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Clustering and Neighbouring technique Based Energy-Efficient Routing for WSNs

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Abstract

Energy efficiency is the main prerequisite for the permanent and reliable operation of wireless sensor networks (WSNs). Clustering techniques are designed to build energy-efficient networks that enhance network lifetime. Clustering poses certain challenges that directly affect the network performance such as the cluster head selection and routing process. This paper proposes an approach called Clustering and Neighbouring technique Based Energy-Efficient Routing (CNBEER). The CNBEER approach utilises the clustering algorithm and neighbouring technique to prolong the network lifetime by reducing its total energy consumption. The clustering method divides a network into equal-sized clusters to mitigate inessential energy consumption. Moreover, the clustering algorithm selects a cluster head based on the G function which considers the current energy and position of the nodes of a base station. The cluster head changes dynamically depending on the G value to ensure that the energy consumed at the sensor nodes remains at an approximately equal rate. The CNBEER approach uses the neighbouring technique to discover the best multihop path to the base station. The performance of the proposed approach achieved improvement in the concept of residual energy and network lifetime compared with existing protocols.

Keywords

WSNs, Clustering algorithm, Network Lifetime, Neighboring technique, G function

1. Introduction

A wireless sensor network (WSN) is compatible with ubiquitous computing owing to its capability to provide a convenient and easy access to relevant information [1]. WSNs cover a variety of applications relevant to the vehicular movement, signals, acoustics, vibrations, humidity, pressure, temperature and so on [2−4]. A WSN comprises indeterminate numbers of sensor nodes (SNs), wireless communication components and a Base Station (BS). SNs can sense, collect and transmit information to a BS through wireless communication. However, SNs cannot be replaced or recharged whilst deployed in the physical environment. SNs have special characteristics, such as limited memory and energy and computational capacity. Energy is an important criterion for determining the network lifetime. Energy efficiency is the main prerequisite for the reliable operation of WSNs [5−7]. Therefore, how to save energy to extend network lifespan is an important topic in WSNs. Clustering techniques are designed to build energy-efficient networks for prolonging network lifetime. The BS organises a network into clusters and selects a number of nodes to become cluster heads (CHs). Each cluster has a member node associated with a CH. CHs gather all the sensed information from their members and deliver it to the BS [8].

Although clustering is applied in order to extend network lifetime, specific challenges that directly affect network performance exist such as the CH selection and routing process [9−11].In numerous clustering routing protocols, the CHs transmit the collected information directly to the BS. However, CHs that are far away from the BS run out of energy quickly owing to long-distance data transmission [12]. In multihop clustering scenarios, CHs are responsible for either delivering information to the BS or routing it among themselves [13−15]. Thus, CHs spend more energy than their member nodes in the cluster due to the traffic from and to their members. In addition, CH nodes endure an extra burden owing to the traffic from other CHs. Subsequently, the energy of CHs can drain rapidly, thereby causing an early death and leading to disconnection in the network connectivity. Therefore, an approach for the CH selection along with the rotation of the role of CHs among SNs are essential issues that considerably influence network lifetime. Furthermore, the regularisation of the consumed energy of SNs to prolong network lifetime is a key challenge in the design of an energy-efficient routing approach for WSNs.

This paper proposes an approach called Clustering and Neighbouring technique Based Energy-Efficient Routing (CNBEER) to address the above challenges. The CNBEER approach uses the clustering algorithm and neighbouring routing technique to improve network lifetime. The clustering algorithm divides sensing regions into a set of equal-sized rectangular clusters to reduce any inessential energy consumption and decrease the number of SNs connected directly to the BS. The clustering algorithm selects a CH depending on the G ration which considers the current energy of the SNs and their position relative to the BS. The CH changes dynamically depending on the G value of the node to ensure that the consumed energy of SNs is at a nearly equal rate. Moreover, the CNBEER approach uses the neighbouring technique to select the best multihop routing path for transferring data packets from the CHs to the BS.

The rest of this paper is organized as follows. Section 2 summarises the works concerning clustering techniques. Section 3 explains the CNBEER approach in depth with a network model. The simulation analysis of the CNBEER approach is discussed in section 4 and the conclusions of the paper are provided in section 5.

2. Related works

A low-energy adaptive clustering hierarchy (LEACH) was developed as a popular clustering protocol in WSNs [16]. The CHs in the LEACH protocol are selected randomly based on probability. The main drawbacks of this protocol include the possibility of selecting CHs without considering the energy level of the SNs and also the single hop communication manner between the CHs and BS. In Ref. [17], A LEACH-Centralized (LEACH-C) was proposed to enhance the performance of the LEACH protocol in terms of network lifetime. The LEACH-C overcomes LEACH limitations by selecting a fixed number of CHs. The LEACH-C tries to reduce the overhead of an entire network by positioning the CH in the centre of a cluster. However, the single hop transmission remains a significant drawback in this protocol. The LEACH-VA protocol was proposed to overcome the problem of randomly selected CHs in the LEACH protocol by

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optimising the routing protocol and calculating the number of CHs [18]. The LEACH-VA determines the number of CHs corresponding to the total energy consumption for each round. Furthermore, the LEACH-VA uses the ant colony algorithm for the multihop routing from remote CHs to those near the BS. Although the LEACH-VA protocol reduces energy waste and improves network lifespan compared with the LAECH protocol, a multiple path optimisation is worthy of investigation.

The PSO−C protocol was proposed to optimise energy management and maximise network lifetime by utilising the PSO algorithm [19]. This protocol defines a new fitness function depending on the distance between the SNs and their associated CHs and the initial energy of SNs in the network. The PSO algorithm selects SNs with an energy level that is higher than the fitness function value as the best CHs. The PSO−C protocol uses single hop transmission to the BS. Thus, it needs to implement multihop routing among the CHs. In Ref. [20], the FCM approach was introduced to ensure the high stability of a WSN. The approach calculates the optimal number of cluster and their location in a network. The Euclidian distance divides the network area into clusters and the FCM algorithm calculates the optimum number of clusters. The GABEEC protocol is presented to increase the network lifetime by using the Genetic Algorithm (GA) [21]. The GA is utilized to determine the optimum number of CHs. Meanwhile, the GAEEP employed the GA to improve the lifespan of WSNs and extend the stability period of a network [22].The GA preserves the

Table 1
Comparison of various related work protocols.

Protocol	Features	Advantages	Limitations
LEACH [16]	CHs selection and rotation are based on probability.	Optimizes energy consumption. Distributes the energy load throughout the network.	Single-hop, Randomly CH selection.
LEACH-C [17]	The LEACH-C protocol selects a fixed number of CHs determined by BS which is dependent on the average energy of the sensors.	Increases the number of data received.Extends the network lifetime better than LEACH. Reduces the overhead of the network.	It has a single hop communication manner to the BS.
LEACH-VA [18]	The LEACH-VA calculates the optimal number of CH per round, and uses the ant colony algorithm for multi-hop communication by CHs.	Reduces the energy consumption. Improves the network lifetime.	Energy is inefficient because of overlooked the arrangement of the clusters. Multiple path optimisation is worthy of investigation.
PSO−C [19]	The PSO-c protocol optimizes the CH selection depending on the PSO algorithm and fitness function.	Improves the network lifetime. Achieves a high data delivery at the BS.	A single-hop communication which fails to consider the BS distance.
FCM [20]	It calculates the optimum number of clusters in a network.	Achieves a high stability network. Inexpensive computationally in comparison with other approaches.	CHs are not determined and clusters are not organized.
GABEEC [21]	It determines the optimal number of CHs by using GA.	Optimizes the lifetime of the network.	A random selection of nodes to be CHs.
GAEEP [22]	The GAEEP protocol selects the best CHs by using GA that depends on the energy level of SNs.	Preserves the battery power of SNs. Extends the stability period of the network.	It considers only the residual energy of SNs for CH selection.
HBO [23]	It utilizes the enhanced k-means method to divide the network into equal-sized clusters. It uses the HBO algorithm to select the shortest path to the BS.	Reduces the energy consuming of the network to the lowest cost.	The CH selection is repeated in every round. The amount of energy spent is increased while controlling and exchanging messages.
WOA-C [24]	The WOA-C focuses on the cluster formation and CH selection depending on the fitness function. The fitness function takes the residual energy of SNs in order to choose the best CHs.	Achieves a longer stability period as well as network lifetime. Enhances the energy utilisation.	It considers only the remaining energy of the SN when selecting CHs.The protocol should consider additional parameters such as distance.
Tabu PSO [25]	It enhances the CH selection and optimizes the multihop routing path based on Tabu and PSO algorithms.	Increases the survival rate of nodes. Decreases energy consumption in the cluster.	The PSO algorithm is employed efficiently but demonstrates decreasing optimal local problems.

energy of SNs by selecting the best CHs. The GA selects the CH in each cluster whose energy is higher than that of average nodes in the network.

The HBO technique was introduced to reduce energy consumption by selecting the optimal multihop routing path [23]. The enhanced k-means algorithm is utilized to divide the sensing area into equal-sized clusters. The HBO algorithm performs a CH selection depending on two parameters which are the distance to BS and energy level. Intelligent agents collect information on the energy level of SNs and of every possible path to the BS. In addition, the HBO algorithm that has intelligent agents is responsible for finding the shortest route to the BS. The WOA-C protocol was presented to enhance the energy utilisation of WSNs by employing the WOA algorithm [24]. The WOA algorithm focuses on the cluster formation and CH selection which is based on the fitness function. The fitness function takes the residual energy in SNs and the overall energy in neighbouring sensors to select the best CHs. However, the fitness function of the WOA-C protocol does not consider additional parameters when selecting CHs. The Tabu PSO technique was developed to prolong network lifetime by selecting the optimal route and efficient CHs [25]. The Tabu PSO scheme optimises routing in the network and enhances the CH selection by using the Tabu search and PSO algorithms. In this method, the average packet loss rate decreases in comparison with those in other related protocols. The PSO algorithm is employed efficiently but it demonstrates decreasing optimal local problems. The comparison of various protocols in this section is listed in Table 1.

3. Proposed work

3.1. Network model

A set of SNs is assumed to disperse randomly in an M*M region. The SNs have the following characteristics:

1. A single BS is available in this network with an awareness of its location.
2. The BS has an unlimited resource in terms of power computing, memory and energy.
3. The BS is static and knows all node information such as identification (ID), location and residual energy.
4. The BS is responsible for aggregating information and managing the network.
5. Each SN has a unique ID.
6. The SNs are non-rechargeable and location unaware.
7. The SNs have the same initial energy and capabilities.
8. The SNs have sufficient data storage and processing power.

Table 2
Symbols used in the proposed work.

Notation	Description
SNs	Sensor nodes in the network
CH	Cluster Head
z	Maximum transmission range
n	Number of SNs after distribution
x	Dimension of deployment area on x-axis
y	Dimension of deployment area on y-axis
W	Width of the lane
L	Length of the cluster
Lane $_{id}$	Lane id numbered from 1 to M
$Cluster_{id}$	Cluster ID for each cluster
$E_{current}$	Current energy of SN
D_{sn}	Distance from SN to the BS
G_i	Cost of node i
$G_{(CH)}$	Cost of Cluster Head
E_{thr}	Energy threshold level

Table 2 summarizes the various symbols used in this article.

3.2. Energy model

The energy consumption in WSNs is caused mainly by the process of receiving and transmitting data. In this paper, the first-order module is utilised to determine the amount of the energy consumed in receiving and transmitting data [16]. The following formula calculates the energy consumed by an SN when a message of k bit is sent to a receiver that is d meters away.

$$EN_{TX}(k,d) = \left\{ \begin{pmatrix} k \times \left(EN_{elec} + EN_{fs} \times d^2\right) & if\ d < Threshold\ distance \\ k \times \left(EN_{elec} + EN_{mp} \times d^4\right) & if\ d \geq Threshold\ distance \end{pmatrix} \right\} \quad (1)$$

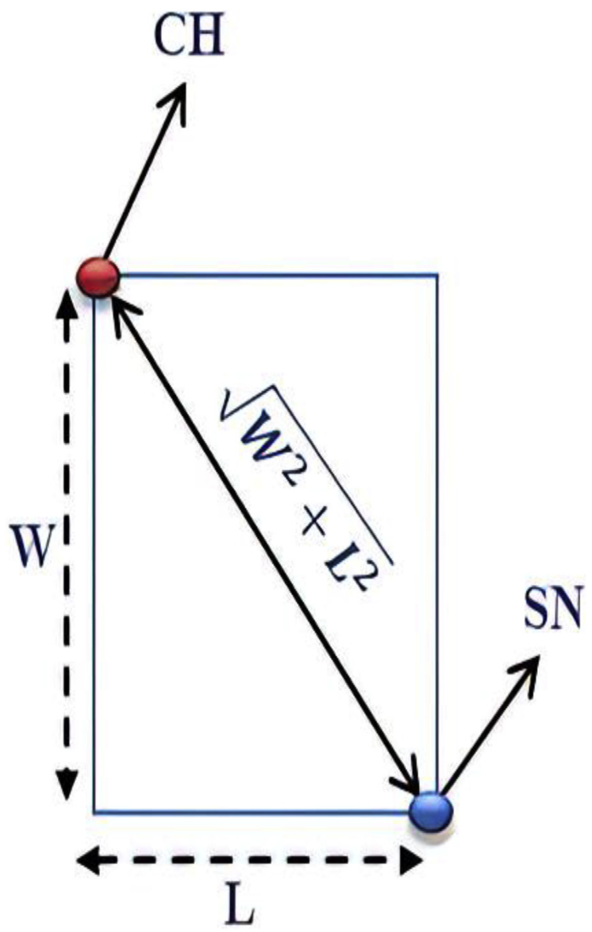

Fig. 1. Communication within cluster.

where EN_{elec} denotes the energy needed to operate the receiver or transmitter circuity, while EN_{fs} *and* EN_{mp} denote the energies required for the transmitter's amplifier. The Threshold Distance is given in:

$$\text{Threshold Distance} = \sqrt{\frac{EN_{fs}}{EN_{mp}}} \tag{2}$$

The energy consumed by an SN in order to receive a message of k bit is as follows:

$$EN_{RX}(k,d) = k \times EN_{elec} \tag{3}$$

3.3. Cluster formation phase

The cluster formation aims to divide the network region into a set of equal-sized rectangular clusters. This phase is executed at the BS after the SN deployment. Initially, the network region is divided into rectangular lanes from bottom to top. These rectangular lanes have the same width (W) and are represented as Lane1, Lane2, …. and Lane n. Each lane divides into clusters of equal length (L). Each cluster holds a fixed number of SNs and assigns the SNs a unique ID. Each cluster has one particular node that acts as a CH.

The choice of W and L's values should ensure that the communication distance between the node and CH within the cluster is always less than the value of the maximum transmission range (z) as given in formula 4. Fig. 1 shows the worst possible thing that happens when CH and its SN are situated at diagonally opposite ends. In such a circumstance, the communication between them is equal to $\sqrt{W^2 + L^2}$ which should be less than z. Moreover, the W and L's values should ensure that the distance between the CHs is less than the *Threshold distance* value. Fig. 2 illustrates the distance between the two CHs at adjacent lanes when they are situated at crosswise opposite corners. The distance between the CHs is equal to $\sqrt{4W^2 + L^2}$ which should be less than the *Threshold distance*, a situation that ensures the energy consumption of SNs is at a rate of d^2. Algorithm 1 outlines the operation of the cluster formation phase.

$$z \geq \sqrt{W^2 + L^2} \tag{4}$$

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Algorithm 1. Cluster formation process
Input: Network region dimension (M*M) ; n
Output: Network division.
Step 1: Initial  x = 0, y=0 ,  i = 1, z = 1,
Step 2: While ( y < M)              //* Partition the network region into rectangular lanes.
Step 3: y_new = y + W
Step 4:  Lane_id= i,                //* Identify the horizontal  lane between y and y_new.
Step 5 : i=i+1,
Step 6: y = y_new
Step 7: While (x < M)               //* Partition each  lane into a number of clusters of equal length .
Step 8: x = x + L
Step 9: Cluster_id  = z,            //* Assign a unique ID to the cluster.
Step 10 : z=z+1,
Step 11: End while
Step 12: End while
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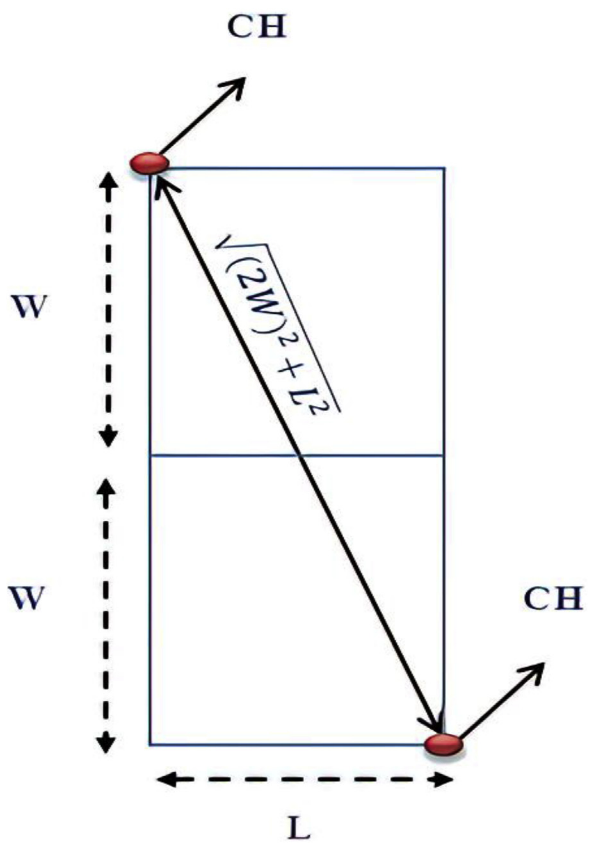

Fig. 2. Communication between clusters.

3.4. CH selection

The CH selection and CH change are key operations in this phase. The selection of an appropriate CH in each cluster is determined by the CH selection method. However, determining the round for changing the CH is controlled by the CH change method. The BS performs these methods at the beginning of each round. Initially, the BS computes the current energy of each SN ($E_{current}$) and the distance between each SN and the BS (D_{sn}). D_{sn} is determined by the Euclidean distance as given in formula 5 where (x_{sn}, y_{sn}) is the coordinate point for the SN and (x_{BS}, y_{BS}) is the position of a BS in the x-y coordinate. Regarding this information, the BS calculates the G ratio, which is given in Equation (6) for each node in the cluster. Next, only the SN with the highest G value is selected as the CH. The G scale is directly proportional to energy and inversely proportional to distance. Therefore, an SN should have the highest energy value and be near the BS to be selected as a CH.

$$D_{sn} = \sqrt{(x_{sn} - x_{BS})^2 + (y_{sn} - y_{BS})^2} \quad (5)$$

$$G_i = \frac{E_{current}(i)}{D_{sn}(i)}, \; i = 1, 2, ..n \quad (6)$$

The energy of a CH decreases during transmitting and receiving operations. Thus, the G value of a CH changes. The BS checks the G value of a CH and its energy level after every round of the operation. The BS compares the current CH with its members based on its G value and selects a new CH that has the largest G value. Moreover, the energy threshold level (Ethr) given in Equation (7) is used to compare the Ecurrent of CHs. A CH is considered dead when its energy level is lower than the Ethr. The Ethr value can be derived from the energy required to transmit and receive data, as mentioned in Equations (1) and (2). α is a constant value. The CH changes dynamically based on the G value to ensure that the consumed energy of the SNs is at a nearly equal rate. The G ratio plays an important role in making the same CH continue for multiple rounds, thereby reducing the amount of energy spent in controlling and exchanging messages during the CH replacement process. Algorithm 2 outlines the CH selection and CH change methods.

$$E_{th} = \alpha \times (EN_{TX}(k,d) + EN_{RX}(k,d)) \quad (7)$$

3.5. Routing phase

The key function of the routing phase is to discover the best route for forwarding data to the BS. The proposed method for selecting the next appropriate CH is based on the eight-neighbouring technique. This technique needs only the G value of the CHs.

In the eight-neighbouring technique, the BS begins operating in the CH that wants to send data packets. The BS checks if the CH is not within the communication range, then it searches for only the eight neighbouring CHs. It selects the CH with the highest G value as the optimal node for the next hop routing path. This procedure is repeated by the next CH until an optimal route to the BS is obtained. After each round, the BS triggers the CH change algorithm to check whether or not the CHs in the optimal path should be changed. If yes, then a new CH in the cluster is selected using the CH selection algorithm. Algorithm 3 describes the route discovery phase operation. The proposed routing phase contributes to making the consumed energy in the network uniform, thereby improving overall network lifetime.

Algorithm 2. CH selection and CH change methods

Input $Cluster_{id}$; $E_{current}$
Output: CH selection and CH change
For each $Cluster_{id}$
Step 1: $D_{sn}(i) = \sqrt{(x_{sn} - x_{BS})^2 + (y_{sn} - y_{BS})^2}$ //* Calculate the D_{sn} for each node i .
Step 2: $G_i = \frac{E_{current}(i)}{D_{sn}(i)}$ //* Calculate the G-value for each node i .
Step 3: CH node = Max (G_i) //* $Node_{(i)}$ have a maximum G-value is selected as the CH
Step 4: If ($G_{(CH)} > G_i$) or ($E_{current}$ (CH) > E_{thr}) //* CH change method
Step 5: Current CH has not changed
Step 6: Else return to step 2
Step 7: End.

Algorithm 3. Route discovery phase

Input: $G_{(CH)}$
Output: Route–Discover
For each $Cluster_{id}$,
Step 1: CH starts collecting data packets from its member nodes
Step 2: If CH is inside the BS range
Step 3: Successful optimal path to the BS is found.
Step 4: If not, the BS checks the G-value of eight neighbouring CHs
Step 5: $CH_{(i)}$ that has the highest G-value is selected as the next hop
Step 6: Return to step 2
Step 7: End.

3.6. Data transmission phase

After the optimal route is determined, the CH becomes aware of its next hop. The BS depends on the TDMA to assign a unique timeslot to each SN in the cluster. The BS constructs a number of tables that correspond with the number of clusters. Each table has information on a specific cluster such as cluster ID, SN ID and TDMA slot, role (member or CH), the next hop and status (sleep or active). The BS transmits a copy of each table to the concerned CHs which forward the tables to member nodes. All SNs (members and CHs) in the network utilise the duty cycle technique to programme the time of their awakening and sleep. This technique reduces inessential activity time, thereby saving the energy of the SNs. The SNs receive the information tables and use the duty cycle technique to switch their status between sleep and active modes. The SNs become active only when they aggregate data and send them to a CH through an allocated timeslot. The CH aggregates all the data from the SNs. When the CH knows its next hop, it transmits a HELLO message to the next hop and waits for a response. The CH starts sending data to the next CH in the allocated timeslot after receiving an acknowledgement message. The CH nearest the BS collects all the data it receives and delivers them to the BS. The flowchart of the CNBEER approach is shown in Fig. 3.

4. Simulation results and discussion

4.1. Simulation environment

The simulation environment is run in MATLAB to evaluate the protocol performance. The deployment region is set to 100 × 100 m^2, where 100 SNs are spread out randomly. The BS is adjusted to the position (100, 50) of the environment region. Every SN in the network has a primary energy level of 0.5 J and a maximum transmission range of up to 30 m. Table 3 presents the value of each parameter used in the simulation[24].

4.2. Simulation results

The performance of the CNBEER approach is compared with that of the existing protocols namely, LEACH-VA [18], PSO−C [19] and WOA-C [24] based on the simulation results. The results of simulations are concerned with the total residual energy and network lifetime.

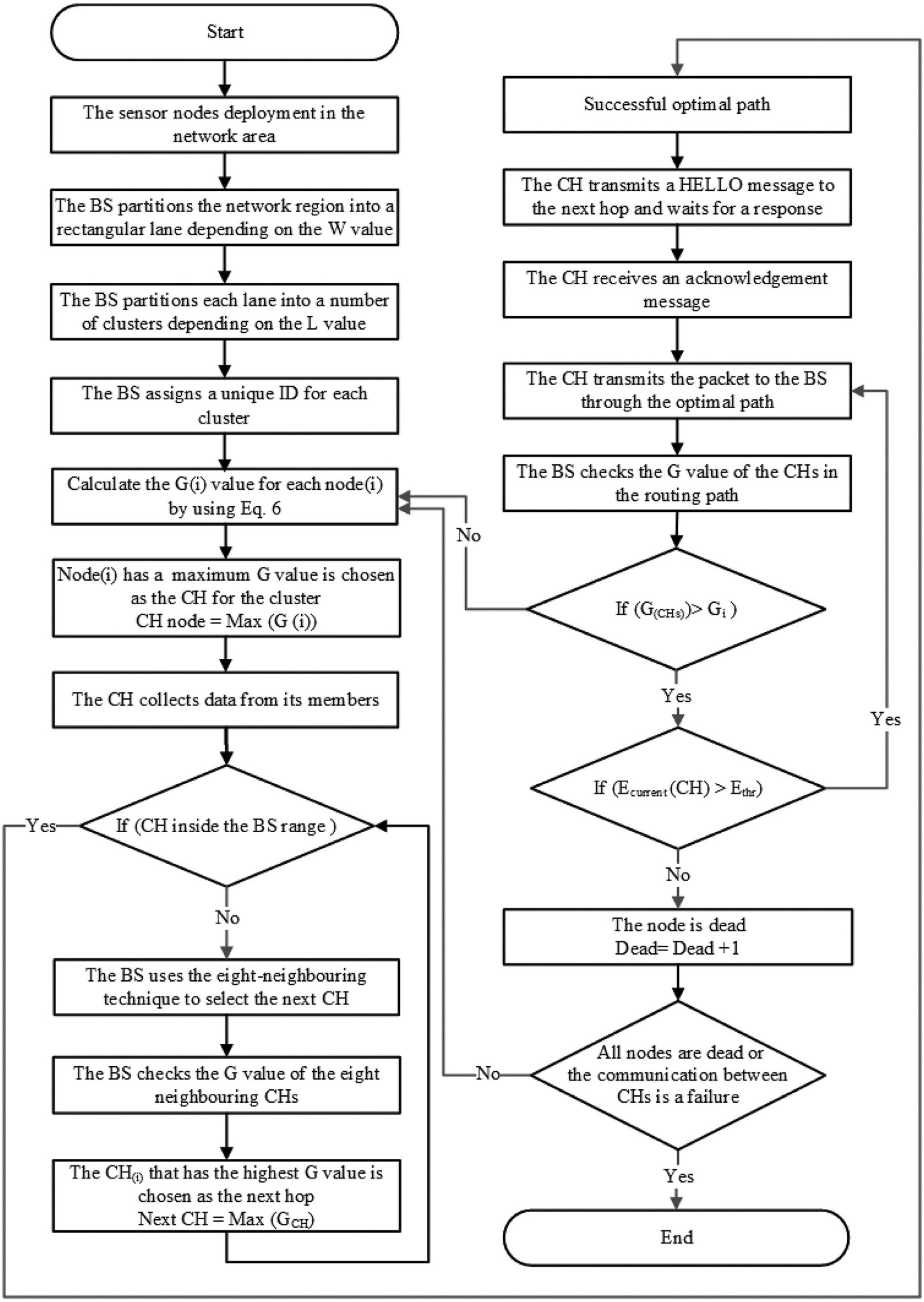

Fig. 3. Flowchart of CNBEER approach.

Table 3
Simulation environment.

Parameter	Value
BS Position	100 × 50
Deployment region	$100 \times 100m^2$
Number of SNs	100
z	40 m
Primary energy level of SN	0.5 J
EN_{fs}	10 pJ/bit/m^2
EN_{elec}	50 nJ/bit
EN_{mp}	0.0013 pJ/bit/m^4
Data packet length	4000 Bit

Network lifetime is a paramount criterion for evaluating the efficiency of an approach for WSNs. Network lifetime is assessed based on the number of rounds from the initial operation of a network to the last node death (LND). The simulation results of network lifetime for all the approaches are plotted in Fig. 4 which shows that the CNBEER protocol exhibits the highest network lifetime compared with the LEACH-VA, PSO−C and WOA-C methods. The lifetime of the proposed method is approximately 10,000 rounds, whereas the network lifetime of LEACH-VA, PSO−C and WOA-C is approximately 3296, 6739 and 7268 rounds, respectively. In terms of the LND, the CNBEER method keeps approximately 18% of all nodes alive until the end of the simulation unlike LEACH-VA, PSO−C and WOA-C, wherein all nodes are lost before the end of the simulation. The CNBEER approach clearly outperforms the other approaches because of the optimised CH selection process and rotation of CH role among the SNs.

Fig. 5 illustrates the simulation results of total residual energy for all approaches. From this figure, it can be seen that the total residual energy in our network is more than that in the LEACH-VA, PSO−C and WOA-C protocols. Energy consumption per round decreases more slowly when the CNBEER protocol is used compared with the other protocols. After 2860 rounds, the total residual energies in the LEACH-VA, PSO−C and WOA-C protocols are 3.587 J, 26.85 J and 26.85 J, respectively. However, the total residual energy in the CNBEER approach is 43.25 J. This result implies that the CNBEER is an energy-efficient method and increases the life of SNs. The CNBEER can be also used to aggregate environment parameters such as humidity and temperature.

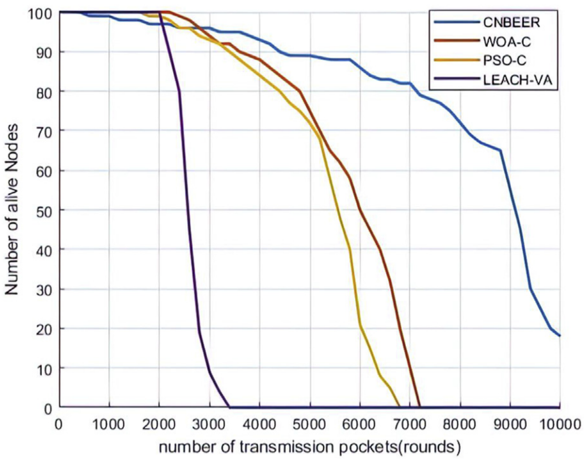

Fig. 4. Network lifetime performance for all approaches.

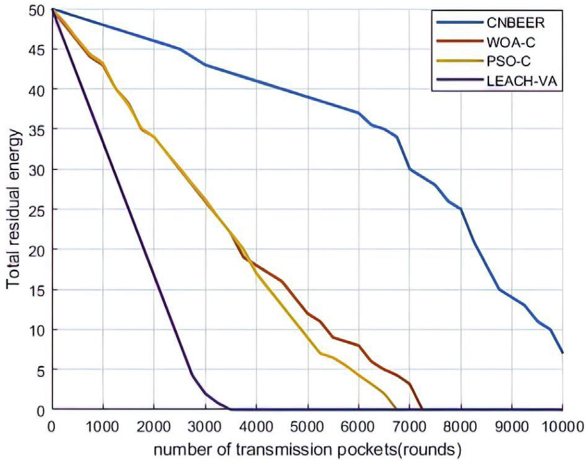

Fig. 5. Total residual energy for all approaches.

5. Conclusion

The clustering algorithm and neighbouring technique are presented as a new approach called CNBEER for data routing in WSNs. The CNBEER protocol forms equal-sized clusters and activates only the nodes that transmit data. The main advantage of the CNBEER protocol is that the G function selects the best CH in the cluster. The CH remains unchanged in each round depending on the G-value of the SNs. Substantial energy is saved and overheads are reduced, as the CH need not be changed for several rounds. The CH change helps to distribute the roles of the CH among the SNs. Thus, the network traffic burden is reduced, and energy consumption becomes uniform among the SNs. Consequently, the CNBEER protocol minimises the occurrence of network partitioning problems. The neighbouring technique establishes an optimal path to the BS by nominating the next CH in the route from only eight neighbouring CHs. The neighbouring method saves energy exponentially by decreasing the number of transmission paths. The described practical scenarios show that CNBEER is an energy-efficient approach that demonstrates better performance than the LEACH-VA, PSO−C and WOA-C approaches in respect of prolonging network lifetime.

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