for calculating the proposed GW-CH level to choose a suitable UE gateway as the CH for sensor nodes.
2. Decrease the traditional cluster head and each sensor node energy cost and its energy cost imbalance during data transmission process.

The remainder of paper is organized as follows. Section 2 presents the system description and mobile UE gateway CH selection algorithm under the cellular help is detailed. Section 3 describes an energy cost analytical model. Section 4 demonstrates the simulation results. Conclusions are finally offered in Section 5.

2 Proposed Scheme

2.1 System Architecture

In the convergence scenario for wireless sensor network (WSN) and cellular network is as follows. In the cellular system, the mobile UEs are under the control of a base station (BS). In the coverage area of a cellular network, there also exists a group of wireless sensor nodes constructing WSN. In the convergence scenario, the cellular UEs can act as the mobile gateways and cluster head for the WSN. The gateway CHs can provide access for the WSN nodes, i.e., gateway UEs are dual-mode and have both WSN and cellular interfaces [12]. In a WSN networks, the mobile UE gateway moves into the coverage area of the low energy sensor nodes, then they broadcast beacon packets to these nodes, and provide the backhaul access to these WSN nodes. Then, the detected data from WSN nodes can be forwarded to the BS via cellular system by the UE gateways CH as illustrated in Figure 1.

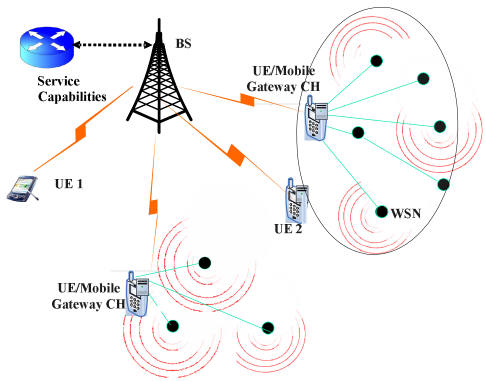


Fig. 1. System architecture of convergent WSN and cellular network

In the convergent network infrastructure, there may be a lot of UE gateway CH candidates in the WSN area, how a UE gateway CH is selected to be a WSN CH with less signaling overload is one of the key problems to be solved. There are two basic use cases:

1. One is that a new capable UE gateway enters into the WSN area;
2. The other is that the serving UE gateway leaves the coverage area of WSN.

In conventional WSN-cellular networks, the mobile UE gateway moves into the coverage area of the low energy nodes, they broadcast POLL packets to the low energy nodes, and provide the access to these WSN nodes. The WSN node will use the contention scheme to access the UE gateway. In the traditional algorithms, when the serving gateway is leaving its responsible area, it won't tell each WSN node about its leaving. This will cause WSN nodes of this area back-off and contend transmission channel, which will bring out overload of the signaling between mobile UEs and WSN nodes. Our proposed algorithm starts at the serving UE gateway leaving the WSN coverage area, and this will cause the UE gateway CH selection. The WSN topology in this paper mainly includes star and tree topology.

2.2 UE Cluster Head Selection Protocol Design

About mobile UE gateway CH selection procedure for the cellular and WSN system, the main define points include:

Define 1: Mobile UE gateway CH level is defined as the capability level that a mobile UE can serve as a gateway CH for the WSN. If the mobile UE is willing to act as a mobile gateway CH, it will calculate the gateway CH level (GW-CH_level).

Define 2: Some new signaling in cellular interface to realize the UE gateway CH replacement, i.e. leaving_REQ, GW-CH_ACK, replacement _REQ, replacement _RSP et al.

Define 3: GW-CH_level information table message field are shown in Table I.

Table 1. GW-CH_level Message Table

Dwelling time (D_t)	Coverage capability (C_r)	Capacity availability (C_a)	Channel quality (C_g)	Channel quality (C_s)

The procedure of a UE gateway CH selection, when the current mobile UE is going to leave the WSN area or disqualified to continue acting as a gateway CH, is illustrated in Figure 2 and Figure 3.

step 1. Once the current serving mobile UE gateway finds that it cannot serve the WSN cluster/group, then it sends the gateway CH leaving request (leaving_REQ) to the BS.

step 2. BS broadcasts the serving gateway CH information to the neighbor mobile UEs who have entered this WSN area after BS receives the leaving_request from the serving UE gateway CH, and BS chooses one neighbor UE gateway as mobile UE CH candidate. The broadcasting information will include at least the GW-CH_ID, GW-CH_level etc.

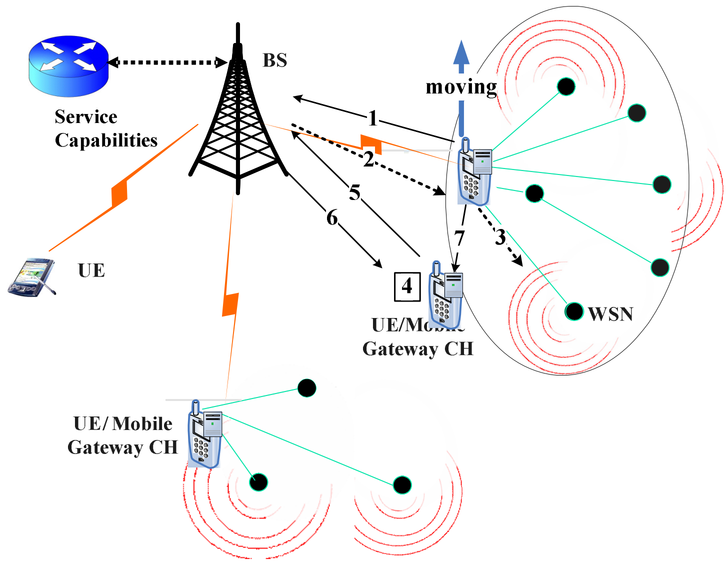


Fig. 2. Mobile gateway CH selection scenario

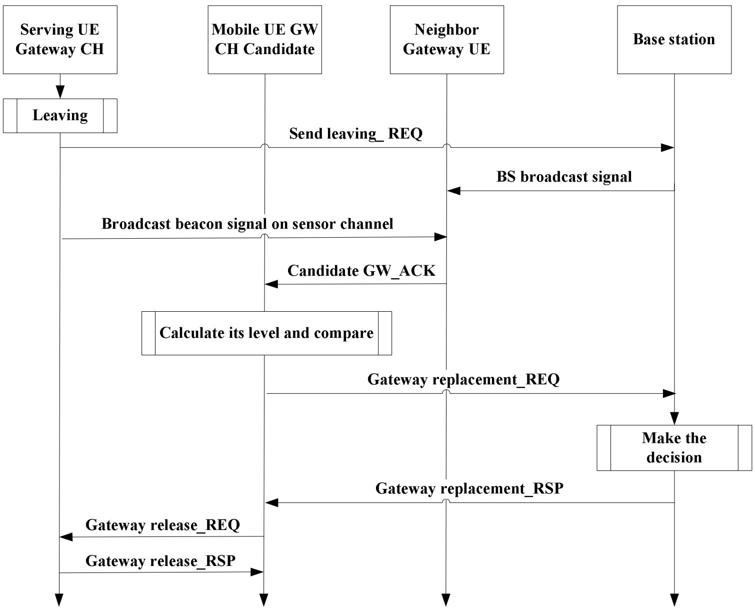


Fig. 3. Mobile gateway CH selection procedures

step 3. The serving mobile UE gateway CH broadcasts a beacon signal through WSN channel for its leaving.

step 4. The mobile UE CH candidate and neighbor UEs listen to the beacon signal from the serving mobile gateway CH, and neighbor UE gateways detect its ID and report itself GW-CH_level in the GW-CH_ACK to the candidate. The current mobile gateway UE candidates compare the neighbor GW-CH_level with its own and will be instead by the neighbor UE if its level is lower than the neighbor UE gateway level.

step 5. The mobile UE gateway CH candidate signals the gateway replacement request (replacement_REQ) and GW-CH_level to BS via cellular uplink, only if its own level is higher than that of current serving gateway.

step 6. BS will select the optimal candidate based on GW-CH_level. Then BS informs the best candidate to replace the current gateway CH (replacement_RSP) and the current serving gateway to prepare for releasing its role.

step 7. The serving UE gateway and the selected mobile gateway CH candidate start the replacement process, which the gateway CH candidate will send gateway CH release request (release_REQ) to the current serving gateway CH. The current serving gateway CH will make a response (release_RSP) with the WSN information exchange including the sensor_ID, sensor remainder energy et al.

2.3 Optimal UE CH Selection Algorithm

In the proposed scheme, we have defined a new parameter named mobile UE gateway CH level (GW-CH_level), which defines the capability level of a UE acting as a gateway for a WSN. The detailed parameter for calculating the proposed mobile UE gateway CH level includes but not limited to below elements:

a) Dwelling time D_t, which means the persistent time of mobile UE for the sensor node acting as a gateway.
b) Coverage capability C_r, which means the number of sensor nodes of the UE covering.
c) Capacity availability C_a, which means load capacity for the UE to serve sensor nodes.
d) Channel quality C_g between the UE gateway candidates and the current serving gateway (assuming closer to the serving gateway, higher qualification to replace the old gateway).
e) Channel quality C_s, which means the average SNR between the UE gateway candidates and sensor nodes.

Note: The above parameters could be included into taken into account for calculating the mobile UE gateway CH level whenever those parameters are feasible to obtain and meaningful. If one or some elements are not available, then the weighting factor for that element(s) could be set to zero. The mobile UE gateway CH level could be defined as

$$\text{GW-CH\_level} = a \cdot D_t + b \cdot C_r + c \cdot C_a + d \cdot C_g + e \cdot C_s \quad (1)$$

where a, b, c, d, e are pre-defined weighting factors in the system parameter table. Note that these weighing factors are chosen such that $a+b+c+d+e = 1$. The weighing factors of individual components can be adjusted during the WSN communication process.

In our proposed scheme, we define the GW-CH_level synthesis value including all the necessary and meaningful information enables the control unit (e.g., BS) to make the proper decision among the mobile UE gateway CH candidates. Moreover, there is no need for all the mobile UE CH candidates send each element to the control unit. This will save a lot of signaling overload. Further by introducing the configurable weighting factor to each element, the priority of the each element can be reflected easily in the system.

3 Performance Analysis

In this section we will analyze the energy cost of data transmission from a sensor node to the next node or gateway. And our analysis mainly focuses on system energy cost of transmitting packets from each sensor node using the traditional CH selection algorithm, normal UE gateway CH selection algorithm (just use the UE replacing CH) and optimal UE gateway CH selection algorithm, where the traditional CH selection algorithm is just using a low energy adaptive clustering hierarchy algorithm.

3.1 Network Model

In this paper we assume a sensor network model with following properties:

- The UE gateway locates at the center of clustered sensor nodes and has enough memory and computing capability.
- All sensor nodes are immobile and have a limited initiated energy.
- All nodes are equipped with power control capabilities to adjust their transmitted power.

3.2 WSN Radio Model

Currently, there have some researches in the low-energy WSN radios. Different assumptions about the WSN scenario characteristics make diversity in energy cost in the transmitting and receiving modes based on different protocols. In our work, we assume a simple model where the power cost E_{elec}=50nJ/bit to run the transmitter or receiver circuitry, and use ξ_{amp}=100$nJ/bit/m^2$ or 0.0013$Pj/bit/m^4$ according to the referenced distance for the transmit amplifier to achieve an acceptable E_b/N_o [13][14]. These parameters are slightly better than the current state in radio design, which is shown in table 2. Both the free space (d^2 power loss) and the multi-path fading (d^4 power loss) channel models were used, depending on the distance between the transmitter and receiver.

Table 2. Radio characteristics

Operation	Energy Cost
Transmitter Electronics (E_{Tx_elec}) Receiver Electronics (E_{Rx_elec}) ($E_{Tx\_elec} = E_{Rx\_elec} = E_{elec}$)	50 nJ/bit
Transmit Amplifier (ξ_{amp})	ξ_{amp1} =100 pJ/bit/m^2($d < d_0$) ξ_{amp2} =0.0013Pj/bit/m^4($d \geq d_0$)

Simple power control can be used to invert this loss by appropriately setting the power amplifier—if the distance is less than a threshold d_0, the free space model is used; otherwise, the multi-path model is used. Thus, to transmit a k-bit message a distance d using our radio model, the radio expends:

$$E_{Tx}(k,d) = E_{Tx\_elec}(k) + E_{Tx\_amp}(k,d) \tag{2}$$

$$E_{Tx}(k,d) = \begin{cases} E_{elec} \cdot k + \xi_{amp1} \cdot k \cdot d^2 & d < d_0 \\ E_{elec} \cdot k + \xi_{amp2} \cdot k \cdot d^4 & d \geq d_0 \end{cases} \tag{3}$$

and to receive this message, the radio expends:

$$E_{Rx}(k) = E_{Rx\_elec}(k) = E_{elec} \cdot k \tag{4}$$

For these parameter values, receiving a message is not a low cost operation; the protocols should thus try to minimize not only the transmit distances but also the number of transmit and receive operations for each message. We make the assumption that the radio channel is symmetric such that the energy required to transmit a message from node *A* to node *B* is the same as the energy required to transmit a message from node *B* to node *A* for a given SNR.

3.3 Energy Cost of Intermediate Nodes

In all proposed scheme, energy cost is analyzed using WSN radio models. In the proposed algorithm, WSN nodes will transmit data to the UE through intermediate nodes. In this case, the intermediate nodes are chosen such that the transmit amplifier energy (e.g., $E_{Tx\_amp}(k,d)$) is used and maybe some of them are not necessary, which will increase energy cost. But when to use the intermediate nodes transmit and when to use the direct communication with the next node if the previous node can communicate with the two next nodes, we use the following algorithm: previous node A would transmit to next node C through intermediate node B if and only if:

$$E_{Tx\_amp}(k, d = d_{AB}) + E_{Tx\_amp}(k, d = d_{BC}) + E_{Rx}(k) < E_{Tx\_amp}(k, d = d_{AC}) \tag{5}$$

3.4 WSN Nodes Energy Cost Analysis

For our experiments, we assume that all sensors are sensing the environment at a fixed rate and thus always have *k*-bit data to send to the CH or UE gateway. For future versions of our protocol, we will implement event-driven simulation, where sensors only transmit data if some event occurs in the environment. WSN nodes energy cost is mainly composed of two parts: the end nodes energy cost $E_{Tx}(k,d)$, the intermediate nodes energy cost $E_{Tx\_amp}(k,d) + E_{Rx}(k)$. Node *i* transmits *k*-bit data energy cost from *j* hop to *j+1* hop,

$$E_{\cos t}(i, j) = E_{tran} + E_{rec} = (E_{elec} * k + k * \xi_{amp1} * d^2_{(V(j),V(j+1))}) + E_{elec} * k = k * \xi_{amp1} * d^2_{(V(j),V(j+1))}) + 2k * E_{elec} \qquad d<d_0 \tag{6}$$

$$E_{\cos t}(i, j) = E_{tran} + E_{rec} = (E_{elec} * k + k * \xi_{amp2} * d^4_{(V(j),V(j+1))}) + E_{elec} * k = k * \xi_{amp2} * d^4_{(V(j),V(j+1))}) + 2k * E_{elec} \qquad d \geq d_0 \tag{7}$$

where $0 \leq j \leq m-1$, $d_{(V(j),V(j+1))}$ denotes distance between the *j* node and the *j+1* node in transfer process.

Node *i* transmits *k*-bit data packet to UE gateway and total transferring energy cost for one round is

$$E_{\cos t}(i) = \sum_{j=1}^{m-1} E_{\cos t}(i, j) \tag{8}$$

where one round data transferring includes *m* hops.

So for *N* nodes data packets in the WSN, and the total energy cost for one round is

$$E_{total}(i) = \sum_{i=1}^{N} E_{\cos t}(i) \tag{9}$$

4 Numerical Results and Discussion

4.1 Simulation Scenario Description

The simulation environment is to distribute 150 and 200 sensor nodes to 200m*200m square randomly. The initial energy of each node is 0.25J. In each round, the sensor node will deliver a random size data packet between 10 and 100 Bytes. Firstly, we assume that the position of the CH is located at a fixed coordinate at the beginning. After the former CH is power off, it will choose a new CH by using a low energy adaptive clustering hierarchy algorithm, which we have used this as a traditional algorithm. The radio model and the transmission method of each round (simulation time) have been presented in Section 3. Moreover, in each round, each sensor has generated data to transmit. The sensor nodes random distribution scenario is shown in figure 4. This WSN area is composed by 200*200 meters square, where sensor nodes are distributed for environment monitoring.

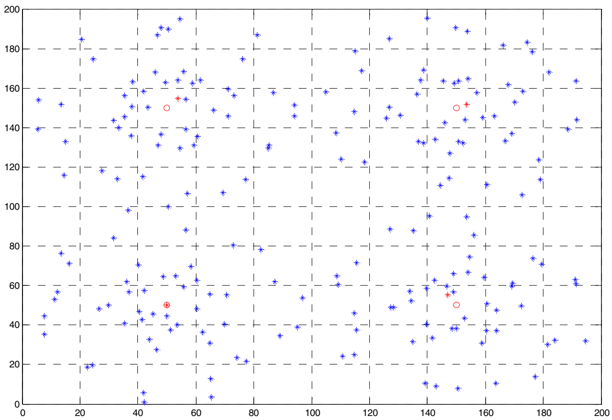


Fig. 4. WSN nodes distribution graph

4.2 Analysis of Simulation Results

The system energy cost with simulation time (rounds) can be described as follows. The nodes at the cluster have different distances to the next node. The energy cost of each transmission is based on the transmission distance, which the energy cost is exponentially incremental according to the transmission distance. In additional, the transmission hops is another important factor and more energy will cost for the extra hops. From figure 5 (a) and (b), we can see that the proposed algorithm greatly reduced the system energy cost because we use the UE gateway as the CH in the proposed optimal UE gateway CH selection algorithm.

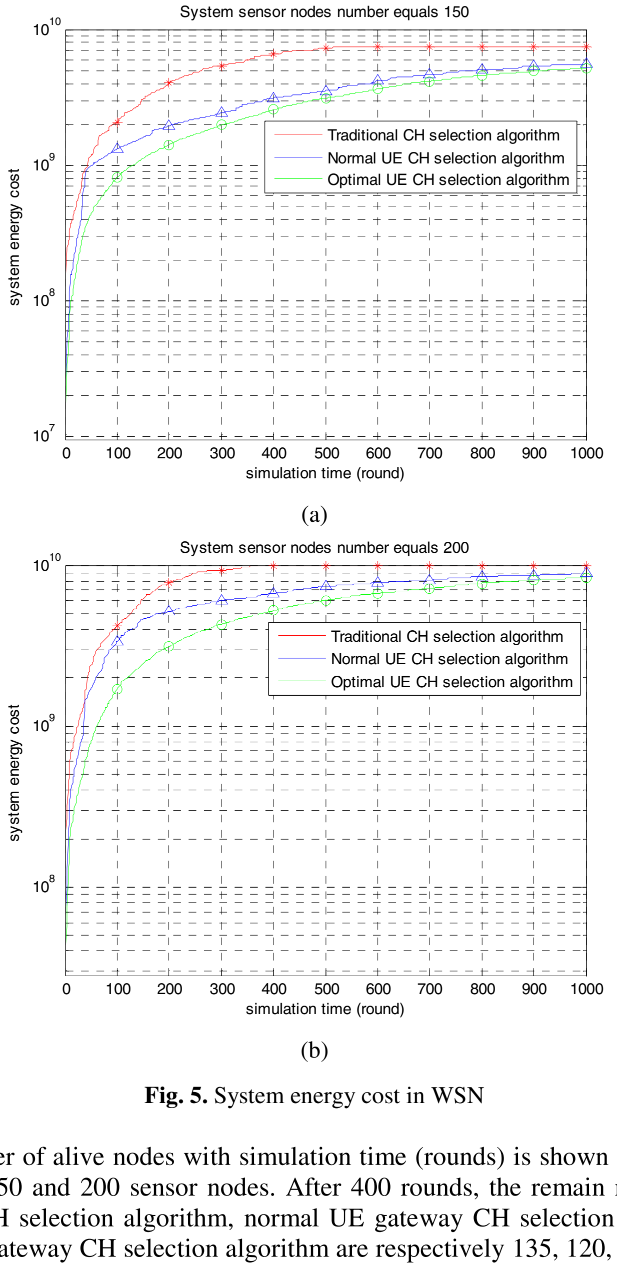
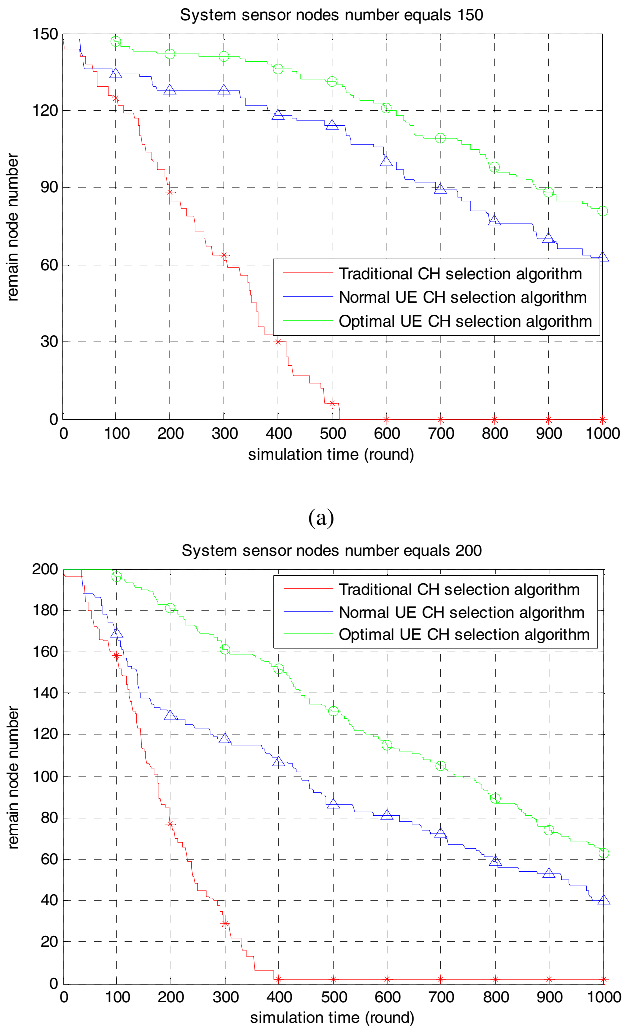


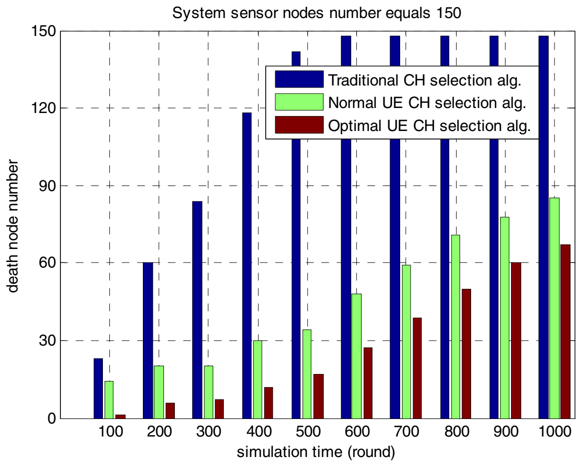
Fig. 5. System energy cost in WSN

The number of alive nodes with simulation time (rounds) is shown as Figure 6 (a) and (b) for 150 and 200 sensor nodes. After 400 rounds, the remain nodes of using traditional CH selection algorithm, normal UE gateway CH selection algorithm and optimal UE gateway CH selection algorithm are respectively 135, 120, and 55 for 150 system sensor nodes. And the remained nodes respectively are 150, 110, and 5 for 200 system sensor nodes after 400 rounds. The reason is mainly that the remaining energy of normal nodes is more than the CH nodes. Therefore, this random selection cannot have a better balance of the remained energy among sensors. In our proposed algorithm, it can select the optimal UE gateway CH to provide the access for the other sensor nodes, which not only reduced the system energy cost but also balanced the other sensor nodes energy cost with a long time rounds. The death nodes of using traditional CH selection algorithm, normal UE gateway CH selection algorithm and optimal UE gateway CH selection algorithm are respectively shown in figure 7 (a) and (b). All of the above results reveal our proposed method present better performance than the other two algorithms. Therefore, optimal UE CH selection method is efficient to be used in the sensor network because it selects a CH from several candidates by using the integrative level among these clusters. And this method can extend the death time of a cluster and the death time of the last sensor nodes are extended.

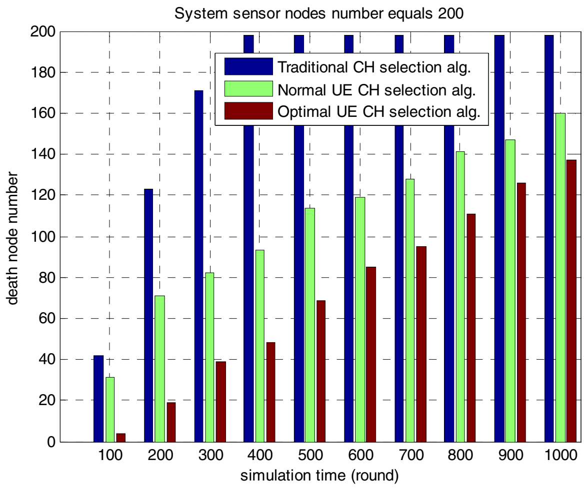


(b)

Fig. 6. System alive nodes in WSN



(a)



(b)

Fig. 7. System death number in WSN

5 Conclusions

The traditional CH selection algorithm cannot have a better balance of the remained energy among sensors and reduce the system energy cost. In this paper, we proposed a novel method considering several parameters to choose the optimal UE gateway CH for hierarchical sensor networks. For a request, we design some new additional signaling. Simulation experiments verified that our proposed method prolonged the lifetime of sensor networks. In the future, we will consider that sensor nodes have the capability to know themselves position and this will moreover optimize the WSN CH selection and decrease the energy consumption.

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