

## *Retraction*

# **Retracted: Simulation Test of Wireless Underground Sensor Network in Stadiums**

### **Journal of Sensors**

Received 13 September 2023; Accepted 13 September 2023; Published 14 September 2023

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1].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) Peer-review manipulation

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**

- [1] D. Wang and H. Ming, "Simulation Test of Wireless Underground Sensor Network in Stadiums," *Journal of Sensors*, vol. 2021, Article ID 6827961, 12 pages, 2021.

## Research Article

# Simulation Test of Wireless Underground Sensor Network in Stadiums

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Received 18 June 2021; Revised 16 July 2021; Accepted 2 August 2021; Published 16 August 2021

Academic Editor: Haibin Lv

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The underground sensor network is a kind of sensor network with sensor nodes buried in the soil. It is used in football fields, golf courses, and other stadiums and can effectively assist the stadium managers to maintain the turf condition. As the turf maintenance in the stadium is still in the manual state, the turf maintenance is time-consuming and laborious. In order to improve this situation and adapt to future development needs, this paper proposes a wireless underground sensor network, designs the network architecture, and uses NS2 network simulation. The performance of the network was simulated and tested by the platform. This article first proposes a distance estimation method for sound and vibration signals based on the generalized correlation of the time difference of arrival based on the characteristics of the real signal when the event occurs. Then, for the range estimation obtained by applying this method, applying the idea of sparse signal reconstruction, a positioning algorithm based on the time difference of arrival based on the velocity function is proposed. Finally, using the above-mentioned positioning algorithm, this paper obtains an overall fusion positioning strategy with the help of the idea of data fusion while taking into account the characteristics of the vibration source on the steel beam based on the positioning results of individual sound and vibration signals. The point of innovation lies in the development of positioning and tracking-oriented platforms, including the development of wireless sensor network gateways and the development of sensor nodes. A network gateway based on network communication was developed to realize the connection with the Internet extranet. The results show that the wireless underground sensor network has strong usability in stadiums, and the network performance can meet the application requirements.

## 1. Introduction

As an emerging research field, wireless sensor networks can find a suitable position in many applications, and positioning is also a member of these suitable applications [1]. The Wireless Underground Sensor Network (WUSN) is a sensor network that embeds most of the sensor nodes in the ground and wireless communication [2]. Currently, wireless underground sensor networks are an emerging market and a promising research field with a wide range of application scenarios. Typical applications include soil condition monitoring, earthquake and landslide prediction, sports ground lawn management, underground infrastructure monitoring, border patrol, and intrusion detection [3–5]. Since the transmis-

sion medium includes the soil, rock, and sand, traditional electromagnetic waves and acoustic waves have dynamic channel conditions, antenna size design, and multipath loss when they are transmitted underground. Generally speaking, positioning in a wireless sensor network is to infer the location estimation of an event in the network node or area through the wireless sensor node receiving different types of information. At the same time, in order to convert the positioning results in the wireless sensor network into absolute coordinates in the global sense, there are generally some nodes in the wireless sensor network that are equipped with satellite positioning system receivers [6].

The magnetic induction communication system transmits signals through the magnetic induction coupling

generated by the transmitting coil and the receiving coil, which is different from the electromagnetic wave communication technology, and can play a stable role even in the severe soil environment [7]. Wireless network communication has become a part of our daily life. The transmission characteristics of electromagnetic waves in the underground environment (soil, water, and rocks) are extremely unsatisfactory. The excessively high soil moisture causes extremely high path loss in the communication link, which greatly limits the wireless electromagnetic wave signal and the transmission distance [8]. The quality of network communication is directly related to the composition of the soil and the operating frequency. Although more electromagnetic transceivers can make up for part of the path loss, this operation is not ideal in the underground environment. Not only will it be restricted by energy, it will be actually deployed. Since most of the nodes are distributed underground, the actual deployment of underground sensor networks consumes human and financial resources when researching underground sensor networks, so simulation has become an important method for researching wireless underground sensor networks [9]. However, the current simulation software does not have a magnetic induction communication module, so this article uses the NS2 simulation tool to expand the communication model suitable for magnetic induction [10].

Aiming at the positioning of patrol personnel and robots in venues, based on the application of the round-trip time ranging network model, this paper proposes the AMW-SMC (Adaptive MDS-dependent Weighting-based Sequential Monte Carlo) algorithm for fast and accurate positioning with multiple moving targets. The AMW-SMC algorithm is based on the adjusted sequential Monte Carlo framework and applies adaptive adjustment and multidimensional scaling to locate moving targets. After that, the effectiveness of the algorithm was verified through simulation and experiments with the help of the distance measurement value acquisition platform. The designed routing algorithm is simulated and implemented, and the performance of the routing algorithm is evaluated based on different network topologies. From the analysis results, compared with the existing typical routing algorithms, the routing algorithms designed in this paper can effectively reduce the energy consumption of the network and prolong the lifetime of the network.

## 2. Related Work

In order to evaluate the performance of the wireless sensor network topology design and network protocol algorithm, it is impossible to achieve it through experiments alone, especially for large-scale wireless sensor networks, because a large number of nodes need to be deployed, adjusted, and maintained, and it is even more difficult to achieve through experiments. Therefore, in order to realize the simulation of wireless sensor networks, researchers have designed and developed many simulation platforms for wireless network simulation research, mainly including NS, OMNET++, and OPNET [11].

Since the magnetic permeability of multiple materials is similar, there will be no large fluctuations due to the change

of the communication medium, so the magnetic communication technology has developed rapidly in recent years. Kandris et al. [12] introduced an efficient underground pipeline communication system based on magnetic induction. MI-WUSN uses magnetic coils as antenna coils and sets multiple passive relay devices between the two transceiver nodes. The coupling effect between the coils completes the information update and prediction processing in the channel to achieve signal reception and forwarding. Similar to the traditional wireless relay concept, this method produces lower path loss, and the transmission range can be greatly improved compared with the EM wave method. Ban et al. [13] did a model analysis on the physical channel of underground magnetic induction network communication. Hussein et al. [14] demonstrated the application of underground magnetic induction communication, designed a simple underground magnetic induction communication scene, and arranged a water circulation system to adjust the moisture in the underground soil verifying the feasibility of magnetic induction communication and the stability of the channel. Chen et al. [15] and others studied the influence of surrounding noise power on underground magnetic induction communication, deduced the noise model under the soil medium, and used Shannon's formula to solve it. The channel capacity in the surrounding environment was mathematically evaluated, and the relationship between the transmission frequency, coil radius, number of winding turns, soil dielectric constant, and other variables and the communication path loss of the underground magnetic induction network was obtained. Sun [16] put forward the innovative concept of using magnetic induction waveguide communication technology to propagate in the case of limited relay deployment. They found that the magnetic induction waveguide communication technology can increase the transmission distance of the underground magnetic induction system. Waveguide communication and direct MI communication have been compared with related experiments. By analyzing the throughput and channel capacity of multiple links, it is found that if the distance between communication nodes is not very large, WUSN of MI waveguide cannot transmit as efficiently as direct MI signals. Some domestic scholars have also made relevant demonstrations on the channel mathematical model of magnetic induction communication and studied and analyzed the key factors that affect the quality of magnetic induction long-distance communication and wireless network communication. However, there is no model of the real network environment, and there is still a certain degree of actual operation of the errors and difficulties.

Hussein et al. [17] first proposed the idea of using wireless technology to replace the wired system for structural monitoring, pioneered the application of wireless sensing technology in the field of structural monitoring, and developed a real-time damage recognition structural health monitoring system. The "Smart Dust" program implemented at the University of California, funded by DARPA (Defense Advanced Research Projects Agency), is aimed at establishing a software and hardware platform for wireless sensor development and then develop a series of low-cost, small size, high reliability wireless sensors, and their networks have

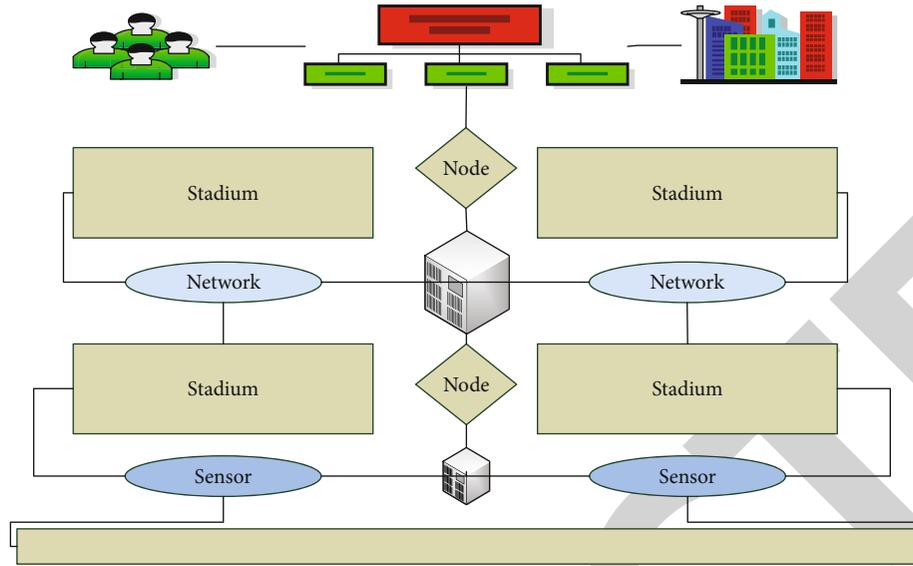


FIGURE 1: Hierarchical distribution of wireless networks.

further promoted the application development of wireless sensors. In addition, the products developed by this project have now become laboratory equipment used by many universities and other research institutions in the world. And a number of well-known professional wireless sensor product production companies such as Crossbow and Microstrain have been derived from this. The wireless sensor products developed abroad generally suffer from high price (average US\$1,000 per measuring point), short wireless transmission distance (30-50 m), technical confidentiality, poor openness (cannot be developed according to actual engineering needs), and other shortcomings. It is not suitable for the safety monitoring field of buildings such as large space structures [18, 19]. From the perspective of miniaturization, low power consumption, low cost, and high reliability of the design, the research of the subject of this article adopts a modular design method to design the sensing processing, microprocessing, wireless transceiver, and energy modules of the wireless strain sensor [20–23]. Debugging, the multi-channel strain sensor samples based on digital interface were integrated, and the unique use conditions of the space structure were used to introduce the solar module design, which initially realized the truly self-sufficient long-term wireless monitoring function technically.

### 3. Construction of Stadium Simulation Model Based on Wireless Underground Sensor Network

**3.1. Wireless Network Level.** The traditional wireless sensor network adopts a layered structure. The network structure diagram is shown in Figure 1. The sensor nodes used for data collection are deployed at the bottom of the communication. The initial energy of each node and the communication range are not much different.

The bottom node sends the data collected by the terminal to other relay nodes in the network. The terminal data is

transmitted to the sink node through one hop or multiple hops. The sink node forwards the data to the data management center through wired or wireless methods to reach the target area monitor.

$$x = x' - i \cdot x'', \quad (1)$$

$$f(x) = \frac{|x'(i) - 1| \cdot |x''(i) - 1|}{|N_1 \cdot x|^2 \cdot |N_2 \cdot x|^2}. \quad (2)$$

When the optimal number of cluster heads in the network is  $x$ , the energy consumption of the entire network is the lowest. The size of  $x$  depends on many parameters, such as network area, number of nodes, and energy model. Different application environment parameter settings are different, and the optimal number of cluster heads  $x$  is also different. Among them,  $u(x)$  is the state transition function,  $f(x)$  is the observation function, and  $n$  and  $m$  are the state variables.  $N_1$  and  $N_2$  are the dimensions of the state variable and the observation value  $x' \in P$ , respectively. The optimal number of cluster heads is obtained on the basis of analyzing the energy consumption of each round of the network, so that the total energy consumption of each round of the network is minimized.

$$\frac{u'(x) - u(x)}{x' - x} = \lim_{n \rightarrow \infty} \sum_{i=1}^n a_i \cdot f(x_i). \quad (3)$$

The transmitter and receiver of communication are modeled as the primary coil and secondary coil of the transformer, the signal transmission and reception are modeled by Faraday's law of electromagnetic induction to model the channel model, the magnetic induction communication system is analyzed by using its equivalent circuit, and the transmission power is analyzed with the relationship between

received power to list the valid expressions.

$$g(z) = \begin{cases} 1, & z \in N(i), \\ 0, & z \notin N(i), \end{cases} \quad (4)$$

$$h(A_n | X, n) = \min \{ \|b - a \cdot x\|^2 + (t-1) \cdot \|x\|^2 \}. \quad (5)$$

When the source node sends data, the working current is triggered. A super-strong magnetic field is generated around the transmitting end coil. The receiving end coil generates electromotive force through the change of magnetic flux around the cut surface of the induction coil. The probability density distribution  $w(n)$  of process noise and measurement noise is generally known, not necessarily zero-mean Gaussian white noise. Process noise and measurement noise are independent of past and current state variables  $s(n)$ . According to the principle of Faraday electromagnetic induction, the receiving end can generate another sinusoidal current. After the end circuit is connected, a power response is generated, and the sensor devices of both sides start to work and enter the mutual communication stage.

$$[w(1) \cdots w(n)] \begin{bmatrix} a(1) \\ \cdots \\ a(n) \end{bmatrix} = [b(1) \cdots b(n)], \quad (6)$$

$$\lim_{n \rightarrow \infty} \sum_{i=1}^n s_i \cdot x(i) = s_n \cdot (x_1 + x_2 + \cdots + x_N) = 1. \quad (7)$$

After the transmitting end starts to work, according to the principle of Faraday electromagnetic induction, a strong magnetic field will be generated around the transmitting end coil to transmit signals. According to the ampere right-hand spiral rule, the changing magnetic field passes through the receiving end coil to generate an electric field, and the receiving end generates an electromotive force. The device starts to work and demodulates the received signal to obtain communication data.

**3.2. Sensing Iterative Algorithm.** As the basis of wireless sensor network networking and the core technology of the network layer, routing algorithms have become the focus of wireless sensor network research [24–26]. We seek an optimal path to transmit data from the source node to the base station. On this path, the node consumes the least energy and is balanced when receiving and forwarding data, so as to maximize the survival time of the network. In a wireless sensor network, each node has limited resources and can only obtain partial information of the network. This requires that its network protocol should not be too complicated, and priority should be given to energy.

$$P(r, \alpha, \beta) = \frac{1}{4\pi r^2 \cos(\alpha + \beta)}, \quad (8)$$

$$\frac{\partial v(x, r)}{\partial x \partial r} = \frac{\oint A dx dr}{4\pi N}. \quad (9)$$

The main goal of the wireless sensor network routing algorithm design is to ensure that nodes can reduce energy consumption as much as possible under the premise of sensing data, transmitting data, and processing data, so as to extend the lifetime of the entire network. In order to minimize the average number of hops, the algorithm always greedily delivers data packets to the node closest to the destination node.  $P$  is the set of all measured values and state variable values up to  $r$  time. The posterior probability density distribution,  $v\{x, r\}$ , constitutes the complete solution of the recursive state estimation problem. This method is simple and effective, but it is not always successful. When all neighbor nodes are farther from the destination node, the local minimum phenomenon is encountered.

Figure 2 shows the flow of the sensing iterative algorithm. We define the link layer interface, complete the physical layer simulation function, and send the signal to the channel. If the communication node does not have more energy to forward or receive the next data after the data transmission is completed, it is called node energy exhaustion, and other nodes will not communicate with the current node anymore, changing the node status flag. This node is removed from the channel, and the remaining nodes outside the channel are added to the channel. We set the size of the link monitoring energy threshold  $CSThresh$ . If the residual energy after the signal is attenuated by the wireless transmission model which is lower than the monitoring threshold, this piece of data will not be processed. It does not disappear, but it is not within the monitoring range; if the remaining energy of the node is small, the energy is greater than the monitoring threshold but less than the signal reception threshold  $RXThresh$ ; we record this illegal data and push the data into the temporary data stack and at the same time give feedback to the sender to receive a signal incorrectly, so that the sender selects the appropriate node to resend the information; if there is anything remaining, the energy is higher than the receiving threshold, and the data can be delivered directly and enter the link layer at this time. Using C++ Propagation as the base class, we create a new magnetic class in the simulation tool. We add the magnetic internal communication method to calculate the loss of node communication energy under the influence of the soil's complex permittivity, magnetic induction signal strength, magnetic flux coupling coefficient, and communication distance.

**3.3. Model Path Optimization.** The energy efficiency of wireless sensor networks refers to the number of routing requests that the network can handle under the condition of limited energy of sensor nodes [27, 28]. Energy efficiency is also an important indicator for evaluating the performance of wireless sensor networks [29, 30]. The routing algorithm should choose a path with low energy consumption and, at the same time, starting from the whole, choose a path with a balanced energy consumption of the entire network. Since the energy of nodes is limited and not easy to replace, if excessive use will cause some nodes to fail quickly and cause routing holes, the design of routing algorithms should first consider energy efficiency. Figure 3 shows the wireless sensor path optimization network. By constructing the distance matrix between

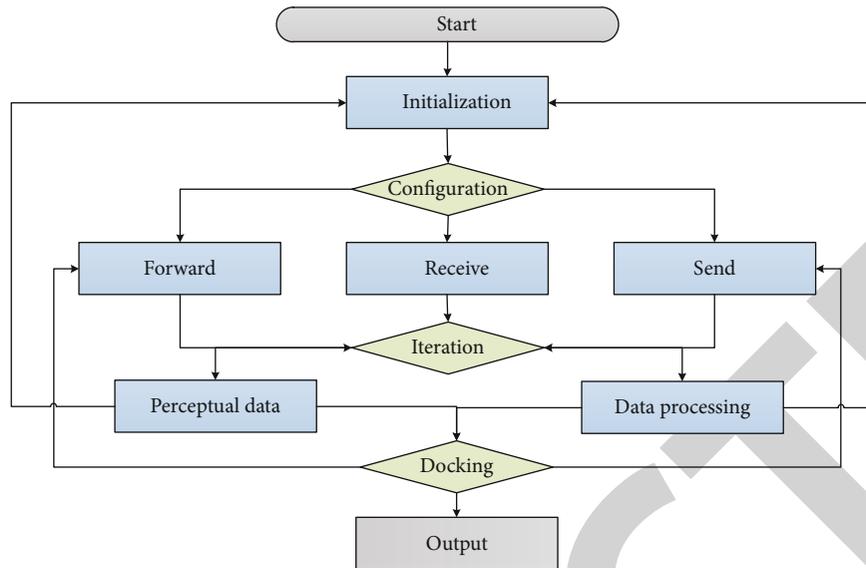


FIGURE 2: Sensing iterative algorithm flow.

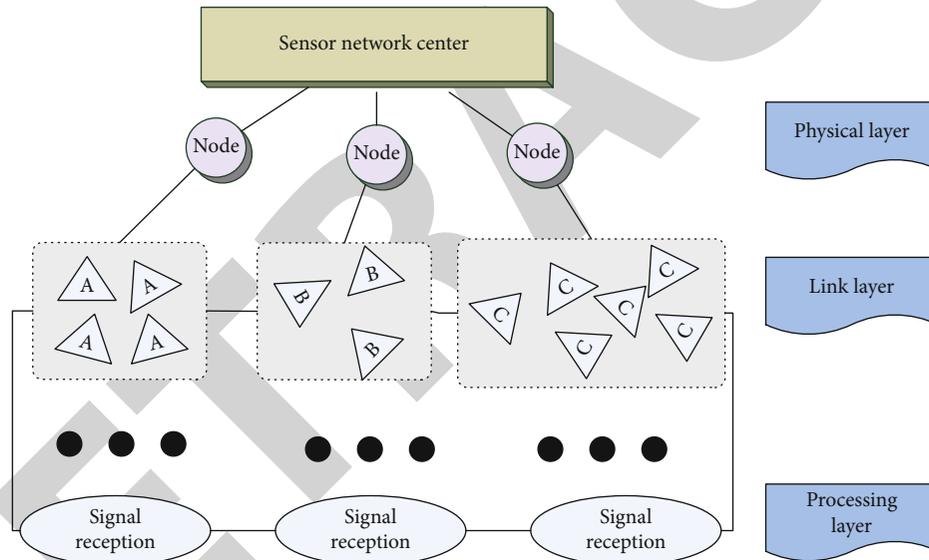


FIGURE 3: Wireless sensor path optimization network.

any two nodes, the location coordinates of each node in the high-dimensional sense can be obtained by singular value decomposition, and finally, the unknown node can be obtained by projecting the high-dimensional coordinates to the required dimension estimated location.

MDS processes all unknown nodes at the same time, which has a very good effect in large-scale sensor networks. At the same time, if the distance measurement value is accurate, MDS will obtain absolutely accurate positioning results, assuming the accuracy of the distance measurement value and constructing an optimization problem to calculate the position of the unknown node to obtain an optimal solution in the sense of least squares or weighted least squares. It should be noted that although these methods are derived from static positioning, they can also be applied to mobile positioning, but at this time, they consider mobile position-

ing as static positioning at each moment. Due to the existence of the space angle, the three-dimensional space loop is more complicated than the two-dimensional plane loop. When designing the routing algorithm, the space loop problem must be fully considered or remedial measures to remove the loop must be taken.

The wireless network communication model takes the mobile node as the core and transfers the signals collected by the terminal through cross-level signal forwarding and receiving processing to complete the signal delivery in different application scenarios. It has a wide range of application prospects. Figure 4 shows the line graph of the transmission loss of the wireless sensor. We add an underground wireless magnetic induction channel communication module to the NS2 software to realize end-to-end wireless underground communication transmission,

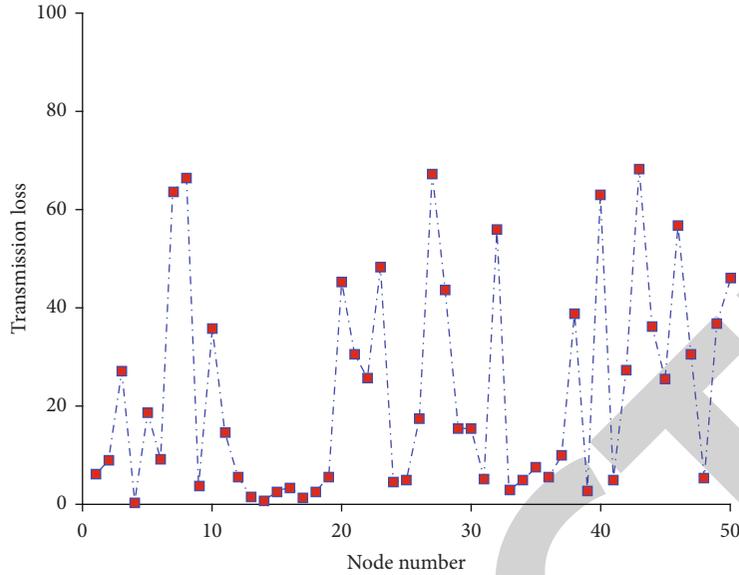


FIGURE 4: Line graph of transmission loss of wireless sensor.

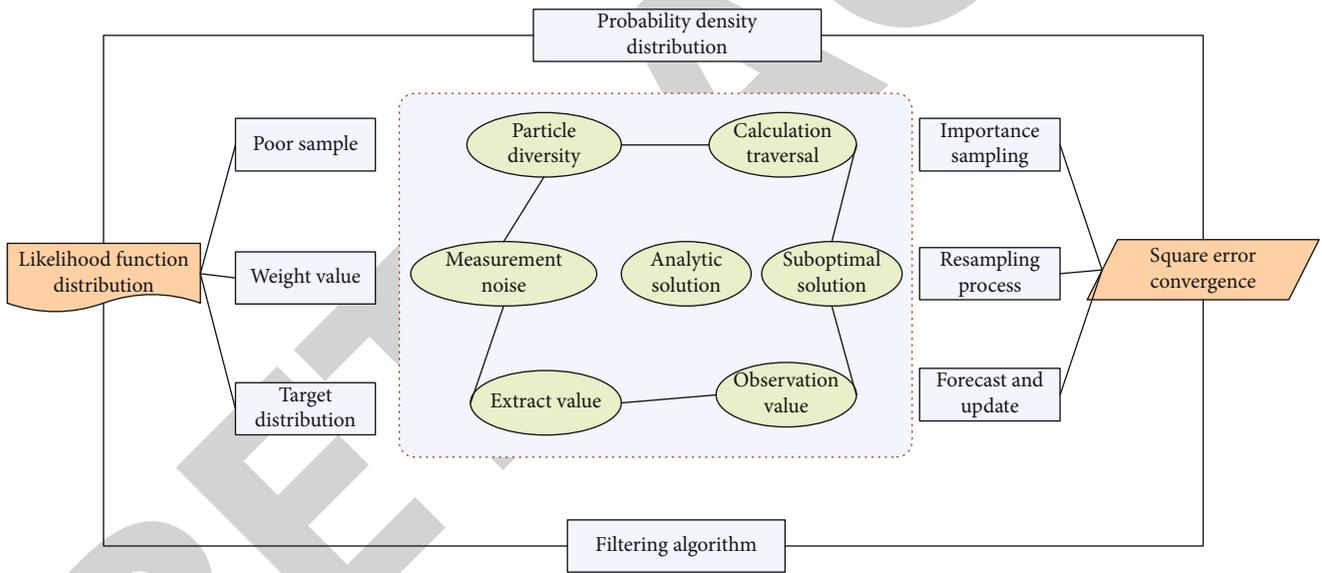


FIGURE 5: The process diagram of wireless sensor experiment.

establish an underground node network topology protocol, and exchange signals at different levels to achieve a more realistic underground magnetic induction wireless communication simulation environment. We create a connection between the C++ magnetic class and the OTcl magnetic class and create a user interface of the OTcl class. When an object is instantiated from the OTcl domain, the C++ class TclObject is mapped to the OTcl class SplitObject, and the constructor of the class SplitObject is called to initialize the object.

To create an OTcl agent/TCP object, we execute “NewAgent/TCP” through a Tcl simulation script. The interpretation and compilation objects have their own class variables. NS2 has a mechanism for binding class variables with differ-

ent structures, and the class variables in one of the modules are changed. Figure 5 shows the process diagram of the wireless sensor experiment. It will cause the other corresponding objects to be changed automatically, achieving real-time effects. When the simulation script starts to execute, NS2 instantiates all static mapping variables, the constructor of the TclClass magnetic object completes the creation of the propagation/magnetic class object and the corresponding static variable binding; the user creates a propagation/magnetic OTcl object, by calling the TclClass class method which stores the variables in the corresponding linked list, and the TclClass class bind() function registers all the mapping variables in the linked list to the system and creates C++ magnetic class member variables.

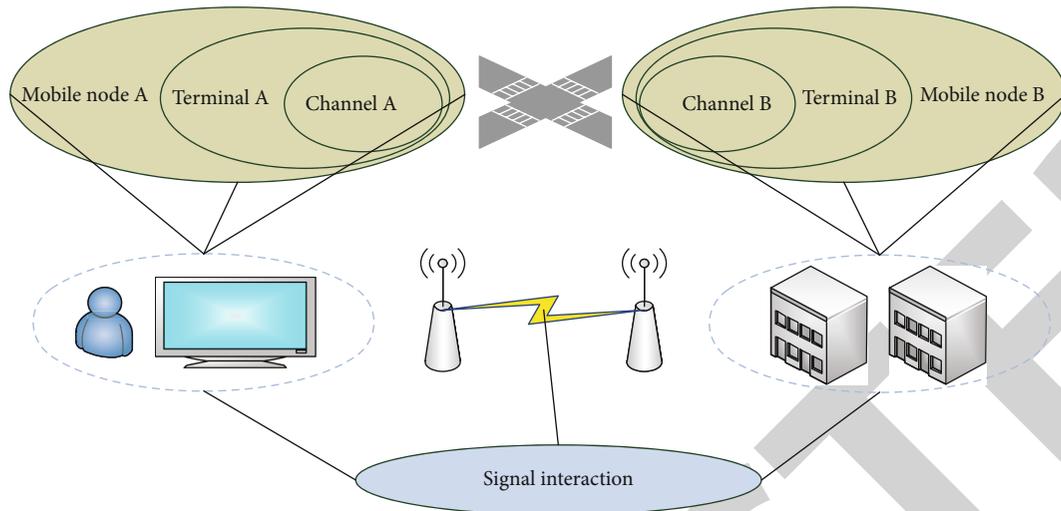


FIGURE 6: Sensor data processing interactive platform.

#### 4. Application and Analysis of Stadium Simulation Model Based on Wireless Underground Sensor Network

**4.1. Sensor Data Preprocessing.** We solve a simplified version of the problem by setting  $\gamma = 1$  and  $0$ . Since we also need to find a corresponding  $n$  to determine the value of  $f(z)$ ; for each  $n$ , we randomly follow the Gaussian distribution and it is less than the obtained  $1, 0, 0,$  and  $0$  initial values of the order of  $1$ , and the average of their restoration results is used as the  $v$  solution for each value of  $n$  to reduce the deviation caused by the selection of special initial values. Figure 6 shows the sensor data processing interactive platform. According to the restoration results obtained by different values of  $n$ , we need to select the corresponding  $n$  as  $f(z)$  to calculate the positioning result. Therefore, by increasing  $n$  from  $7$  to  $50$ , we give the reduction results of all the values of  $n$  and the change trend of their  $0.5$  norm.

From the reduction results, it can be found that the overall trend of the reduction results obtained for different  $n$  is the same, but there are also some differences between the partial reduction results and the overall results. Since the increase in  $n$  means that the sampled result will be closer to the actual curve that should be obtained, and since the parts that are significantly different from the whole have longer  $0$ -order retention characteristics, the selection of these is not very good  $n$  values; a reasonable guess is that they are the results produced when  $n$  is relatively small. The overall shape of the reduction is almost the same, but the unstable part is significantly reduced, which also verifies our assumption that the unstable part is caused by the reduction result when  $n$  is less. Regarding the stability from  $n = 20$ , we will quantitatively explain its stability through all reduction results in both vertical and horizontal senses. The paper shows that when  $n$  is from  $20$  to  $50$ , the average square changes between the obtained reduction result at each point and the result obtained when  $n = 20$ .

**4.2. Topological Structure Performance Evaluation.** In this paper, under the condition of soil moisture of  $5\%VWC$ , the NS2 simulation software is used to analyze the transmission distance under the two communication modes of EM and MI at different operating frequencies. Simulation record statistics are mainly to collect the data generated by simulation, in order to draw meaningful inferences from these data, such as network bandwidth and network delay. When conducting simulation experiment, it is necessary to initialize the type of each network functional component, including wireless channel type, propagation model, antenna type, and routing protocol. In underground communication, there is an obvious conflict in the antenna design during EM wave communication. In order to facilitate the deployment of sensor nodes, the antenna size is expected to be as small as possible. Considering that the signal can be effectively transmitted and received to achieve long-distance transmission, a large antenna can ensure that the operating frequency is maintained. Working at MHz or lower frequencies, however, the antenna size is too large to be deployed in the soil well. Figure 7 shows the fitting curve of sensor signal packet loss rate versus operating frequency. It can be seen that when the operating frequency is  $300$  MHz, as the transmission distance increases, the MI signal attenuates more than the EM wave signal. The dots represent the activated nodes, and the solid lines represent the online estimation results of the proposed tracking scheme. It can also be seen that the estimated results successfully follow the actual trajectory. The actual active area size at each positioning time is also adaptive to the node density. This is because the MI communication loss is a  $4$ th-order function of the transmission distance  $d$ ; increase the operating frequency up to  $900$  MHz, the path loss of the EM wave system increases significantly, and the absorption of the medium is the main cause of the EM path loss in the soil, so the higher operating frequency causes severe attenuation of EM.

In order to evaluate the performance of the network, NS2 network simulation software is used. The network model is

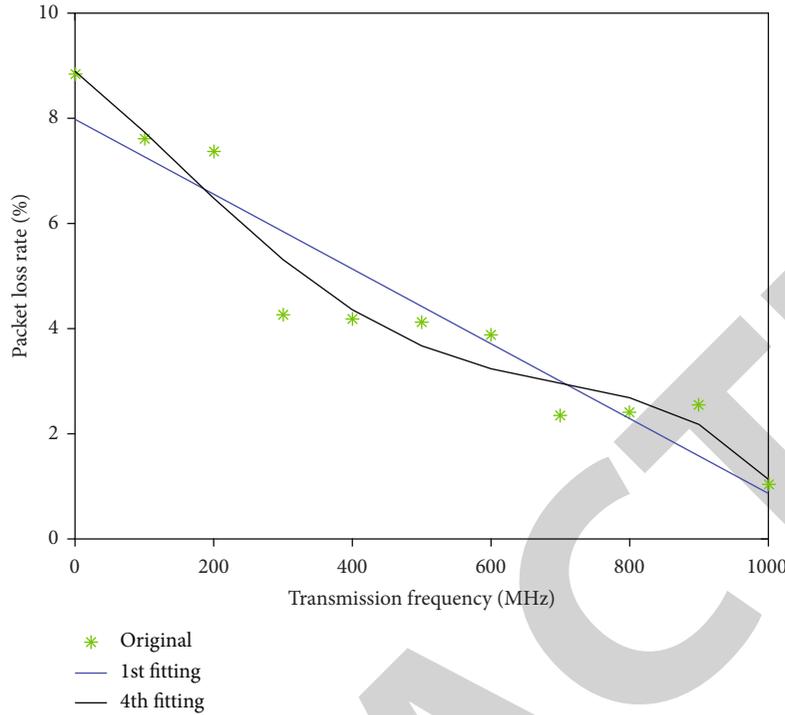


FIGURE 7: Fitting curve of sensor signal packet loss rate with working frequency.

established in NS 2.34, and the monitored area is a square area of  $100\text{ m} \times 100\text{ m}$ , in which  $11 \times 11 = 121$  sensor nodes are arranged. There are 3 layout schemes for mobile data collectors: (1) 4 data collectors, 1 mobile data collector; (2) 5 fixed data collectors, 2 mobile data collectors; and (3) 6 fixed data collectors, 3 mobile data collectors. The routing protocol uses the LEACH protocol commonly used in WSN.

Each numerical point is simulated 10 times. After the experiment, the average value of 10 results is taken to obtain the relationship between the data delivery rate and the average end-to-end delay of the network with the number of data collectors. Figure 8 shows a three-dimensional histogram of wireless sensor network performance evaluation. As the number of data collectors in the network increases, the data delivery rate of the network increases and the average end-to-end delay decreases. When the number of data collectors increases from 5 to 9, the data delivery rate increases from 97.8%. As large as 99.7%, the average end-to-end delay is reduced from 100 to 80. This is because as the number of data collectors in the network increases, the communication coverage area of the data collectors increases, so the data delivery rate increases, while the delay decreases, and better network performance is obtained. The simulation shows that the performance indicators of the network are good and can meet the actual application requirements. At the same time, the number of data collectors should be increased when feasible, so as to ensure better network performance.

**4.3. Example Application and Analysis.** This article sets up a simple experimental scenario; the initial energy of the transmitter is set to 10 dB and 20 dB. The number of unknown nodes is  $n = 30$ , the number of reference nodes is  $m = 4$ ,

and the node communication radius is  $R = 5\text{ m}$ . The unknown nodes are randomly arranged in a rectangular area of  $9\text{ m} \times 9\text{ m}$ . In order to facilitate observation, the reference nodes are arranged at the 4 vertices of the quadrilateral area. The path loss of the channel module established by MATLAB mathematical modeling and NS2 simulation is compared, and the remaining energy of the node under different communication distances is derived. The path loss changes under NS2 simulation are shown. As the processing unit of the wireless sensor, it can collect and preprocess the digital signal output by the sensor and reserve an analog signal acquisition interface; at the same time, the processor also exchanges data with the wireless transceiver module to realize data transmission. In addition, in the microprocessing module, light and sound devices are also integrated to perform various working status displays and early warnings. It can be seen from the figure that the calculation results of transmission loss in MATLAB gradually increase with the increase of the propagation distance, and the NS2 simulation results are consistent with the changes in the transmission loss modeled by MATLAB. It is just that MATLAB uses mathematical formulas to derive the path loss of the two nodes during signal transmission, and NS2 simulation modeling is used to truly simulate the communication of the nodes in the complex underground environment. In the process of simulation, the transmission loss includes sending energy, receiving energy, idle energy consumption, and energy loss caused by retransmission of packets that did not reach the receiving threshold of the receiving node. Therefore, the loss in the simulation is higher than the estimated value of the mathematical theory, and every time the same parameter is set, the path of the communication link loss will fluctuate slightly, rather than the only constant value.

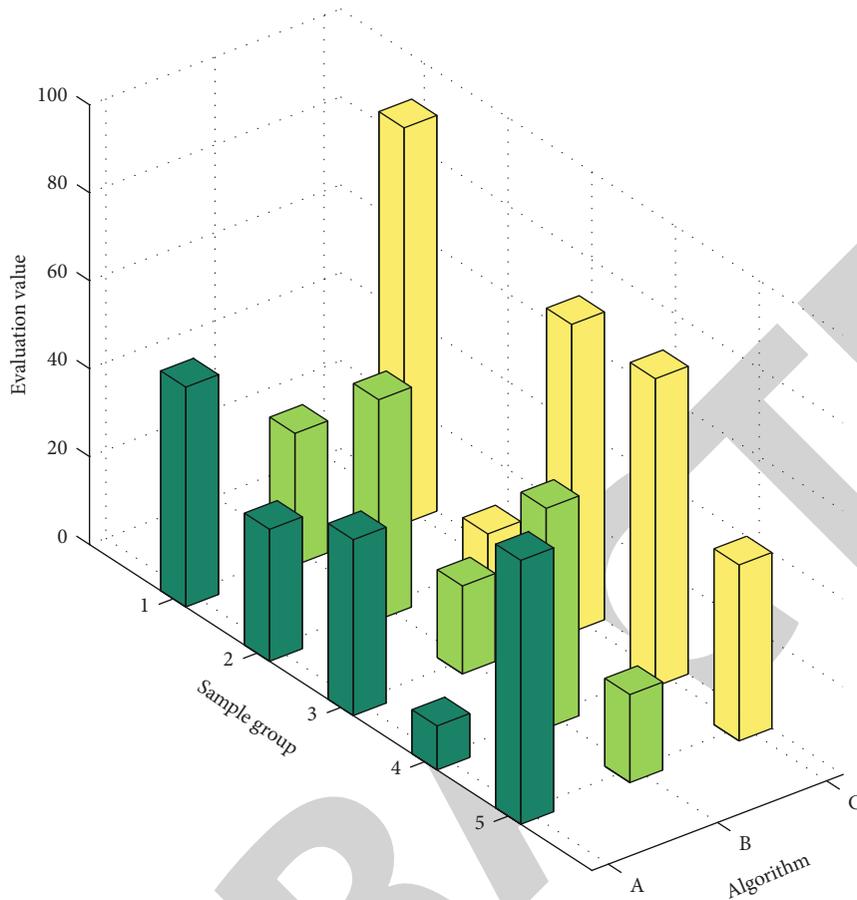


FIGURE 8: Three-dimensional histogram of wireless sensor network performance evaluation.

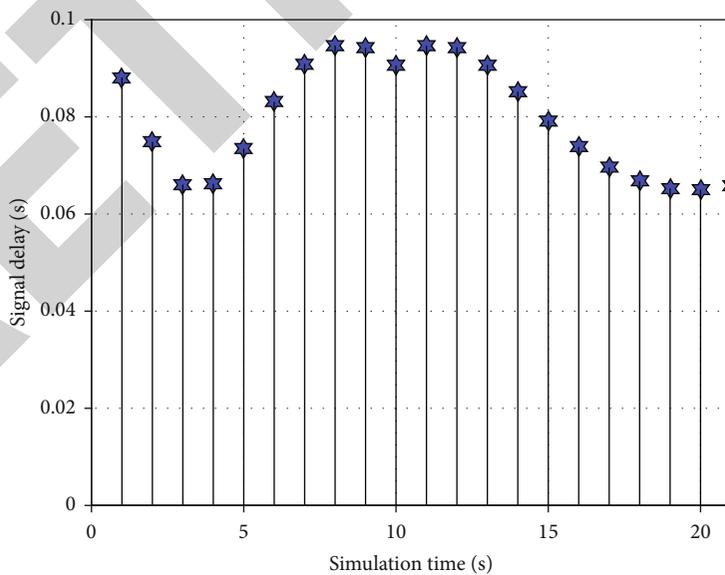


FIGURE 9: Dependence of communication link signal delay with simulation time.

On the basis of completing the software and hardware development of the entire system, network testing of the entire equipment is carried out in the gymnasium. Nine nodes are used during the test. This paper sets 50 communi-

cation cluster nodes in the underground roadway, and the monitored roadway area is  $1\text{ km} \times 0$ . In the narrow and long area of  $1\text{ km}$ , the parameters are set to  $G=1$  and  $h=0.2$ . Firstly, the traditional LEACH algorithm and the improved

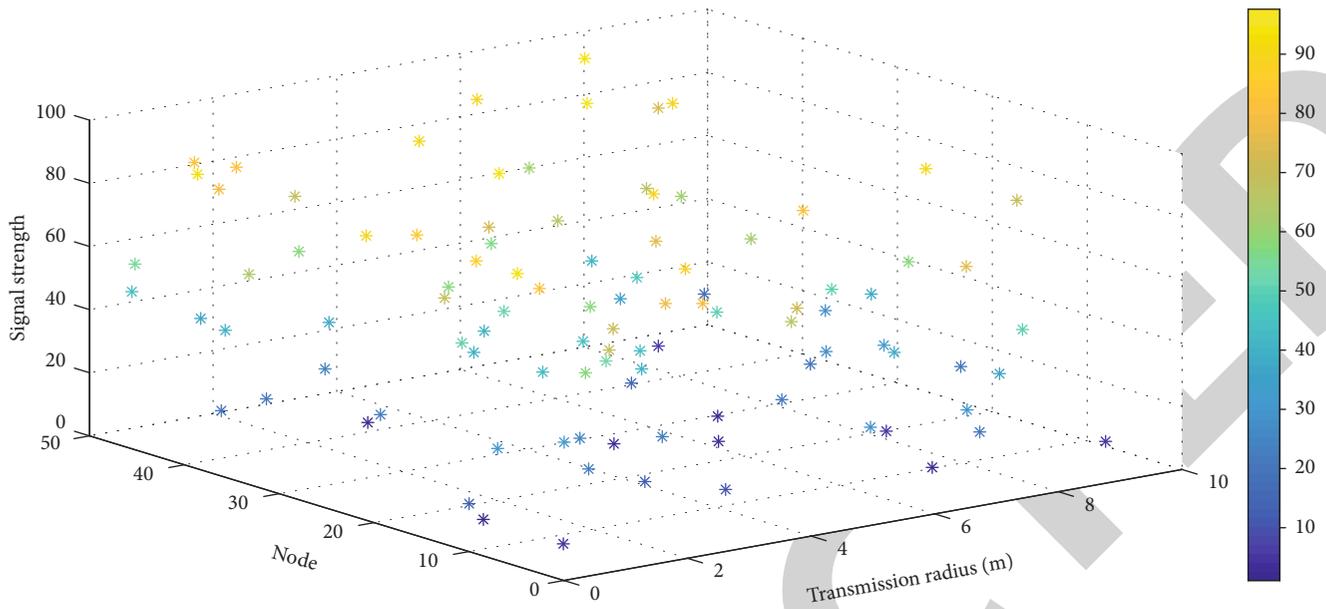


FIGURE 10: The distribution of three-dimensional scattered points of sensor signal strength with nodes and transmission radius.

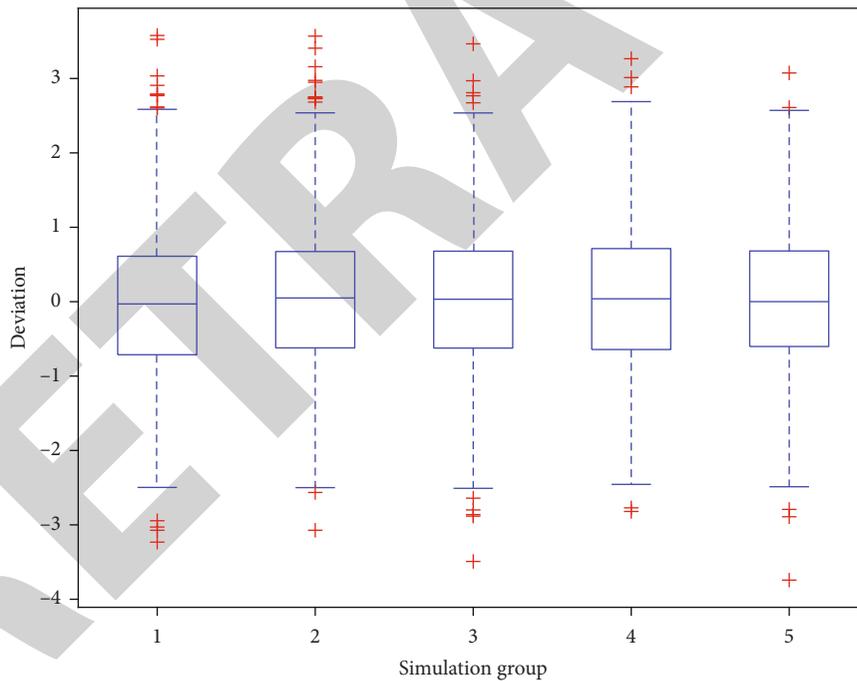


FIGURE 11: Statistical box plot of data deviation of different simulation sample groups.

LEACH algorithm are simulated and compared. In the experiment, the wireless communication node of the underground tunnel is in an overload working state, and excessive signals are transmitted during work, which makes the wireless communication node of the underground tunnel enter the dead state prematurely, thus shortening the experiment time. Figure 9 shows the dependence of the signal delay of the communication link with the simulation time. Among them, no. 5 is a sink node, 2 and 6 are routing nodes, and the others are terminal nodes. The stability of the network

is monitored according to different layout distances. After 4 days of networking test, the wireless data is collected and transmitted every five seconds. From the data, it can be seen that the wireless sensor network composed of this node is within 80 m, and the communication packet loss rate is less than 3%, which meets the application requirements of data communication. After completing the packet loss rate test, in order to meet the accuracy of the monitoring, the temperature and humidity of the node were checked accordingly. The high-precision handheld temperature and humidity

detection device is used to calibrate the temperature and humidity information detected by the collection node.

Figure 10 shows the three-dimensional scatter distribution of sensor signal strength with nodes and transmission radius. In order to facilitate comparison, first set  $k = 60$  to compare the positioning situation before and after improvement. The simulation results show that the positioning error of the forward iterative algorithm is 8.2%. It can be seen that as the simulation time increases, the average energy consumption intensity of nodes under the three network topologies has shown an upward trend; the comparison of different topologies at the same simulation time shows that the average energy consumption of nodes under the mine topology is the least compared with the same topology at the same simulation time. In contrast, the four clustering routing algorithms improved in this paper are all less energy-consuming than the benchmark algorithm.

Since node clustering, data fusion, and data forwarding all consume node energy, the energy-saving effect of improved routing calculations in the initial stage of network operation is not obvious. Figure 11 shows the statistical box plots of data deviations for different simulation sample groups. However, with the passage of simulation time, the benchmark algorithm only selects the next hop node based on the distance, causing several key nodes close to the base station to die quickly, affecting the base station receiving data, resulting in an increase in the average energy consumption of the node, and an improved routing algorithm has more advantages. The smaller the uncertainty torus is, the smaller the uncertainty of the likelihood distribution of the source location will be. Conversely, the greater the variance of the measurement noise, the greater the uncertainty of the likelihood distribution of the source location. From an overall point of view, the maximum likelihood method takes into account the interference caused by noise to positioning, which enhances the anti-interference ability of the algorithm, and the application of the algorithm is better in terms of robustness to noise changes. It can also be seen from the figure that the effect of the five improved routing groups under uniform topology has the smallest difference. This is because the initial energy consumption of nodes is the same and evenly distributed, and the probability of each node being selected is basically the same. The topology is more uniform.

## 5. Conclusion

Aiming at the construction and development needs of future stadiums, this paper proposes a wireless underground sensor network, designs the network architecture, establishes an underground channel model and a network model in the NS2 network simulation platform, and conducts a preliminary analysis of the performance of the network simulation. Based on the introduction and analysis of the traditional LEACH algorithm, this paper designs an optimized algorithm and optimized sensor network workflow, which reduces the possibility of over-biased sensor nodes being selected as cluster head nodes, and improves the selection of routing nodes, which makes routing of wireless communication nodes in underground tunnels more energy-saving. In

order to solve the intelligent monitoring of indoor stadium environmental information, the model is used as the main control chip, the wireless sensor network of the indoor stadium is built, and the optimal number of wireless communication nodes in underground tunnels is selected to achieve the optimization of monitoring coverage and node setting combination. We completed the hardware design and software design of the entire system, and finally, after testing and analysis, the system has good network communication quality and accurate monitoring data, which can meet the monitoring requirements of indoor stadium environmental information. The research results show that the network has good performance and strong usability, and as the number of data collectors in the network increases, the network performance is better. The research results of this paper can be used in the construction of future stadiums and have certain reference value for the research and application of wireless underground sensor networks.

## Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Acknowledgments

This work was supported by the Xinxiang Medical University.

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