

Retraction

Retracted: SCR-CC: A Novel Sensing Clustering Routing Algorithm Based on Collaborative Computing in Heterogeneous Sensor Networks

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

- (1) Discrepancies in scope
- (2) Discrepancies in the description of the research reported
- (3) Discrepancies between the availability of data and the research described
- (4) Inappropriate citations
- (5) Incoherent, meaningless and/or irrelevant content included in the article
- (6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation. The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

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Research Article

SCR-CC: A Novel Sensing Clustering Routing Algorithm Based on Collaborative Computing in Heterogeneous Sensor Networks

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In order to better improve the reliability of data transmission and extend the network lifetime, the paper proposes the Sensing Clustering Routing Algorithm Based on Collaborative Computing (SCR-CC). The proposed algorithm uses the characteristics of the perceptual radius, which obey the normal distribution, and gives the process of completing the expected value of the data transmission of any two nodes in the cluster. Secondly, the paper analysed the necessary conditions of the existence for the expected value of the number of neighbour nodes when the redundant nodes are closed and the working nodes meet arbitrary differences. Thirdly, the cluster angle formed by the base station and the cluster is used to optimize the clustering structure and complete the dynamic clustering process to achieve the energy balance of the entire network. Finally, the simulation experiments show that the proposed SCR-CC algorithm compared with the other three algorithms reduces the number of failed nodes by 11.37% on average and increases the network lifetime by 27.09% on average; therefore, the efficiency and effectiveness of the SCR-CC algorithm are verified.

1. Introduction

The wireless sensor network is a network system composed of high-density random deployment of sensor nodes [1-3]. It is a large self-organizing network that integrates the physical world and the information world [4-7]. It changes the interaction way between humans and nature and also realizes the organic combination of data acquisition, data transmission, and data processing.

Wireless sensor networks are mainly used in engineering fields such as military and national defences, industrial control, remote monitoring, environmental monitoring, medical monitoring, and intelligent transportation [8–12]. The energy of sensor nodes is limited, and its behavioural characteristics are mainly embodied in that it has a certain computing capability, communication capability, storage capability, and perception capability. How to effectively improve the network lifetime and restrain the rapid energy consumption of sensor nodes is a key issue in the research field of wireless sensor networks [13–16]. The wireless sensor network architecture mainly includes distributed sensor nodes, sink nodes, management nodes, and communication systems. In the initial stage of the network, the sensor node transmits the collected data directly or indirectly to the sink node through wireless communication, and then the sink node sends the data to the management end in a wireless or wired way. The process forms an uplink for data transmission, and the control terminal can also send instructions, monitoring tasks, and resource configuration commands to the sensor nodes through this link, and the process forms an uplink for transmission of control commands.

With the increase of the number of random time rounds, the wireless sensor network architecture presents a heterogeneous form; that is, the sensing radius and communication radius of any two sensor nodes are different, the size and shape of the cluster are different, and the coverage area is also different [17, 18].

In the monitoring area, each working sensor node can play a different role, such as cluster head node, member node, and relay node. In the cluster, the member nodes collect data and send the data to the cluster head node in a multihop manner along a present path.

In this process, data may be fused at the cluster head node or relay node. When data is transmitted among clusters, the relay node provides data forwarding services for neighboring clusters, and meanwhile, the data will be transmitted in a multihop manner or sent directly to the sink node [19–22]. During the above two processes, the cluster head node consumes more energy. In general, the node with higher energy is usually selected as the cluster head node, and at the same time, in order to better balance the energy of the entire network, the method of periodically rotating the cluster heads is used to solve the energy consumption problem.

In HSNs, in order to improve the reliability of data transmission, link retransmission technology, error correction code technology, and multipath transmission technology are generally used:

- (1) Link retransmission technology is an important technology for HSNs data transmission. Its characteristics are mainly reflected in that the link failure rate in HSNs is much higher than that of wired networks, and the failure rate will increase as the number of hops increases. The link retransmission technology just needs one retransmission to send the message successfully to the required node. Considering the effectiveness of HSNs network channels, link retransmission is an effective method. Its shortcomings are reflected as follows. First, the link retransmission technology will have a certain impact on the communication channel; when data is retransmitted in the channel, channel resources will be occupied with multiple times. Second, when a node receives data information, it needs to save the message for a period of time until it receives the confirmation information of the next hop. The data information will occupy the limited storage space of the node for a long time, which increases the delay of the entire network.
- (2) The error correction code technology can recombine the original data information by receiving any m(n > m) symbols among the *n* symbols. Compared with the link retransmission technology, the error correction code technology can achieve higher data reliability without link retransmission, and the operability is stronger. The main aspect of the deficiency is as follows. When the data packet is decomposed into several diversified symbols, it is necessary to consider the quantitative relationship between the data message and the symbols. The number of data messages cannot exceed the number of bits used to represent the message, and the number of symbols is smaller than the capacity of the external storage space used for calculation, which is more complicated to implement.
- (3) Multipath technology is the most common data transmission mechanism for HSNs. The introduction of multipath technology is to improve the reliability of data transmission and achieve network load balancing. When an unpredictable event occurs

on a known link while transmitting data, another path can be selected as a backup transmission path, which can effectively improve the reliability of data transmission. Since sending data packets on an alternative path can also be considered as another way of expressing data retransmission. Therefore, to a certain extent, it will have an impact on the number of data packets sent to the network. Multipath technology mainly relies on flooding routing discovery protocol to obtain alternate paths and allows each sensor node to continuously monitor neighboring nodes while updating the routing list to prevent routing interruption caused by the failure of sensor nodes and neighboring nodes. It is necessary to periodically broadcast flood messages to the HSNs network according to a certain number of time rounds and regularly strengthen the single path to repair failed or degraded path messages. The multipath method can effectively improve the reliability of data transmission and can achieve network load balancing. Multipath includes two types with the disjoint multipath and winding multipath.

The main contributions of the SCR-CC algorithm are as follows:

- (1) In the second section, this paper mainly analyses and researches the routing methods and a solution proposed by other scholars and introduces the key problems solved in this paper.
- (2) In the third section, based on the network model, the process of solving the expected value of data transmission between any two nodes in the cluster is given; when the redundant node is turned off, the condition that any two nodes are different is satisfied; the necessary condition for the existence of expectation for the number of neighboring nodes is proved.
- (3) In the fourth section, the influence of the cluster angle on the cluster structure, the optimization of the cluster angle, and the dynamic clustering process are analysed, and the functional relationship between the cluster angle and energy consumption is given. Based on the above analysis, this paper gives the implementation process of the SCR-CC algorithm.
- (4) In the fifth section, this paper mainly conducts comparative experiments with the other three algorithms on the four characteristics of failed nodes and time delays and network throughput and network lifetime, and the efficiency and effectiveness of the SCR-CC algorithm are verified.
- (5) The last section summarizes the paper and gives specific directions for future research.

2. Related Work

In recent years, many scholars at home and abroad have carried out in-depth and detailed research work on routing protocols. A lot of research work has shown that routing protocols can be divided into two different types, that is, plane routing and hierarchical routing [23, 24]. In the plane routing protocol, all sensor nodes have the same status and functions, and the nodes complete the data collection task, data transmission, and routing process through collaborative computing. Compared with ad hoc, heterogeneous sensor networks (HSNs) have a higher distribution density of nodes, the sensing area formed by the superposition of nodes is more complex, and the collection of data among adjacent nodes in the network is mostly based on the same phenomenon, which leads to the existence of a large number of redundant nodes. In hierarchical routing, network nodes are divided into corresponding clusters according to different clustering algorithms, and the logical view of the network presents a hierarchical relationship. Generally speaking, the formation of a cluster is based on the remaining energy of the sensor node and its proximity to the cluster head. The main purpose of hierarchical routing is to reduce the number of data messages sent by multihop communication and data fusion of the nodes in the cluster, which reduces the energy consumption of sensor nodes.

2.1. Plane Routing Protocol. Literature [25] proposes a routing control protocol based on dynamic prejudgment on the basis of flooding routing. The protocol neither does any maintenance on the network nor does any calculations on routing; it only requires the sensor nodes that receive the data information to send data packets out in a broadcast manner. The process is as follows. After a sensor node receives the data information from the previous-hop node, it first predicts whether its next-hop node has a certain storage space; if the storage space requirement is met, the sensor node sends the data information to the next-hop node or the data information will remain in the local sensor node until the beginning of the next cycle, and then the storage space of the next-hop node will be judged again. This cycle process continues until the data information is transmitted to the destination node. Literature [26] proposed a collaborative adaptive routing algorithm based on energy balance. The algorithm mainly focuses on two aspects. First, in order to better transmit data information to the next-hop node and avoid data sending and repeatedly receiving a large amount of redundant information in the channel, each sensor node needs to use a collaborative mode to determine whether other nodes need the data before sending data. At the same time, any sensor node can determine whether there is duplicate data information in other data receiving sensor nodes through metadata. Second, any sensor node in the network must monitor local energy consumption information in real time and change the working mode according to the energy difference relationship to extend the running time of the node itself and the entire network and ultimately achieve the purpose of extending the lifetime of the entire network. Literature [27] proposes a dynamically controllable routing protocol based on the data centre. The protocol is based on the data-centric fusion calculation of data information sent from different source nodes to reduce the generation of data redundancy, suppress the number of repeated transmissions of data, and improve the quality of service and resource

scheduling efficiency of the entire network. Thereby, it also extends the network lifetime. Literature [28] proposed Quick Convex Hull-Based Rendezvous Planning for Delay Harsh Mobile Data Gathering (QCHBRP). This proposed algorithm can effectively connect two nonadjacent wireless sensor networks through relay nodes and can also construct a shorter data transmission path to reduce data transmission delay. The basic idea of the algorithm is to use the path of the mobile base station to form a convex hull and record the inflection point of the convex hull as the position of the relay node to connect multiple nonadjacent wireless sensor networks. Then, the relay node is used as the gateway of two nonadjacent wireless sensor networks to reduce the number of data forwarding and transmission delay. And then, the QCHBRP algorithm divides the entire network into multiple grids and provides related approximate calculations for the distance among the grids so as to plan the optimal path from the source node to the destination node. Literature [29] proposes an enhanced routing control protocol. After the protocol collects low-rate data through the sink node, it sends enhanced information to the sensor node, where the data reaches the fastest. The enhanced information represents that the sink node requires high-speed data transmission. The corresponding neighboring nodes repeat the above operations in the same way and send the enhanced information to the next-hop node in turn until the data information is transmitted to the destination node, which forms a path from the source node to the destination node. The data will be sent to the sink node by the above optimal path. Literature [30] proposed an optimized network routing control protocol based on the ant colony algorithm. The protocol uses the ant colony algorithm to prove that most ants sending pheromone to each other can find the shortest path from the source node to the destination node. This protocol combines the network gradient and localization algorithm to calculate the shortest route of the wireless sensor network, which can well meet the requirements of WSN for saving, robustness, and scalability. Literature [31] proposes a highly reliable backup routing protocol. The basic idea of the protocol is to improve the reliability of routing by maintaining multiple available paths. The protocol uses localized algorithms to establish the optimal path between the source node and the sink node during operation. Meanwhile, in order to ensure that the protocol can still work normally when the optimal path fails, multiple redundant paths that do not intersect with the optimal path are constructed. Once the failure phenomenon occurs, the redundant path can be started for communication, and the communication path can ensure to be kept unblocked.

Literature [32] proposes a dynamic tree planning routing protocol. In order to generate multiple paths between each source node and sink node, the protocol needs to maintain multiple tree structures. Each dynamic tree grows outward with a node falling within the effective transmission radius of the sink node as the root. The selection of the path requires meeting certain QoS requirements and having certain energy reserves. Each node can select a path according to the energy of each path, the QoS measurement, and the priority of the data packet and send the data to the sink node. Although the plane routing protocol has a simple structure and is easy to implement, it also has some shortcomings. First, data will occupy the communication channel for a long time, which causes communication channel congestion, and the delay will increase, which is not conducive to data and information communication. Second, during data transmission a large number of data copies are

conducive to data and information communication. Second, during data transmission, a large number of data copies are generated, which results in a large amount of overlap. When two adjacent sensor nodes of the same kind are processing an event at the same time, the data collected by the two ones are similar, the calculations process are similar, and the complexity will become higher and is not good for calculations. Third, when the sensor nodes collect heterogeneous data, the inability by sending data to the sink node through the gradient path will cause the sink node or relay node to receive more multiple heterogeneous data with varying amounts, and the sink node and relay node are not used to complete the localized data fusion process. Fourth, in the path maintenance stage, energy issues are often ignored, the network lifetime is not extended, and it is not suitable for wireless sensor networks with frequent changes in largescale topology.

2.2. Hierarchical Routing Protocol. Literature [33] proposed a hierarchical routing algorithm based on low power consumption. The algorithm uses a random election of cluster heads, and the energy consumption of the entire network is evenly distributed to each sensor node itself, with the purpose of restraining the rapid energy consumption of the entire network. During the execution of the algorithm, the remaining energy of sensor nodes is used as a controllable parameter to establish a clustering structure. And during the reconstruction process of each cluster, the remaining energy of sensor nodes is constantly compared, and high energy is used as the cluster head node. After the finish of the first round of cycles, it compares the remaining energy among the sensor nodes again, and the cycle continues to complete the selection process of the cluster head node. Literature [34] proposed a path reconstruction routing protocol. This agreement is designed and improved on the basis of the LEACH agreement. The basic idea is that, under the premise of maintaining communication among cluster member nodes and adjacent nodes, multiple cluster head nodes communicate with the sink node in turn, and after the first round of cycles, it determines whether multiple cluster head nodes and sink nodes meet the alternate communication conditions, if the communication conditions are met, it continues to repeat the above operations, and if the communication conditions are not met, it compares the remaining energy of the cluster member nodes and lets the high-energy cluster members act as the cluster head node and repeat the last operation. Literature [35] proposed Compressed Sensing Routing-control-method with Intelligent Migration mechanism (CSR-IM). This method firstly determines the moving speed and position of the target node through the compressed sensing theory, and meanwhile, it uses the knowledge of probability to give the lower bound calculation process of the estimated value of the target node

in any period. Secondly, for the purpose of reducing the network load, a routing tree cantered on fog nodes is established to effectively obtain the data in the routing, which optimizes the data aggregation routing process and balances the energy cost of the entire network. Literature [36] proposed a Distributed and Morphological Operationbased Data Collection Algorithm (DMOA). The algorithm firstly uses a data collection algorithm to calculate the location information of each node according to the structured entropy value and meanwhile completes the process of mapping an event monitoring area, assisting in the construction of the location of neighboring nodes to reduce energy consumption. Secondly, the location information is distributed according to the cluster members to form the event backbone node and send the sensing data. According to the event sensing area range, Sink can approximately restore the event area data fusion operation. Thirdly, cluster members use a certain time unit as a period parameter to transmit data to the cluster head node to achieve the purpose of limiting the energy consumption of sensor nodes. Literature [37] proposed a clustering routing algorithm based on efficient data interaction. The algorithm firstly uses the signal strength of the sensor node to measure the distance information of all its neighboring nodes. After it determines the location information of the nearest neighboring node, it sends a signal to the neighboring node so that only the neighboring node receives the information. Secondly, the source node can only be the head node of the chain, any sensor node in the link can send and receive data to the neighboring nodes, and only the sensor node closer to the sink node can be selected to transmit data to the sink node in the link. Thirdly, in the data transmission process, the algorithm uses parallel processing to avoid channel conflicts and data redundancy to improve transmission data efficiency. Literature [38] proposed a data fusion method with a tree-type hierarchical structure. This method uses a tree structure as the research basis, and each layer of nodes can pass data to the upper or lower layer of nodes. This method requires that each layer of nodes can transmit data information to neighboring nodes of a given layer in a time period, and then the neighboring nodes that receive the data can repeat the above operations and finally pass the data to the sink node. By analogy, the last top layer can only keep one node as the first node of the chain. In order to make nodes converge communication among nodes in turn to balance the energy consumption of nodes, this method adopts the way of cyclically comparing the remaining energy of nodes in the chain after the finish of a certain period of time to repeatedly select the first node of the chain to achieve the goal of energy balance of the entire link. Literature [39] proposed a clustering routing protocol with real-time access to data information, which uses a multicluster structure of operation. In the process of cluster establishment, when the cluster head must be selected, the cluster head node can not only use the TDMA method to achieve data transmission but also broadcast the hard threshold and soft threshold in a flooding manner to all members in the cluster. When the cluster is stable, the cluster member node can perceive the data information; when the cluster member node detects the

amount of data for the first time and reaches the upper limit of the hard threshold, it turns on the transceiver of the sensor node for data transmission and reception and retains the received data information in the memory unit. When the amount of data is greater than the hard threshold, the soft threshold is activated to control, and the sensor node will temporarily store the data outside the storage space in the neighboring node. When the storage space of the local node is greater than the amount of overflow data, the local node will give it to the neighboring. The node sends the request and sends the data back to the local node. The protocol can effectively reduce the amount of data transmission, thereby improving the utilization of the entire network space.

Hierarchical routing can effectively alleviate the problem of channel congestion and restrain the rapid consumption of energy, but there are also certain shortcomings. First, after a sensor node is elected as the cluster head node, the position of the cluster head node is far away from the cluster member node or concentrated in a certain area; there will be no cluster head nodes around a large number of nodes; during data transmission, a large amount of network energy will be consumed. Second, in the initial stage of the network, since all sensor nodes have equal energy, and each of the cluster head nodes consumes roughly the same energy, the remaining energy of all nodes will be calculated repeatedly when the next cycle comes, and the amount of calculation is relatively large. It does not well suppress the delay problem. Third, energy balance is to achieve the purpose of prolonging the network lifetime. However, when energy balance is performed on the entire cluster, all sensor nodes have the same energy level, so it is very likely that all nodes in the cluster will fail in a certain period of time. Fourth, dynamically selecting the cluster head node will cause frequent changes in the cluster topology, which will consume a lot of network energy. Based on the advantages of the abovementioned plane routing and hierarchical routing, this paper proposes a Sensing Clustering Routing Algorithm Based on Collaborative Computing (SCR-CC). At the theoretical level, this paper presents the expected value proof process for completing data communication between any two nodes and uses heterogeneous characteristics to prove the necessary conditions for the existence of the expected value of the number of neighboring nodes when the working nodes meet any mutual differences.

The calculation of the cluster angle formed during data transmission, which is carried out through the base station and the cluster, is carried out, and the process of clustering structure optimization and dynamic clustering is also given. Finally, the effectiveness of the algorithm in this paper is verified by simulation experiments.

3. Network Model and Methods

3.1. Network Model. The number of sensor nodes in the network is N, and they are randomly deployed in the $M \times M$ square monitoring area. All sensor nodes are distributed in various clusters with different numbers to form nonuniform clusters. All nodes in the cluster can complete sensing tasks and data collection tasks and send the collected data to the

cluster head node. After the cluster head node performs effective fusion processing on the received data, the cluster head node sends the processed data to the sink node in a multihop manner, as shown in Figure 1.

The basic assumptions of the network model of the nonuniform cluster structure used are as follows:

- All sensor nodes can obtain their own location information through a certain positioning algorithm (such as RSSI and DTOA) and have a unique ID.
- (2) Once deployed, the sensor nodes cannot be moved and remain static.
- (3) The energy of the sink node is not subject to any restriction, at the initial moment, all sensor nodes have the same energy, and the computing and communication capabilities and storage capabilities are the same.
- (4) All sensor nodes are synchronized along with time.
- (5) The length of the boundary of the monitoring area is much longer than the sensing radius of the sensor node, ignoring the boundary effect. The sensing radius of all sensor nodes obeys the normal distribution $N(r_0, \delta^2)$. r_0 is the average perceptual radius of heterogeneous sensor nodes.
- (6) In the initial stage of the network, all sensor nodes are homogeneous; when the network completes the Nth round, all sensor nodes are heterogeneous.

In order to better read this paper, we have explained the main parameters, as shown in Table 1.

According to the characteristics of the sensor nodes, the energy consumption factors of the sensor nodes are mainly concentrated in the communication module, the calculation processing module, and the circuit conversion module. Among them, the communication module consumes a large amount of energy, which is mainly composed of the communication module itself and data fusion. The communication module mainly considers the energy consumption of the transmitting and receiving circuit and the energy consumption of the module power amplification. When the wireless sensor network communication module sends *l* bit data to the distance d, the energy consumption mainly includes the energy consumption of the transmitting circuit and the energy loss on the power amplifier. Within a certain controllable signal-to-noise ratio range, the energy consumption of one node to send data is as follows:

$$E_{tx}(l,d) = E_{elec}(l) + E_{amp}(l,d).$$
 (1)

Among them, $E_{tx}(l,d)$ represents the network energy consumed when sending *l* bit data to the target node whose distance is *d*. $E_{amp}(l,d)$ represents the network energy consumed by the power amplifier when sending *l* bit data to the target node with a distance of *d*. $E_{elec}(l)$ is expressed as the network energy consumed by *l* bit data in the transmitting circuit. The calculation of $E_{amp}(l,d)$ is related to the transmission channel model. When the transmission distance is less than the threshold d_0 , the energy consumption of the power amplifier adopts the free space model, when the

 ε_{fs} $\varepsilon_{\rm amp}$

R $r_0 \\ \delta^2$

D

 M^2

 η_k

Θ

Р

R



FIGURE 1: Network model of nonuniform clustering structure.

Parameter	Description
d_0	Distance threshold
Eelec	Energy consumed by 1-bit data
Eamp	Energy consumed by the power amplifier
ε_{fs}	Proportional parameter
$\varepsilon_{\rm amp}$	Proportional parameter

TABLE 1: Parameter description.

transmission distance is greater than the threshold d_0 , the energy consumption of the power amplifier adopts the multichannel attenuation model, and the formula is as follows:

$$E_{\rm amp}(l,d) = l\varepsilon_{fs}d^2, \quad d < d_0, \tag{2}$$

Sensing radius

Expect radius Variance

Euler distance

Monitoring area

Proportional dimension

Cluster angle

Density of nodes

Communication radius

$$E_{\rm amp}(l,d) = l\varepsilon_{\rm amp}d^4, \quad d \ge d_0, \tag{3}$$

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp}}}.$$
 (4)

Among them, ε_{fs} and ε_{amp} are the energy consumption required in the corresponding model, respectively. d is the

transmission distance and d_0 is the distance threshold parameter. Substituting formulas (2) and (3) into formula (1), we can get the following formula:

$$E_{tx}(l,d) = \begin{cases} lE_{elec} + l\varepsilon_{fs}d^2, & d < d_0, \\ lE_{elec} + l\varepsilon_{amp}d^4, & d \ge d_0. \end{cases}$$
(5)

Considering the receiving circuit, when the sensor node receives l bit data, the network energy consumed is as follows:

$$E_{rx}(l,d) = lE_{\text{elec}}.$$
(6)

3.2. Issues and Solutions. The number of sensor nodes is N, which randomly deploys in the $M \times M$ monitoring area and divides into clusters of different sizes and numbers in a nonuniform manner; the transmission method is multihop to complete the data transmission among nodes. The clusters can transmit data by the relay node, or the cluster head node can transmit directly with the base station. The sensing radius of all sensor nodes obeys the normal distribution $N(r_0, \delta^2)$. When meeting the basic coverage of moving target nodes in advance, how to complete the data transmission among multihop nodes in the family and turn off redundant nodes and calculate the number of working nodes' expected value will be the first focus of this paper.

Theorem 1. In a cluster, the expected value of normal data communication between any two adjacent nodes is $E(\eta_k) = 1 - [1 - (\pi(r_0^2 + \delta^2)/S(M^2))]^k$, where k is the number of working nodes in the cluster and $S(M^2)$ is the area of the monitoring area.

Proof. The node is randomly deployed in the $M \times M$ square area of the monitoring area, and its area is M^2 . In order to ensure normal communication among nodes and the convenience of calculation, the paper takes a single hop as the research basis. In the cluster, any neighboring node can maintain normal communication, and any node s_i must be covered by another neighboring node s_i ; that is, s_i must be located within the disc with r_i as the sensing radius, and the formula is as follows:

$$p_i = \frac{S(\pi r_i^2)}{S(M^2)}.$$
(7)

Since the sensing radius of any sensor node s_i obeys the normal distribution $N(r_0, \delta^2)$ and $r_0 \ge 3.3\delta$, the probability that any node can maintain data communication with another node in the cluster is as follows:

$$p = \int_{0}^{2r_0} p_i \frac{1}{(2\pi)^{1/2}} \exp\left(-\frac{(r_i - r_0)^2}{(2\delta^2)}\right) dr_i.$$
 (8)

We let $x = (r_i - r_0/\delta)$ and substitute formula (7) into formula (8); we can get the following formula:

$$p = \frac{1}{S(M^2)} \left(\frac{\pi}{2}\right)^{1/2} \left[\int_{-\frac{r_0}{\delta}}^{\frac{r_0}{\delta}} \delta^2 x^2 \exp\left(-\frac{x^2}{2}\right) dx \right] + \frac{1}{S(M^2)} \left(\frac{\pi}{2}\right)^{1/2} \left[\int_{-\frac{r_0}{\delta}}^{\frac{r_0}{\delta}} 2\delta x r_0 \exp\left(-\frac{x^2}{2}\right) dx + \int_{-\frac{r_0}{\delta}}^{\frac{r_0}{\delta}} r_0^2 \exp\left(-\frac{x^2}{2}\right) dx \right].$$
(9)

Calculating formula (9), we can get formula (10):

$$p = \frac{1}{S(M^2)} \left(\frac{\pi}{2}\right)^{1/2} \left[-\delta^2 x \, \exp\left(-\frac{x^2}{2}\right) \right| \frac{\frac{r_0}{\delta}}{\frac{r_0}{\delta}} + (2\pi)^{1/2} \delta^2 + (2\pi)^{1/2} r_0^2 \right] \approx \frac{\pi (r_0^2 + \delta^2)}{S(M^2)}.$$
 (10)

In the cluster, since all the sensor nodes are relatively independent, the probability of any node in the monitoring area to communicate with the adjacent *k* nodes is as follows:

$$p_{k} = \sum_{i=1}^{k} {k \brack i} p^{i} (1-p)^{k-i} = 1 - \left(1 - \frac{\pi \left(r_{0}^{2} + \delta^{2}\right)}{S(M^{2})}\right)^{k}.$$
 (11)

For the monitoring area, the expected value of ensuring data communication between one node and at least one of the k nodes is as follows:

$$E(s_i) = p_k S(M^2), \tag{12}$$

$$E(\eta_k) = \frac{E(s_i)}{S(M^2)} = p_k = 1 - \left[1 - \frac{\pi(r_0^2 + \delta^2)}{S(M^2)}\right]^k.$$
 (13)
he proof is complete.

The proof is complete.

Theorem 2. Turning off redundant nodes and when any two nodes in the cluster are mutually different, the necessary conditions for the existence of the expected value of the number of neighboring nodes are

$$E(n) \ge \left[\frac{\ln\left[1 - E(\eta_k)\right] - f(\varphi)}{f(\varphi)}\right] \cdot \frac{4\pi r_0^2 + 2\pi\delta^2}{S(M^2)}.$$
 (14)

Among them, we let $f(\varphi) = \ln[1 - (\pi (r_0^2 + \delta^2)/S(M^2))].$

Proof. According to formula (13), we can get the expected value of data communication between any two adjacent nodes; therefore, the number of nodes in the cluster can be obtained as follows:

 $kf(\varphi) = \ln[1 - E(\eta_k)].$

$$k = \frac{\ln[1 - E(\eta_k)]}{f(\varphi)}.$$
 (16)

In the cluster, since any two adjacent nodes are different from each other, we use r_i to denote the sensing radius of the sensor node s_i and r_i to denote the sensing radius of the sensor node s_i . In order to meet the maximum data communication radius range, the sensor nodes s_i and s_j should be located within the radius of $r_i + r_j$. The probability formula is as follows:

$$p_{(i,j)} = \frac{\pi (r_i + r_j)^2}{S(M^2)}.$$
(17)

In the cluster, any sensor node is different from its neighboring nodes, and it satisfies that the sensing radius obeys the normal distribution $N(r_0, \delta^2)$, $r_0 \ge 3.3\delta$; therefore, the probability when any sensor node communicates with its neighboring nodes is shown as follows:

$$p = \int_{0}^{2r_{0}} \int_{0}^{2r_{0}} p_{(i,j)} \frac{1}{2\pi\delta^{2}} \exp\left[-\frac{(r_{i} - r_{0})^{2} + (r_{j} - r_{0})^{2}}{2\delta^{2}}\right] dr_{i} dr_{j}.$$
(18)

After calculating formula (18), we can obtain the following:

$$p = \frac{1}{S(M^2)} \left[\int_0^{2r_0} \int_0^{2r_0} \frac{r_i^2}{\delta^2} \exp\left[-\frac{(r_i - r_0)^2 + (r_j - r_0)^2}{2\delta^2} \right] dr_i dr_j \right] + \frac{1}{S(M^2)} \left[\int_0^{2r_0} \int_0^{2r_0} \frac{r_i r_j}{\delta^2} \exp\left[-\frac{(r_i - r_0)^2 + (r_j - r_0)^2}{2\delta^2} \right] dr_r dr_j \right].$$
(19)

(15)

According to formula (10), we can get the following formulas:

$$\int_{0}^{2r_{0}} \int_{0}^{2r_{0}} \frac{r_{i}^{2}}{\delta^{2}} \exp\left[-\frac{(r_{i} - r_{0})^{2} + (r_{j} - r_{0})^{2}}{2\delta^{2}}\right] dr_{i} dr_{j} \approx \pi \left(r_{0}^{2} + \delta^{2}\right),$$

$$\int_{0}^{2r_{0}} \frac{r_{i}}{(2\pi)^{1/2}\delta} \exp\left[-\frac{(r_{i} - r_{0})^{2}}{2\delta^{2}}\right] dr_{i} = \int_{-\frac{r_{0}}{\delta}}^{\frac{r_{0}}{\delta}} \frac{(r_{0} + \delta x)}{(2\pi)^{1/2}} \exp\left(-\frac{x^{2}}{2}\right) dx.$$
(20)

After calculating formula (21), we can obtain the following:

$$\int_{0}^{2r_{0}} \frac{r_{i}}{(2\pi)^{1/2} \delta} \exp\left[-\frac{(r_{i} - r_{0})^{2}}{2\delta^{2}}\right] dr_{i} = r_{0},$$
(22)

$$\int_{0}^{2r_{0}} \int_{0}^{2r_{0}} \frac{r_{i}r_{j}}{\delta^{2}} \exp\left[-\frac{(r_{i}-r_{0})^{2} + (r_{j}-r_{0})^{2}}{2\delta^{2}}\right] dr_{r} dr_{j} = 2\pi r_{0}^{2}.$$
(23)

Comprehensive formulas (19), (20), and (23), we can obtain the following relations:

$$p = \frac{4\pi r_0^2 + 2\pi\delta^2}{S(M^2)}.$$
 (24)

Among the k working nodes, the expected value for any node to maintain normal data communication with its neighboring nodes is shown as follows:

$$E(n) = (k-1)p.$$
 (25)

Substituting formulas (16) and (24) into formula (25), we can get formula (26):

$$E(n) = \left[\frac{\ln\left[1 - E(\eta_k)\right] - f(\varphi)}{f(\varphi)}\right] \cdot \frac{4\pi r_0^2 + 2\pi\delta^2}{S(M^2)}.$$
 (26)

Therefore, the condition for the expected number of neighboring nodes to be met is as follows:

$$E(n) \ge \left[\frac{\ln\left[1 - E(\eta_k)\right] - f(\varphi)}{f(\varphi)}\right] \cdot \frac{4\pi r_0^2 + 2\pi\delta^2}{S(M^2)}.$$
 (27)

The proof is complete.

4. Cluster Angle Optimization

4.1. Formation of Cluster Angles. In the nonuniform clustering algorithm, the cluster head node is not only the control centre of the cluster but also the processing centre and computing centre of the cluster for data fusion; therefore, for the cluster head node, the energy consumed is higher than other member nodes in the cluster. In order to prolong the network lifetime, the survival time of clusters closer to the Based Station (BS) must be prolonged. Compared with other clusters, the scale of the cluster closer to the base station should be smaller than the scale of other clusters far away from the base station. On the one hand, according to formula (5), when the cluster size is larger, the distance between adjacent cluster heads will become larger, which forces the distance parameter to a value of 4.

In this case, when the cluster head node sends data, a lot of network energy would be consumed. On the other hand, since the topology of the cluster structure changes frequently, the energy consumption is large, and the signal attenuation index of the communication between the neighboring cluster head and the relay node must be considered; therefore, the distance parameter in this paper is set to 2. When dividing the front and back clusters, due to the different areas of the clusters, the paper uses V to represent the monitoring area with an angle of θ . The monitoring area is divided into several clusters with BS as the centre, which is shown in Figure 2.

If *n* sensor nodes are randomly deployed in a V-shaped monitoring area with an angle of θ , θ is called the clustering angle, the V-shaped monitoring area is divided into *m* fanshaped areas, and each subarea is called a cluster. The distance between two clusters is $d_i(1 \le i \le m)$, which represents the single-hop distance of data communication among clusters. Starting from the base station and extending outwards, the closest distance from the cluster to the base station is called the top-level cluster; the farthest distance from the base station is called the subregion V_1 is called C_1 , the cluster



FIGURE 2: Structure of cluster angle.

formed by the subregion V_2 is called C_2 , and so on, *n* sensor nodes are divided into *m* clusters, the radius of the *V* region is *R*, and we can get the following relations:

Let n_i be the number of nodes in the cluster C_i and S_i be the area of the subregion V_i , and then formula (29) can be obtained:

$$R = d_1 + d_2 + d_3 + \dots + d_{m-1} + d_m.$$
(28)

$$\begin{cases} \sum_{i=1}^{m} n_{i} = n, \\ n_{i} = \rho S_{i} = \frac{\rho \theta}{2} \left[\left(\sum_{j=1}^{j} d_{j} \right)^{2} - \left(\sum_{k=1}^{k=i-1} d_{k} \right)^{2} \right] = \frac{\rho \theta}{2} \left(d_{i}^{2} + 2d_{i} \sum_{k=1}^{k=i-1} d_{k} \right), \\ n_{i+1} = \rho S_{i+1} = \frac{\rho \theta}{2} \left[\left(\sum_{j=1}^{j} d_{j} \right)^{2} - \left(\sum_{k=1}^{k=i} d_{k} \right)^{2} \right] = \frac{\rho \theta}{2} \left(d_{i+1}^{2} + 2d_{i+1} \sum_{k=1}^{k=i} d_{k} \right), \end{cases}$$
(29)

where ρ is the distribution density of nodes in the cluster. For high-density wireless sensor networks, the clusters which are closer to the base station should be smaller in size, which will extend the lifetime of the wireless sensor network; therefore, the number of member nodes in the cluster which is closer to the base station should be smaller than the number of members in the farther cluster, that is, $n_{i+1} \ge n_i$.

In order to the convenience of calculation, we suppose that the single-hop distance in data communication is d_{1hop} , which satisfies $d_1 = d_2 = d_3 = \ldots = d_{m-1} = d_m$. In the cluster, the cluster head node must complete at least one data processing task, which receives the data information sent by the cluster member nodes and the data information uploaded to the cluster by the lower cluster head. After the cluster head node of the cluster performs fusion processing on the two types of data, it sends the fused data to the upper cluster. If the amount of data processed is large, the energy of the cluster head node would be very likely to be exhausted and unable to complete the task, which will cause network failure.

In the case of fewer cluster members, after the cluster head node completes the data transferring of other cluster heads, a large amount of energy remains, which causes unnecessary waste of energy. Therefore, reasonable planning of the cluster size is essential to network performance. This is the second focus of this paper.

4.2. Optimization of Cluster Angle. Now we take Figure 2 as an example to illustrate, the cluster head node of cluster $C_i(i \le m)$ mainly completes the fusion of the lower layer data and the data of this layer, as well as the calculation and processing tasks. Firstly, if there is a lot of data to be processed, the cluster head node is likely to be unable to process a large amount of data due to energy problems, which will cause the network to fail. Therefore, each cluster must limit the scale of the cluster. Secondly, the topology of the cluster changes frequently, and the cluster head node is constantly changed with time as the rotation cycle; the change will not only bring about a large amount of energy consumption of the cluster head node of the cluster but also involve the energy consumption of each node in the cluster and will also affect the energy consumption of the cluster heads of neighboring clusters. If the cluster head nodes of each cluster adopt a continuous type to act as the control and processing centre of the cluster until the number of work reaches a certain optimal value f_0 , then the energy required for the next round of new cluster head nodes will be significantly reduced. It can be seen from Figure 2 that C_m is the largest cluster, and the goal of optimizing network energy can be achieved by controlling the single-hop distance d_{1hop} and the clustering angle θ . Within the same clustering angle θ , the optimal value that the cluster head node of a certain cluster continuously serves as the control and computing centre of the cluster should satisfy the following formula:

$$\sum f_1 \ge \sum f_2 \ge \sum f_3 \cdots \sum f_{m-1} \ge \sum f_m.$$
(30)

When the clustering angle θ is used as the dividing plane and formula (30) is satisfied, network connectivity can maintain a certain degree of stability and sustainability. At the same time, it can also ensure that the data of the bottom cluster reaches the top cluster and is successfully sent to the base station. By the above analysis, it can be seen that the parameter single-hop distance d_{1hop} and the clustering angle θ play a vital role in the clustering scale, and the optimal number of times f_0 that the cluster head node continuously occupies the local control and calculation tasks also plays an important role for restraining the network energy consumption.

Theorem 3. In a given network of single-hop distance d_{1hop} and clustering angle θ , the optimal clustering angle θ_{opt} should satisfy the following relations:

$$\theta_{\rm opt} = \sqrt{\frac{8\pi^3 (3E_{\rm elec} + E_{\rm cpu})}{N (2E_{\rm elec} + E_{\rm cpu})}}.$$
 (31)

Proof. Let N_c be the number of cluster head nodes, N be the number of sensor nodes, R be the distance from the farthest cluster to the base station, m be the number of clusters, θ be the clustering angle, d_{1hop} be the single-hop distance of the sensor node, and E_{cpu} be the consumed energy when the node of the sensor processes single-byte data, and the signal attenuation coefficient is 2.

When the sensor node calculates and analyses l bit byte data, the energy consumed is as follows:

$$P_{\rm cpu} = lE_{\rm cpu}.$$
 (32)

In the single-hop mode, the data l bit is uploaded from the bottom cluster to the top cluster, and the energy consumed is as follows:

$$E = l \times \left[\frac{R}{d_{1\text{hop}}}\right] \times \left(2E_{\text{elec}} + E_{\text{cpu}} + \varepsilon_{\text{amp}} \times d_{1\text{hop}}^2\right), \quad (33)$$

where $|R/d_{1hop}|$ is the number of divided cluster layers and we take the upper limit. The single-hop distance with the lowest energy consumption is as follows:

$$d_{\rm opt} = \sqrt{\frac{2E_{\rm elec} + E_{\rm cpu}}{\varepsilon_{\rm amp}}}.$$
 (34)

In a given network, the clustering angle θ and the number of cluster head nodes can be expressed as follows:

$$\begin{cases} N_c = m \left[\frac{2\pi}{\theta} \right], \\ m = \left[\frac{R}{d_{1\text{hop}}} \right]. \end{cases}$$
(35)

According to formula (35), we can get the following relations:

$$N_c = \left[\frac{2\pi}{\theta} \times \frac{R}{d_{1\text{hop}}}\right].$$
 (36)

In a cluster, when a cluster member node sends data to the cluster head node once in a certain period, the cluster head node can complete the specified data fusion and calculation processing operations. In the cluster, the distance between the cluster member node and the cluster head node is relatively close, and the signal attenuation index is 2. We assume that the average distance from the cluster member node to the cluster head node is d_{ave} , and the energy consumption of the cluster member node is as follows:

$$E_{cn} = l \Big(E_{\text{elec}} + \varepsilon_{\text{amp}} d_{\text{ave}}^2 \Big).$$
(37)

The average distribution density of cluster member nodes in each cluster can be expressed as follows:

$$\rho(x, y) = \frac{R^2}{N_c}.$$
(38)

The average distance from the cluster member node to the cluster head node can be approximately expressed as follows:

$$d_{\text{ave}}^{2} = \iint \left(x^{2} + y^{2}\right) \rho(x, y) dx dy = \iint r^{2} \rho(r, \theta) dr d\theta = \frac{R^{2}}{2\pi N_{c}}.$$
(39)

In any cycle, when a cluster member node sends *l* bit data to the cluster head node, the total network energy consumed is as follows:

$$E_{\rm cn_tot} = l \left(N - N_c \right) \left(E_{\rm elec} + E_{\rm cpu} + \frac{\varepsilon_{\rm amp} R^2}{2\pi N_c} \right).$$
(40)

In each cycle, the cluster head node of the cluster is not only responsible for receiving the data information sent by the upper cluster head node but also fusing and calculating the data information received and meanwhile sending the processed data to the upper cluster head node or base station. Therefore, according to formula (33), the energy consumed by the cluster head node of this cluster is as follows:

$$E_{\rm ch_tot} = lN_c \Big(2E_{\rm elec} + E_{\rm cpu} + \varepsilon_{\rm amp} \times d_{\rm 1hop}^2 \Big).$$
(41)

In the whole process, when all cluster head nodes and cluster member nodes in the network complete data transmission, the network energy consumed is as follows:

$$E_{\text{tot}} = E_{\text{cn_tot}} + E_{\text{ch_tot}} = l \left(N - N_c \right) \left(E_{\text{elec}} + E_{\text{cpu}} + \frac{\varepsilon_{\text{amp}} R^2}{2\pi N_c} \right) + N_c \left(2E_{\text{elec}} + E_{\text{cpu}} + \varepsilon_{\text{amp}} \times d_{1\text{hop}}^2 \right)$$

$$= l \left[N \left(E_{\text{elec}} + E_{\text{cpu}} \right) - \frac{\varepsilon_{\text{amp}} R^2}{2\pi} + \frac{\varepsilon_{\text{amp}} N R^2}{2\pi N_c} + N_c \left(3E_{\text{elec}} + E_{\text{cpu}} \right) \right].$$
(42)

When the optimal single-hop distance formed by each cluster head node with the same clustering angle θ is satisfied, there are the following relations, $d_{1hop} = d_{opt}$. According to formula (34) and formula (35), the total energy consumed by the entire network E_{tot} , which can be calculated as a function of the clustering angle θ , that is, $E_{tot} = f(\theta)$, we take the derivative of the variable θ and set it to 0, and then the optimal clustering angle θ_{opt} can be obtained, which is shown as follows:

$$\theta_{\rm opt} = \sqrt{\frac{8\pi^3 (3E_{\rm elec} + E_{\rm cpu})}{N(2E_{\rm elec} + E_{\rm cpu})}}.$$
(43)

The proof is complete.

4.3. Implementation of SCR-CC Algorithm. In the subcluster (SC) establishment phase, the base station first broadcasts a message to all clusters, and the message includes the coordinates and identification ID of the base station. When the single-hop distance of cluster member nodes meets $d_{1\text{hop}} \ge d_{\text{opt}}$, the base station determines the top cluster head node according to the remaining energy of the cluster members and the location information of the cluster members, when the determination of the top cluster head node has been completed, the base station will use the same method to determine the next-level cluster and so on. When the cluster member node successfully receives the base station message, it will feed back its location message and identification ID to the base station and determine which adjacent cluster it belongs to according to the constraint conditions. The main functions of the constraint conditions are as follows. Firstly, it allows cluster member nodes to quickly find which adjacent cluster they belong to. Secondly, cluster members can determine their own location and identification when they broadcast messages. Thirdly, it can provide the basic information of constructing clusters for adjacent clusters. The neighboring clusters can construct this cluster according to the construction method of the upper cluster. The constraints are as follows:

$$S = \left\lfloor \frac{2\pi}{\theta} \right\rfloor, \ L = \left\lfloor \frac{d_{\text{tot}}}{d_{1\text{hop}}} \right\rfloor$$

$$\left\lfloor \frac{d_i}{L} \right\rfloor \times d_{1\text{hop}} \le \sqrt{x^2 + y^2} \le \left(\left\lfloor \frac{d_i}{L} \right\rfloor + 1 \right) \times d_{1\text{hop}}.$$
(44)

After the subcluster is successfully established, the head node of the subcluster will send broadcast information to the cluster. After the cluster member node successfully receives the message, it uses the constraint formula (44) to calculate which adjacent subcluster it belongs to, and meanwhile, it transmits the feedback message to the subcluster head node. When the subcluster head node successfully receives the feedback message sent by the cluster member node, it analyses the location message and ID of the cluster member node and calculates the optimal location information of the subcluster head node, and according to the TDMA mechanism, the cluster member node and the next-level subcluster member nodes will be allocated working time slots; then the candidate cluster head node of the cluster will be determined by formulas (34) and (43). When the cluster member node successfully receives the working time slot and the candidate cluster head node message from the subcluster head node, the cluster member node enters a stable working state, and at the same time, it sends the collected data information to the subcluster head node. When the subcluster member nodes are working in the nonslot phase, the transmitting module is turned off and enters the dormant state to save network energy. In each cycle, the cluster member node must record the number of its work and the number of elected subcluster head nodes and determine whether to become a candidate node through the remaining energy size and location information of the cluster member node. The steps of being successfully elected as the head node of the subcluster in the SCR-CC algorithm are as follows:

Step 1. Construct subclusters and cluster member nodes.

Step 2. The subcluster cluster head node broadcasts the message, and the cluster member node successfully receives the message from the subcluster cluster head node.

Step 3. After the cluster member node receives the message, it sends a feedback message to the subcluster cluster head node.

Step 4. The subcluster head node analyses the message sent by the cluster member node, calculates the working times of the cluster member node and the working time slot of the cluster member node and the lower cluster head node, and determines its candidate subcluster head node.

Step 5. The subcluster head node continuously receives the message sent by the cluster member node, and after the data is effectively merged, it is sent to the upper cluster head node or the base station.

Step 6. Determine whether the remaining energy and location information of the cluster head node of the subcluster and the workload meet the constraint conditions.

Step 7. If the constraint conditions are met, then go to Step 2.

Step 8. If the constraints are not met, enter the next cycle and replace the cluster head node of the subcluster.

The subcluster head establishment and data forwarding in the SCR-CC algorithm are shown in Algorithms 1 and 2.

5. Results and Discussion

In order to evaluate the system further, this paper uses MATLAB2017b to randomly deploy 3500 sensor nodes in a square area of $100 \times 100 \text{ m}^2$, $300 \times 300 \text{ m}^2$, and $500 \times 500 \text{ m}^2$. The base station is set at the centre of the square area, a circular disk is constructed with the centre as a circle with a radius of D/2, and the circular disk is tangent to the four sides of the square. Base station coordinates are as follows: BS1 = (150, 150), BS2 = (250, 250), *R*1 = 150, and *R*2 = 250. The initial energy of the sensor node is 5 J, the sensing radius is 5 m, the data packet length is 500 bits, the broadcast data length is 200 bits, $E_{\text{cpu}} = 5 \text{ nJ/bit}, \quad \varepsilon_{\text{amp}} = 0.65 \text{ nJ/m}^2/\text{bit}, \text{ and } E_{\text{elec}} = 50 \text{ nJ/bit}.$ According to formula (34), the single-hop distance is calculated as $d_{opt} = 12.71$ m; according to formula (35), the number of clusters is $m_1 = 11.08$ and $m_2 = 19.66$, and the lower limit of the above three sets of values can be obtained; that is, $m_1 = 11$ and $m_2 = 19$. In order to save network energy consumption, the number of subcluster member nodes closer to the base station is smaller than the number of member nodes in the subcluster farther away. Since the communication distance of the subclusters farther from the base station is longer and the member nodes consume more network energy, the member nodes of the farther subclusters firstly appear as the fail nodes. At the same time, the network model adopted in this paper also guarantees that the final failure node should be located in a subcluster closer to the base station.

5.1. Comparison of Failed Nodes. Figures 3-6, respectively, show the comparison diagrams between cluster head nodes and failed cluster head nodes under different monitoring areas and times. Now we take Figures 3 and 6 as examples for analysis. Figure 3 shows the comparison diagram between the cluster head node and the failed cluster head node when the monitoring area is $300 * 300 \text{ m}^2$ and t = 100 s. It can be seen from Figure 3 that the three algorithms are compared with the SCR-CC algorithm; as the number of cluster head nodes increases, the number of failed cluster head nodes will also increase; however, in the proposed SCR-CC algorithm, the number of failed cluster head nodes is relatively stable or the increasing number of failed cluster nodes is less than the other three algorithms. When the number of cluster head nodes is 45, the number of cluster head nodes in the SCR-CC algorithm is 8 and 11; however, the number of cluster head nodes in the other three algorithms is 15, 21, and 25. When the number of cluster head nodes is 60, the number of failed cluster head nodes in the SCR-CC algorithm is 8 and 14; however, the number of failed cluster head nodes in the other three algorithms is 18, 36, and 40, respectively. Under different numbers of cluster head nodes, the number of

failed cluster head nodes in the SCR-CC algorithm is relatively stable. Figure 6 is the diagram that shows the comparison of the number of cluster head nodes and the number of failed cluster head nodes at the condition of $500 * 500 \text{ m}^2$ and t = 300 s. It can be seen from Figure 6 that when the number of cluster head nodes is 80, the number of failed cluster head nodes in the SCR-CC algorithm is 17 and 19; however, the number of failed cluster head nodes in the other three algorithms is 23, 25, and 29, respectively; when the number of cluster head nodes is 110, the number of failed cluster head nodes in the SCR-CC algorithm is 35 and 43; however, the number of failed cluster head nodes in the other three algorithms is 56, 61, and 65, respectively.

Figures 7–10, respectively, show the comparison schematic diagrams between cluster member nodes and failed cluster member nodes under different monitoring areas and times. Now we take Figures 7 and 10 as an example for analysis. Figure 7 uses $300 * 300 \text{ m}^2$ and t = 100 s as the reference condition. It can be seen from Figure 7 that as the number of cluster member nodes increases, the number of failed cluster member nodes for the four algorithms also increases, but in the SCR-CC algorithm, the increased range of the number of failed cluster member nodes is significantly smaller than that of the other three algorithms. When the number of cluster member nodes is 700, the number of failed cluster member nodes of the SCR-CC algorithm is 40 and 46; however, the number of failed cluster member nodes of the other three algorithms is 57, 66, and 85, respectively. When the number of cluster member nodes is 1100, the number of failed cluster member nodes of the SCR-CC algorithm is 130 and 154; however, the numbers of failed cluster member nodes of the other three algorithms are 219, 246, and 355, respectively.

Compared with the other three algorithms, the number of failed nodes in the SCR-CC algorithm reduces by an average of 11.37%. The main reason is that the SCR-CC algorithm divides the entire network into clusters of different sizes; by optimizing the relevant parameters of the cluster size, the energy consumption in the cluster is reduced, and the cluster head node is used as the control centre and data processing centre of the cluster; the selection of the head node is based on the remaining energy and location information to achieve the goal of reducing frequent cluster head replacement. However, the other three algorithms are based only on the remaining energy and do not consider the location information of the cluster head node. In addition, the CSR-IM algorithm and the DMOA algorithm both use the replacement of the cluster head node within a unit time to achieve the purpose of energy balance within the cluster. The disadvantage is that the cluster head node is replaced too frequently, which requires more energy consumption of the network to maintain the energy balance of the entire network. Therefore, the number of failed nodes in the SCR-CC algorithm is much smaller than that of the other three algorithms.

5.2. Comparison of Network Lifetime. Figures 11–13 show the comparison of the number of sensor nodes and the network lifetime of the SCR-CC algorithm with the other three algorithms under the conditions of $\theta = 30^{\circ}$ and

(1) for $(i = 1, j = 1; i \le N; i++, j++)$ if $(CH_i = = 1)$ (2)(3) (Calculating the network energy consumed by the cluster member node sending l bit data by formula (37); (4)Calculating the network energy consumed by the cluster head node by formula (38); (5) $link[i].node = E_{cn_{tot}};$ (6) $link[j].node = E_{ch_{tot}};$ (7)for $(i = 1, j = 1; i \le N; i++, j++)$ (8) $\{if (node.d[i] = = 0)\}$ (9) node.d[i] = dist[j];(10)else (11)if (node.d[i] > dist[j])node.d[i] = dist[j];(12)else (13)node.d[i] = node.CH[j];(14)(15)Calculating the attribution of the cluster member nodes by formula (41);}





ALGORITHM 2: Data forwarding of SCR-CC algorithm.



FIGURE 3: Comparison of the number of failed cluster head nodes at $300 \times 300m^2$ and t = 100 s.



FIGURE 4: Comparison of the number of failed cluster head nodes at $300 \times 300 \text{ m}^2$ and t = 300 s.



FIGURE 5: Comparison of the number of failed cluster head nodes at $500 \times 500 \text{ m}^2$ and t = 100 s.



FIGURE 6: Comparison of the number of failed cluster head nodes at $500 \times 500 \text{ m}^2$ and t = 300 s.

different parameters and different monitoring areas. Now we take Figure 13 as an example. It can be seen from Figure 13 that as the number of sensor nodes increases, the network lifetime of the four algorithms will also increase, but the increased range in the SCR-CC algorithm is more obvious; however, the other three algorithms have a small increase. When the number of sensor nodes is 1400, the network lifetime in the SCR-CC algorithm is 1100 s (m = 11) and 1010 s (m = 19), and the network lifetime of the other three algorithms is 750 s, 700 s, and 610 s, respectively. When the number of sensor nodes is 2600, the network lifetime in the SCR-CC algorithm is 2450 s (m = 11) and 2240 s (m = 19), and the network lifetime in the SCR-CC algorithm is 2450 s (m = 11) and 2240 s (m = 19), and the network lifetime of the other three algorithms is 1650 s, 1510 s, and 1240 s, respectively.



FIGURE 7: Comparison of the number of failed cluster member nodes at 300×300 m² and t = 100 s.



FIGURE 8: Comparison of the number of failed cluster member nodes at 300×300 m² and t = 300 s.

Figures 14–16 show the comparison of the number of sensor nodes and the network lifetime of the SCR-CC algorithm with the other three algorithms under the conditions of $\theta = 45^{\circ}$ and different parameters and different monitoring areas. Now we take Figure 15 as an example. It can be seen from Figure 15 that as the number of sensor nodes increases, the network lifetime of the four algorithms will also increase, but the increased range in the SCR-CC algorithm is more obvious than the range in the other three algorithms. When the number of sensor nodes is 700, the network lifetime in the SCR-CC algorithm is 1300 s (m = 11) and 1020 s (m = 19), and the network lifetime of the other three algorithms is 570 s, 540 s, and 500 s, respectively. When the number of sensor nodes is 1100, the network lifetime in



FIGURE 9: Comparison of the number of failed cluster member nodes at $500 \times 500 \text{ m}^2$ and t = 100 s.



FIGURE 10: Comparison of the number of failed cluster member nodes at $500 \times 500 \text{ m}^2$ and t = 300 s.

the SCR-CC algorithm is 3700 s (m = 11) and 3020 s (m = 19), and the network lifetime of the other three algorithms is 1650 s, 1500 s, and 1380 s, respectively.

Figures 17–19 show the comparison of the number of sensor nodes and the network lifetime of the SCR-CC algorithm with the other three algorithms under the conditions of $\theta = 60^{\circ}$ and different parameters and different monitoring areas. Now we take Figure 19 as an example. It can be seen from Figure 19 that as the number of sensor nodes increases, the network lifetime of the four algorithms will also increase, but the increased range in the SCR-CC algorithm is more obvious; however, the other three algorithms have a small increase and tend to be stable. When the number of sensor nodes is 1800, the network lifetime in the SCR-CC algorithm is 2900 s (m = 11) and 1400 s (m = 19),



FIGURE 11: Comparison of network lifetime under different parameters $(100 \times 100 \text{ m}^2; \theta = 30^\circ)$.



FIGURE 12: Comparison of network lifetime under different parameters $(300 \times 300 \text{ m}^2; \theta = 30^\circ)$.

and the network lifetime of the other three algorithms is 750 s, 700 s, and 610 s, respectively. When the number of sensor nodes is 3000, the network lifetime in the SCR-CC algorithm is 5600 s (m = 11) and 3800 s (m = 19), and the network lifetime of the other three algorithms is 1950 s, 1780 s, and 1450 s, respectively.

Compared with the network runtime of the other three algorithms, that of the SCR-CC algorithm has an average increase of 27.09% in network lifetime. The main reason is that after the cluster establishment of the SCR-CC algorithm is completed, the cluster head node broadcasts a message to the entire network, and the member node that receives the broadcast information calculates which cluster it belongs to according to the constraint formula (44), and meanwhile, it feed backs the message to the cluster head node. When the



FIGURE 13: Comparison of network lifetime under different parameters ($500 \times 500 \text{ m}^2$; $\theta = 30^\circ$).



FIGURE 14: Comparison of network lifetime under different parameters ($100 \times 100 \text{ m}^2$; $\theta = 45^\circ$).



FIGURE 15: Comparison of network lifetime under different parameters ($300 \times 300 \text{ m}^2$; $\theta = 45^\circ$).



FIGURE 16: Comparison of network lifetime under different parameters ($500 \times 500 \text{ m}^2$; $\theta = 45^\circ$).



FIGURE 17: Comparison of network lifetime under different parameters ($100 \times 100 \text{ m}^2$; $\theta = 60^\circ$).



FIGURE 18: Comparison of network lifetime under different parameters ($300 \times 300 \text{ m}^2$; $\theta = 60^\circ$).



FIGURE 19: Comparison of network lifetime under different parameters ($500 \times 500 \text{ m}^2$; $\theta = 60^\circ$).

cluster head node successfully receives the message from the cluster member node, it calculates the position information of the cluster member node according to formula (39) and determines the candidate cluster head node and the optimal value as the continuous cluster head node. When the cluster member node successfully receives the working time slot and candidate cluster head node information from the cluster head node, the cluster member node is in the working state; that is, it sends data information to the cluster head node in a stable working time slot. Outside the work clearance, the cluster member node shuts down all sensing modules and enters the dormant state to reduce energy consumption, and meanwhile, the cluster member node records the working number of the current cluster head node and analyses whether to replace the cluster head node based on the remaining energy. When the working times of the cluster head node reach the maximum, the candidate cluster head node is about to become the new cluster head node in a new round, and the current cluster member node and the cluster head node located in the next sector are notified by a broadcast message. The other three algorithms only rely on the remaining energy of cluster member nodes and supplementing new nodes to achieve energy balance and are not suitable for large-scale wireless sensor networks.

6. Conclusions

Aiming at the routing problem of heterogeneous sensor networks, this paper proposes a Sensing Clustering Routing Algorithm Based on Collaborative Computing (SCR-CC). Firstly, the expected value of normal communication between two adjacent nodes is analysed. Secondly, it gives the necessary conditions for the existence of the expected value of the number of neighboring nodes when the redundant node is turned off. Thirdly, it analyses the conditions for the formation of fan-shaped cluster angles and the cluster angle optimization process under limited conditions, and the constraint of the satisfied optimal cluster angle is given. In the implementation of the SCR-CC algorithm, this paper presents the basic process and related mechanism of replacing the cluster head node, which proves that, in the monitoring area, the mechanism that the maximum number of works that the current cluster head node continuously assumes as the cluster head node and is replaced by a candidate node effectively suppresses energy consumption and prolongs the network lifetime. Finally, simulation experiments verify the efficiency and effectiveness of the SCR-CC algorithm in this paper.

In the next stage, our research work is mainly focused on how to complete the routing and backup problems of heterogeneous sensor networks and the transmission of multidimensional data under the premise of satisfying a certain coverage rate.

Data Availability

The data underlying the results presented in the study are available within the manuscript.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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