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Research on "Hot Zone" in Coal Mine Based on Multihop Uneven Clustering Algorithm for Vitual MIMO

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Abstract: In view of the special geographical environment of mine tunnel, this paper analyzes why improved Low Energy Adaptive Clustering Hierarchy (LEACH) protocols and virtual Multiple Input Multiple Output (MIMO) algorithms cause "hot zone" which shortens the life of Wireless Sensor Network (WSN) and forms the “blind area”. Based on this problem, this paper proposes a multihop non-uniform clustering algorithm named Virtual Multiple Input Multiple Output-Improved (VMIMO-I). The advantages of this algorithm are: (1) the competition radius of the cluster closer to the Sink node should be smaller, in order to the cluster head has enough energy to forward the information of other clusters. (2) There are several cooperative nodes in each cluster for multihop data transmission between clusters to save energy consumption of cluster heads; (3) There should be several clusters near the Sink node can directly transmit data to the Sink node, instead of sending all the data to the cluster head nearest to the Sink node. Then, this paper introduces the transmission process model based on this algorithm and analysis the energy consumption within and between clusters. With the simulation result on Matlab based on Minimum energy formula of VMIMO-I algorithm model, VMIMO-I algorithm is more applicable to be used in mine tunnel with lower energy consumption and more network lifetime than LEACH protocol.

Keywords: Coal Mine Roadway, Wireless Sensor Network (WSN), VMIMO-I, LEACH

1. Introduction

With the improvement of coal mine comprehensive automation level and the construction of perception mine IoT, the common image and disaster signal transmission which can be transmitted by LEACH protocol, which is often used in coal mine WNS, has been unable to meet today's coal mine communication goals. Literature [1, 2] made different improvements to LEACH protocol according to the actual needs of the mine. But the geological conditions of mine tunnel are quite complex, and the flatness of tunnel wall is relatively poor, so there must be reflection, refraction, scattering waves in the received radio waves, which leads to the serious multipath fading in mine tunnel. Because MIMO system uses spatial diversity technology to combat multipath fading in wireless communication, and improves channel capacity without increasing transmission power, MIMO system can transmits high-quality pictures, voice, video and other signals, and weaken multipath fading. Literature [3, 4] has proved that MIMO system can save sensor energy more than LEACH protocol. So MIMO system can solves the bottleneck of LEACH protocol in mine tunnel. In the WSN of mine tunnel, sensor nodes can not have antenna array, because of limited volume, so virtual MIMO technology just uses the characteristics of dense distribution of sensor nodes to make several single antenna sensor nodes form virtual multi-antenna array through cooperation of sensor nodes, so as to carry out reliable communication.

Krunz et al. studied the problem of virtual MIMO clustering and energy management and propose energy-efficient clustering and power management schemes for virtual MIMO algorithm in a multihop WSN [5]. The algorithm divides WSN into several clusters. Each cluster has a master cluster head and a slave cluster head. They are responsible for collecting data in the cluster for transmission, which saves the energy consumption of cluster heads and improves the life cycle of WSN. Cheng et al. proposed a new multihop virtual MIMO transmission algorithm [6] based on the optimal energy allocation transmission protocol in literature [7]. This algorithm requires data to be transmitted from each cluster to the Sink nodes in multiple hops, which can save more network energy consumption. However, due to the characteristics of mine tunnel, the WSN is distributed in a long strip, and the Sink node is at the exit of the tunnel, the information will flow to the Sink from one side, so the data flow will be in the shape of "Mallet", which is bound to cause unbalanced energy distribution. The closer the Sink node is, the higher the flow, the heavier the load, and the shorter the life span, which will affect the WSN life and cause the problem of 'hot zone'[8]. Therefore, the above algorithms is not suitable for virtual MIMO system in mine tunnel.

Aiming at 'hot zone' problem in mine tunnel, this paper proposes a virtual MIMO algorithm VMIMO-I based on multihop uneven clustering. This algorithm can actively balance the energy of sensor nodes especially the head nodes in WSN. It reduces the energy consumption and achieve the goal of improving the life of WSN.

2. Model Introduction of VMIMO-I Algorithm

In each round, the energy consumption of cluster heads includes the processing of data inside the cluster and the communication between the clusters. The cluster heads close to the Sink nodes need to transmit their own data to the Sink nodes and also transmit the data from the cluster heads which are far away from the Sink nodes. Therefore, the purpose of VMIMO-I algorithm is to make the cluster heads close to the Sink nodes have enough energy to provide inter cluster communication. So, the competition radius of the cluster closer to the Sink node should be smaller. And there should be several clusters near the Sink node can directly transmit data to the Sink node, instead of sending all the data to the cluster head nearest to the Sink node, let it forward all the data, leading to its premature energy depletion.

2.1. Transmission Strategy of VMIMO-I Algorithm Model

The WSN model using VMIMO-I algorithm is shown in Figure 1.

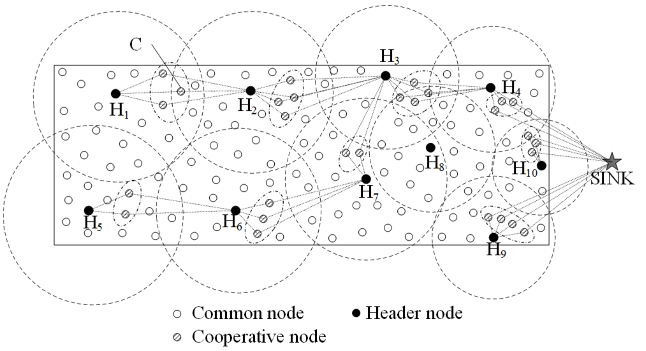

Figure 1. *The WSN model used VMIMO-I algorithm.*

As can be seen from Figure 1, N sensor nodes are evenly arranged in the long strip of mine tunnel, and they spontaneously cluster periodically. For each cluster, they can be regarded as their own virtual MIMO individuals. Each circle in Figure 1 represents a cluster, and $H_1, H_2, . H_{10}$ is the header node of each cluster. The member nodes in the cluster send the collected data to the header node, and the header node fuses these data and broadcasts them to the cooperative nodes. The cooperative nodes receives the data from header node and selects the next hop path (header node or the Sink node) for transmission. Loop in turn until all data are transmitted to the Sink node.

2.2. Analysis Algorithm of VMIMO-I

2.2.1. Header Node Selection

All nodes of WSN generate a random number of 0 -1, and compare it with the threshold $T(n)$. If the generated random number is less than $T(n)$, the node will be selected as the header node in this round. The threshold $T(n)$ formula is set as the following formula.

$$T(\mathrm{n}) = \begin{cases} \dfrac{N_r}{N\text{-}N_r \times (r \bmod \dfrac{N}{N_r})} & n \in G \\ 0 & others \end{cases}$$

In the above formula:

$N(\mathrm{r})$ is the number of virtual MIMO clusters in WNS, N is the number of all nodes in WSN, r is the number of rounds in the current network, and G is the set of sensor nodes not selected as header node.

In the WSN model shown in Figure 1, circles of different sizes represent the size of the competitive region of candidate header nodes. The algorithm stipulates that after the candidate header nodes wins the election, all the nodes within its competition region can not become header nodes and must withdraw the election. H_8, which is freely clustered and elected as the header node, is located in the competition region of the successful header node H_7, so H_8 will not become the header node.

2.2.2. Member Nodes Joining Cluster

The algorithm stipulates that all nodes have a unique ID. Once the header node is selected, it will broadcast a message to nearby non-cluster head node that it is the cluster head. At this time, the non header nodes must turn on the receiver to receive this message. If multiple messages are received in the interval, the non header nodes will select the header node with the strongest strength and send the join request message to the header node. All nodes sending the joining message are members of the cluster. As shown in Figure 1, the node C is located in the competitive region clusters of H_1 and H_2, if the signal strength of H_1 is stronger, it will choose to join the H_1 cluster.

2.2.3. The Competition Radius of Clusters

In this algorithm, the header nodes near the Sink node not only collect and send the data of its cluster, but also forward the data from the clusters far away from the Sink node. Therefore, in order to balance the WSN energy consumption, it is necessary to make the competition radius of the clusters close to the Sink node smaller than the clusters far away from the Sink node, so that header nodes near the Sink node have enough energy to forward the data of the cluster far away from the Sink node.

The header node calculates its competition radius spontaneously. The competition radius of each header node is

$$R_c = (1 - c\frac{d_{\max} - d(H_i, S)}{d_{\max} - d_{\min}})R_c^0$$

In the above formula:

c is a coefficient which can be used to control the value range, $d(H_i,S)$ is the distance between header nodes and the Sink node, $d_{\max}$ / $d_{\min}$ is the maximum and minimum distance from all sensor nodes in WSN to the Sink node, R_c^0 is the maximum competitive radius of all clusters.

In this paper, the maximum communication distance between two wireless sensor nodes under the mine is 75 meters[1], which is set as the maximum competition radius, so $R_c^0 = 75$. Based on some literatures and the characteristics of mine tunnel, let $c = 1/2$.

2.2.4. Selection of Multihop Path

This paper defines the 'next hop' decision threshold is $\Delta_1 = \frac{E_{H\_H}}{E_{remain}}$ and the 'hot zone' decision threshold is Δ_2 .

E_{H_H} is the energy consumption per bit from the current header node to the next hop header node, and E_{reain} is the residual energy of the current header node.

In order to balance the energy consumption in WSN and prevent the 'hot zone' problem. When $d(\mathrm{H_i},\mathrm{S}) \geq \Delta_2$, each header node will choose the smallest value of Δ_1 as next hop selection. When $d(\mathrm{H_i},\mathrm{S}) < \Delta_2$, the header nodes directly transmit data to the Sink node. Figure 1 shows a multihop path.

The critical distance of free space model or multipath attenuation model is $d_0 = 37$, and the maximum communication distance between two sensor nodes in mine tunnel is 75 meters[1]. In this paper, the 'hot zone' decision threshold $\Delta_2 = 56$.

2.2.5. Selection of Cooperative Nodes

In this paper defines the decision threshold of cooperative nodes is $\Delta_3 = \frac{E_{c\_H}}{E_{remain}}$.

In the above formula:

E_{c_H} is the energy consumption from a member node in a cluster to the next hop header node selected by the 'next hop' decision threshold Δ_1, and E_{reain} is the residual energy of this node.

After the header node of the virtual MIMO system broadcasted the next hop path data, the member nodes in the cluster will automatically calculate the value of Δ_3 immediately after receiving the data, and send the calculation result to the header node. After the header node received the value of Δ_3 from its member nodes, it selects N_c minimum member nodes as its cooperative nodes.

3. Model Energy Analysis Based on VMIMO-I Algorithm

This section establishes the total energy consumption model of the VMIMO-I algorithm firstly, then sets the limiting conditions by three parameters (modulation series b , the number of virtual MIMO clusters N_r and the number of cooperative nodes in the cluster N_c), Finally this paper uses brute force method to simulate the VMIMO-I algorithm and compares with LEACH protocol in MATLAB.

3.1. Analysis of Energy Consumption in Cluster

The total energy consumption E_{intra} of a virtual MIMO cluster can be expressed as the following formula:

$$E_{intra} = E_{intra\_t} + E_{intra\_c} = E_{data\_t} + E_{coop\_t} + E_{data\_c} + E_{coop\_c} \tag{1}$$

In the above formula:

E_{intra} is the total energy consumption of virtual MIMO in cluster, E_{intra_t} is the energy consumption of transmission in cluster, E_{intra_c} is the energy consumption of circuit in cluster, E_{data_t} is the energy consumption of transmission the collected data from all member nodes in the cluster to header node, E_{coop_t} is the energy consumption of transmission the fusing data from header node to cooperative nodes, E_{data_c} is the energy consumption of circuit from all the member nodes in the cluster to header node, and E_{coop_c} is the energy consumption of circuit from the header node to cooperative nodes.

In the process of short distance data transmission within cluster, the channel model in this paper used AWGN as reference [9], and modulation mode used BPSK.

In BPSK modulation mode, the probability of the bit error is $P_b = Q(\sqrt{2\gamma})$, where γ is the instantaneous signal-to-noise ratio of the sensors receiver.

$$\gamma = \frac{P_{data\_r}}{2B\sigma^2 N_f} \tag{2}$$

In the above formula:

P_{data_r} is the received signal power of header node; N_f is the receiver noise figure, and $N_f = N_r / N_0$, where N_r is the power spectral density of the receiver noise, N_0 is the power spectral density of the single sideband thermal noise. σ^2 is the power spectral density of additive white Gaussian noise, and $\sigma^2 = N_0 / 2$.

In the case of wireless transmission space, Chernoff bound can approximately consider that:

$$P_b = e^{-\gamma} \tag{3}$$

Therefore, it can be obtained from Formula 2 and formula 3.

$$P_{data\_r} = -2B\sigma^2 N_f \ln(\mathrm{P_b}) \tag{4}$$

Then,

$$P_{data\_t} = P_{data\_r} G_d = -2B\sigma^2 N_f \ln(P_b)\mathrm{G_d} \tag{5}$$

Where G_d is the square fading factor [10], and

$$G_d = G_1 \overline{d_{intra}}^2 M_l \tag{6}$$

Where G_1 is the power gain factor at $d=1$, $\overline{d_{intra}}$ is the average distance from the member nodes to header node in the process of intra cluster transmission, M_l is a constant used to compensate for noise and interference attenuation caused by hardware deviation.

In the case of BPSK modulation, the bandwidth of virtual MIMO system is equal to its transmission rate, that is $B = LP_i / T_i$. Where B is the bandwidth, L is the bit data transmitted by the member nodes N_i with probability P_i, and T_i is the time of transmitting L bit data.

Summarizing the previous work in literature [11], there is a clear formula for E_{data_t}.

$$E_{data\_t} = (1+\alpha)\sum_{i=1}^{\frac{N}{N_r}-1} (P_{data\_t} \times T_i) \tag{7}$$

Where, α is the RF power amplifier coefficient.

It can be seen from formula (5) (6) (7).

$$E_{data\_t} = -2(1+\alpha)\sum_{i=1}^{\frac{N}{N_r}-1} N_f \sigma^2 \ln(P_b) G_1 M_l \overline{d_{intra}}^2 LP_i \tag{8}$$

According to literature [12],

Where, P_{ct} and P_{cr} respectively represent the power consumption of the circuit caused by the sensor node sending data and receiving data. Nowadays, wireless sensor nodes usually adopt low-power circuit design, so P_{ct} and P_{cr} can be recognized as constant values.

According to literature [12],

$$E_{data\_c} = \sum_{i=1}^{\frac{N}{N_r}-1} [(P_{ct}+P_{cr}) \times T_i] = \sum_{i=1}^{\frac{N}{N_r}-1} [(P_{ct}+P_{cr}) \times \frac{LP_i}{B}] \tag{9}$$

E_{coop_t} and E_{coop_c} have been derived in literature [9], and the formula is as follows:

$$E_{coop\_t} = -2(1+\alpha)N_f \sigma^2 \ln(P_b) G_1 d_{c\_\max}{}^2 M_l L_f \tag{10}$$

Where, $d_{c\_\max}$ is the maximum distance between the cooperative nodes to the header node in the cluster, and L_f is the amount of L bits transmitted by the member node to the header node. And

$$L_f = \frac{\sum_{i=1}^{\frac{N}{N_r}-1} LP_i}{f_{agg}\sum_{i=1}^{\frac{N}{N_r}-1} P_i - f_{agg} + 1}$$

where f_{agg} is the aggregation factor which is between (0,1).

$$E_{\mathrm{coop\_c}} = \frac{(P_{\mathrm{ct}} + N_c P_{cr})L_f}{B} \tag{11}$$

According to the formulas 8-11, the total energy consumption in the cluster of VMIMO-I algorithm model is:

$$E_{intra} = N_r(E_{data\_t} + E_{coop\_t} + E_{data\_c} + E_{coop\_c}) \tag{12}$$

3.2. Multihop Energy Analysis Between Clusters

The process of multihop transmission is as follows: each header node transmits the data to their respective cooperative nodes. After the cooperative nodes useing STBC coding, it transmits the encoded data to the next hop header node according to the selected multihop path, until all the data is transmitted to the Sink node.

Because the multihop between clusters is long-distance transmission, the channel model adopts k-order Rayleigh flat fading channel model ($k=4$). And the modulation mode is MQAM to further reduce the transmission delay and circuit energy consumption [9].

As described in reference [13], in the MIMO system based on MQAM modulation in high SNR environment, the average bit error rate (P_b) of the receiver when $b \ge 2$ can be expressed as:

$$P_b = \frac{4}{b}(1-\frac{1}{2^{\frac{b}{2}}})Q(\sqrt{\frac{3b\gamma_b}{2^b-1}}) \tag{13}$$

Where γ_b is the signal-to-noise ratio and b is the modulation series.

According to formula 13, we use Chernoff bound approximation to calculate the energy consumption per bit transmission E_b as:

$$E_b = \frac{2}{3}(\frac{P_b}{4})^{-\frac{1}{N_c}} \frac{2^b-1}{b^{\frac{1}{N_c}+1}} N_c N_0 \tag{14}$$

Then, according to the link power conversion formula of the long band link propagation model in reference [14], the transmission power of each cooperative node is obtained by using formula 15.

$$P_{t\_hop,i} = \frac{1}{N_c} E_b R_b \frac{(4\pi)^2 d_{hop,i}{}^4 M_l N_f}{G_t G_r \lambda^2} \quad (15)$$

Where R_b is the transmission data rate in MQAM modulation, and $R_b = bB$ when $b \geq 2$, $d_{hop,i}$ is the average distance between the cooperative node in the i-th hop and the header node or the Sink node in the next hop.

In reference [11], it is deduced the time of data transmission to the Sink node is $T = L_f / R_b^{eff}$. When all the data are transmitted to the Sink node, the total number of hops is n. Therefore, the transmission energy consumption of all cooperative nodes in each cluster is derived as follows:

$$E_{t\_hop} = \sum_{i=1}^{n} N_c \times (1+\alpha) P_{t\_hop,i} \times T = \sum_{i=1}^{n} N_c \times (1+\alpha) P_{t\_hop,i} \times \frac{L_f}{R_b^{eff}} \quad (16)$$

The Sink node is close to the exit of mine tunnel, it can supply power directly. So the energy loss of the SINK node can not be discussed in the transmission model of this article. Therefore, the energy consumption of circuit in each cluster for multihop data transmission is:

$$E_{c\_hop} = \frac{N_c P_{ct} L_f}{R_b^{eff}} \quad (17)$$

In literature [15], in the long-distance transmission process of WSN, due to the complex environment of mine tunnel, it is easy to cause the transmission energy loss of radio waves. Therefore, the cooperative nodes need to increase the transmission energy consumption. In this paper, it is concluded that the increased transmission energy consumption of cooperative nodes is equal to the transmission energy loss, and the transmission energy loss E_{loss} is:

$$E_{loss} = P_{loss} \times T = \sum_{i=1}^{n} \frac{P_{ct} G_t G_r \lambda^2}{(4\pi)^2 d_{hop,i}{}^2} \times \frac{L_f}{R_b^{eff}} \quad (18)$$

According to formulas 16-18, the total energy consumption of multihop in VMIMO-I algorithm model is as follows:

$$E_{hop} = N_r (E_{t\_hop} + E_{c\_hop} + E_{loss}) \quad (19)$$

3.3. Minimum Energy Solution of VMIMO-I Algorithm Model

The total energy consumption of VMIMO-I algorithm model is:

$$E_{total}(N_c, N_r, b) = E_{intra} + E_{hop} \quad (20)$$

Many literatures show that the optimal number of cooperative nodes N_c is usually within 2-10. As described in reference [6], when the modulation level of WSN is too large, in order to ensure a certain bit error rate, the transmission power of the power amplifier has to be increased correspondingly, so the total energy consumption of the system also increases correspondingly. If the modulation level is too small, the transmission rate is low, and the circuit energy consumption increases correspondingly, so the modulation level is usually even and less than 12.

The number of optimal cooperative nodes is usually more than 2 and less than 10. Although too many cooperative nodes will improve energy efficiency, it will also lead to significant increase in the average delay.

To sum up, the minimum calculation formula of total energy consumption of VMIMO-I algorithm model of mine tunnel is as follows:

$$\arg\min E_{total}(N_c, N_r, b)$$

$$s.t. \begin{cases} 2 \leq N_c \leq 10 \\ 1 \leq N_r \leq \dfrac{N}{N_c} \\ 2 \leq b \leq 12 \text{ (even numbers)} \end{cases}$$

There are many methods to calculate $\min E_{total}(N_r, b, N_c)$, such as branch and bound method. However, the search space of this algorithm model is not large. In order to be convenient, we use brute force method to solve this problem.

Before the deployment of virtual MIMO sensor nodes in mine tunnel, the optimal operation parameters of the network can be obtained through pre-calculation, then the parameters can be directly programmed into the sensor nodes. In the subsequent network operation, The Sink node periodically calculate and broadcast the parameters to the new nodes according to the actual network conditions.

4. System Simulation

In this paper, the mine tunnel scene of $600\text{m} \times 4\text{m}$ is used for simulation test. In order to facilitate the outburst effect, a total of 400 sensor nodes are randomly distributed in the long strip of mine tunnel. The Sink node is located $(650, 2)$ at the exit of mine roadway.

According to reference [15], the best carrier frequency in mine roadway is $f_c = 1GHz$.

The main simulation parameters of VMIMO-I algorithm used in mine tunnel are shown in Table 1.

Table 1. *The specific values of simulation parameters.*

name	Parameter	Setting
Circuit power consumption of sending data	P_{ct}	$98mW$
Circuit power consumption of receiving data	P_{cr}	$113mW$
RF power amplifier	α	0.47
Noise variance	σ^2	$-135db/Hz$
compensation coefficient	M_l	$40db$
Receiver noise coefficient	N_f	$10db$
Receiving and transmitting antenna gain product	G_tG_r	$5dBi$
Data aggregation factor	f_{agg}	0.7
Error rate	P_b	1×10^{-3}
Power gain factor	G_1	$30db$
Amount of data transmitted	L	$2000bits$
System bandwidth	B	$20kHz$
Data transmission probability sensor nodes	P_i	0.8
SSTBC encoding rate	R	0.75

In this paper, the initial energy of each sensor node is set to $1J$, so the total energy of the network is $400J$.

In order to make VMIMO-I algorithm model have a real reference significance in the long strip of mine tunnel, this paper simulates LEACH protocol with it in the common scene by Matlab. And mainly compares with two ways which network energy consumption and network life cycle.

The simulation results are shown in Figure 2 and figure 3.

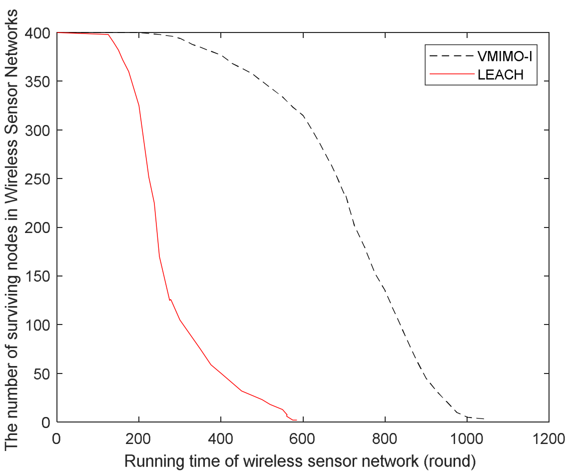

Figure 2. *Comparison with network lifetime.*

It can be seen from Figure 2 that the initial death time of WSN adopting LEACH protocol and VMIMO-I algorithm is about 190 and 300 rounds respectively, and the death time of all sensors is 590 and 1050 rounds respectively. These data show that VMIMO-I algorithm model has advantages over LEACH protocol applied in mine tunnel, and the life cycle of WSN is increased by 78%.

It can be seen from Figure 3 that the total energy consumption of WSN based on VMIMO-I algorithm is much lower than that based on LEACH protocol in the whole network life.

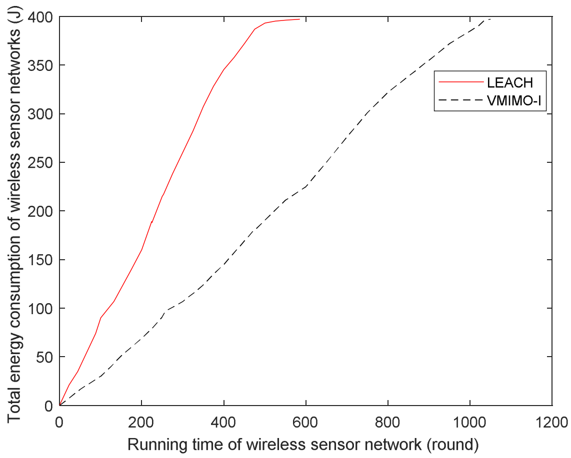

Figure 3. *Comparison with t network energy consumption.*

When the time runs to the 533rd round, the survival topologies of sensor nodes in WSN based on LEACH protocol and VMIMO-I algorithm are shown in Figure 4 and figure 5 respectively.

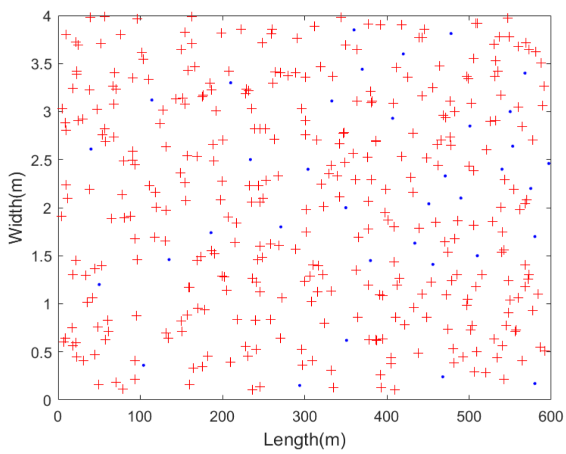

Figure 4. *Survive topologies of sensor nodes based on LEACH protocol.*

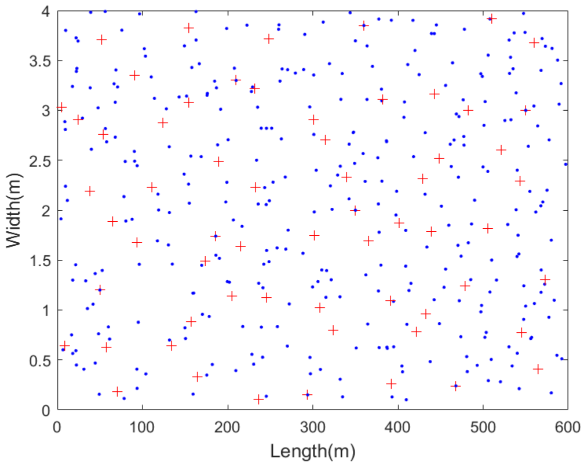

Figure 5. *Survive topologies of sensor nodes based on VMIMO-I algorithm.*

Where, + is the died sensor nodes that have exhausted its energy, and • is the surviving sensor nodes that have enough energy.

It can be found from Figure 4 that when the WSN runs to 533 rounds, the death rate of sensor nodes using LEACH protocol is about 91%, and most of the surviving sensor nodes are close to the Sink nodes. This is because the LEACH protocol adopts single hop communication mode, and the sensor nodes far away from the Sink nodes die of energy exhaustion due to the long distance transmission.

It can be found from Figure 5 that when the WSN runs to 533 rounds, the death rate of sensor nodes adopting VMIMO-I algorithm is about 16%, and the distribution of dead nodes is very average. This is mainly because VMIMO-I algorithm selects the transmission path with the minimum total energy consumption as the optimal transmission strategy, so it balances the energy consumption of all sensor nodes and improves the network life.

5. Conclusion

LEACH and its improved protocols of Single Input Single Output (SISO) system can not get ideal effect in mine tunnel because of the complexity of wireless communication network. Therefore, this paper studies the virtual MIMO system.

Due to the long strip distribution of WNS in mine tunnel and the complex underground geographical environment influenced of Virtual MIMO this paper proposes VMIMO-I algorithm. Then this paper analyzes the total energy consumption of virtual MIMO using this algorithm, and simulates the minimum energy consumption by MATLAB according to the limitation of the number of cooperative nodes, the number of virtual MIMO clusters and modulation series. The results show that the VMIMO-I algorithm can effectively avoids the "hot zone" problem, reduces the network energy consumption and increases network life cycle by 83.9% compared with the wireless sensor network with LEACH protocol.

6. Expectation

The WSN in mine tunnel is a complex and challenging but promising subject. However, there is still a gap for these theoretical analysis to be applied to mine tunnel, which still needs to be strengthened in the future study and work. The main contents can be studied further as follows:

1. In this paper, it is assumed that any two sensor nodes can communicate, but in practical, it may lead to the failure of any two sensor nodes to communicate directly due to the mixture of coal and rock on four walls of the mine tunnel, and many kinds of equipment in the space of mine tunnel.

2. In this paper, the main characteristics of wireless communication environment of mine tunnel have been briefly described, but for the simulation, the influence of four walls of the mine tunnel, machine equipment and other things caused the reflection and refraction of radio waves is ignored. So in the real application, we need to make a big step.

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