A Wireless Communication Method with Dynamic Adding Nodes for the Underground Search and Rescue Robot

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Abstract – A wireless communication method with dynamic adding nodes for Underground Search and Rescue robot is proposed: fix the address of the controller, add repeater nodes into the net dynamically, and shift the address of the mobile terminal. With this method, the Search and Rescue robot can reach the deeper place of a mine to help rescue and keep in touch with the controller through wireless communication in a single channel, even in a complex laneway where radio wave cannot go through the thick wall. The collision in the process of the two-way multi-hop communication in the single channel will also be resolved by the communication direction priority and response signal mechanism, to enhance the reliability of communication. Finally, a sample is designed and an experiment is conducted to verify the efficiency of the method.

Key words* – *multi-hop wireless communication*; *underground search and rescue*; *robot

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1 Introduction

There are many coal mines in China, and most of them are deeply underground. Once an accident happens in a mine, the rescuers can't get the information as soon as possible to rescue people trapped in the mine. It will help the rescuers to know the situations and send a S&R (Search and Rescue) robot deep into the mine to collect information before they get in, and send it to the controller computer outside the mine, which will improve the efficiency and reduce the losses[1-2].

The communication problem is a barrier in the development of the Underground Search and Rescue(USR) robot. Most of the S&R robots, working in other accidents pots, disasters or ruins caused by earthquakes or fires, are able to communicate with their controllers through wire or traditional wireless communication, but neither of the methods is effective in the mission of a USR robot. The mine accidents often happen at the excavated spots which are much deeper, and there are so many complicated turns and crosses in the laneways far away from the entrance of the mine that both kinds of communication methods are restricted. Because the wire communication requires a long and heavy piece of cable connected with the robot and thus makes it difficult to move. And the traditional wireless communication is also not effective because the communication function is so limited that the radio wave becomes much weaker than on the ground, and it cannot pass through the thick wall and cannot go far away in the laneways[3-5].

A wireless communication with dynamic adding nodes for the USR robot is proposed: that is, to fix the address of the controller, to add repeater nodes dynamically, to shift the address of mobile terminal, and to break the communication restrictions of the USR robot. And then with the communication direction priority and response signal mechanism, the communication collision happening in the process of the two-way multi-hop communication in a single channel can also be resolved, so that the robot can go into the deep place where an accident happens, collect the information about the environment there, and then send it out.

2 Principle

2.1 Multi-hop communication

There are $N+1$ nodes in all (including 1 controller node, $N-1$ repeater nodes and 1 robot node), whose ID numbers are from 0, 1… to $n-1$ and n. The node 0 is set as the controller node, node n as the robot node, and the others are set as the repeater nodes. And then $n+1$ communication addresses, from $A_0, A_1, A_2 \cdots$ to A_{n-1} and A_n, are assigned to those nodes. Among them, the addresses from A_0, A_1 to A_{n-1} are bind to those nodes which have the same ID numbers as the receiving addresses. And the node 0 has the address A_1 as its transmitting address, when the other nodes, node i, for example, have two addresses A_{i-1} and A_{i+1} as their two-side transmitting addresses, except node n, which has a list of all the ad-

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dresses stored in it, rather than a fixed receiving address or transmitting address.

When the USR robot starts working, it will take all of the nodes with it except the node 0. Among these nodes, the node n is installed in it, while the others are connected with the robot by machines and can be put down on the ground by the robot. The node 0 links with the controller computer through some type of data bus. There is a direction flag byte in the data packet, which will be "down" when data packet is transmitted from the controller to the robot, and "up" when data packet is transmitted from the robot to the controller.

The principle is shown as following:

Step 1: The USR robot starts to work with N nodes on it, and then A_1 is set as the receiving address of the node n , and A_0 as its transmitting address. When the robot gets some sensor data about the environment, the data will be transmitted from the node n as a data packet with "up" to the node whose receiving address is A_0 At the start, the node should be the node 0. Then the node 0 will continue to transmit the data packet to the controller computer through the data bus. If the controller computer gives a certain instruction to the robot, the instruction will be transmitted as a data packet from the computer to the node 0 with a "down" flag in t , then to any node with the receiving address A_1 , which should be the node n at that moment.

Step 2: After moving forward for a long distance (not beyond the longest effective communication distance between the two nodes), or reaching a turn of the laneway, the node 1 will be put down by the robot and begin to work, then the receiving address of the node n shifts to A_2 , and the transmitting address shifts to A_1 . Then a data packet with the flag set as "up" will be transmitted from the node n to the node 1, whose receiving address is A_1 at that moment, when the robot collects some information about the environment. The node 1 identifies the communication direction of the data packet often receiving it, and if it is "up", the node 1 will repeat the received data to another node with A_0 as its receiving address at that moment, the node 0, then to the controller computer.

If the controller computer gives a certain instruction to the robot, the instruction will be transmitted from the computer to the node 0 through the data bus, then to the node 1 as a data packet with the flag "down" in, which sets A_1 as its receiving address at that moment. The node 1 identifies the communication direction when receiving it, and then repeat the received data packet to the robot node, the node n , which sets A_2 as its receiving address at that moment, if the direction is "down".

Step $(m-1)$: The receiving address of the robot node n will shift to A_{m+1} , and the transmitting address will shift to A_m at the same time, when the robot put down the node m on the ground. The node n will transmit the data packet to the node m , whose receiving address is A_m . Then the node m will repeat the data packet to the node $m-1$, then "up" to another one again and again, till multi-hop to the node 0. Finally, the data packet will be transmitted from the node 0 to the controller computer through the data bus; In another case, if there is a certain instruction from the controller computer to the robot, it will be transmitted to the node 0 through the data bus, then be transmitted to the node1 from the node 0, and then to the node 2 from the node 1, "down" to another node again and again, till reach the robot node, the node n , which sets A_{m+1} as the receiving address at that moment. Then a "down" multi-hop transmitting is finished.

Following the process, a multi-hop chain net exists with more and more nodes while the robot moves further and further away from the controller computer. With the distance becoming longer (not beyond the effective communication distance) between each pair of repeaters, the USR robot will be able to communicate with the controller computer not only in a long distance but also where there is a L-turning or U-turning between them, or even with too thick a wall that radio wave cannot pass through. And the quality can also be ensured for the effective distance between the two repeaters.

2.2 Priorities of communication direction and response signal mechanism

When there is no instruction transmitted from the controller computer, the communication chain is a one-way multi-hop communication in a single channel and no collision happens, for there are only continual data packets from the USR robot to the controller. But once the controller computer transmits an instruction "down" to the robot, while the robot is transmitting a data packet "up" to the controller computer at the same time, two kinds of collision will happen because there is only one single channel.

1) Collision happens on a single node: the instruction data packet repeated by the node $m-1$ from "up" and the message data packet repeated by the node $m+1$ from "down" arrive at the node m at the same time.

2) Collision happens on two nodes: the instruction data packet, when the node $m-1$ repeats from "up" node, is being repeated from the node m to the node $m+1$, while the message data packet, when the node $m+2$ repeats from "down" node, is being repeated from the node $m+1$ to the node m at the same time.

Because all of the nodes work in the same channel and cannot transmit or receive any data packet at the same time, both of the above situations will cause collisions, and break down the two-way multi-hop communication process.

To resolve the existing collision problem, a mechanism using the direction priority and response signal is proposed based on the features of chain communication and the condition that the underground communication

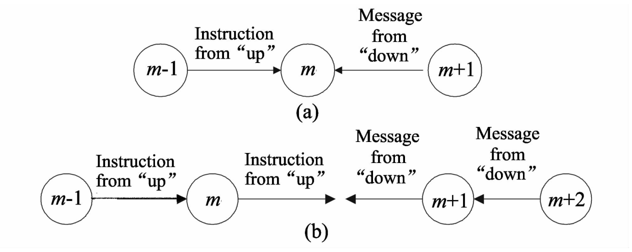

Fig.1 (a) Collision happens on single node; (b) Collision happens on two nodes

distance is so limited that the radio wave from the node m becomes too much weaker to get to the node $m+2$ or the node $m-2$ as a noise.

Set the first byte of the data packet as the flag of transmitting direction, which should be "up" or "down". And the "down" is set prior to "up". Then the working process of the node m is set as following:

Step 1: The node m responds to the repeater as soon as it receives the data packet, and run to Step 2;

Step 2: Repeat the packet "up" or "down" to another node following the direction flag in the received data packet. And when it's done, run to Step 3;

Step 3: delay and wait for the response signal. If there is a response signal before the end of the delayed time, jump to Step 7, else run to Step 4;

Step 4: If the direction is "down", jump to Step 6, or shift to the receive mode, then run to Step 5;

Step 5: Check if there is another data packet received. Jump back to Step 1 and begin another repeated process when it is Yes, otherwise wait for a short period of time and then run to Step 6;

Step 6: Jump back to Step 2, and retransmit the data packet.

Step 7: Continue waiting for another data packet, or jump back to Step 1 to start the process again if there is a received data packet.

Follow the method, when the collision happens on the single node, and the nodes $m-1$ and $m+1$ fail to receive the response signals from the node m, the node $m-1$ will transmit the data packet again at the moment for its flag is "down", and the node $m+1$ will delay for a short time and shift to receive mode to wait for the data packet. Therefore, the node m can only receive the data packet repeated from the node $m-1$ at the moment, and then repeat the data packet "down". If the node $m+1$ is still in Wait and Receive mode at that moment, it will receive the data packet, stop repeating the old data packet "up", begin to repeat the data packet, and ensure that the instruction from the controller can get "down" to the terminal, the robot node; If the wait mode has already ended and the node $m+1$ has began to transmit again, then both the nodes m and $m+1$ will transmit at the same time, so a collision will happen on the two nodes (as shown in Fig.2(a)).

The node m and node $m+1$ will be in transmit mode at the same time, and cannot receive the response signal from the other, when a collision happens on the two nodes. So following the priority, the two nodes will begin to transmit again at the moment or shift to the wait and receive modes. Because the node m will the transmit the data packet while the node $m+1$ is in the receive mode, the node $m+1$ will get the data packet, cancel the old mission of repeating "up", then begin to repeat the data packet "down", and ensure the availability of the two-way communication and the instruction can reach the robot from the controller (as shown in Fig.2(b)).

Seen from those figures above, the method can solve the collision problem happening in the process of the two-way communication and ensure the availability of the two-way communication, which means the sensor data can arrive at the controller from the robot in real time, and the robot can also receive the instruction from the controller as soon as possible.

3 Experiment

A sample system is built following the method, by chosing LPC2132 as the MCU, and nRF905 as the RF unit, which works at 430 MHz. The flow charts of the robot node and the node i are shown in Fig.3.

For some reasons, the experiment is carried out in an experiment field simulated as a laneway of an underground mine, which is a tunnel deep beneath, made of earth and equipped with iron fences in some lengths. The structure and size of the tunnel are shown in Fig.4(a), with the map shown in Fig.4(b).

The experiment process is that:

Step 1: The node 0 is connected with the controller computer by the serial bus, and is set at Site A in Fig.4(b). The node 3 is moving along the route from Site A to Site B with the nodes 1 and 2 together, which are at the sleep mode.

Step 2: Check the data the node 0 receives through the controller computer, and send some instructions to the node 3. Once the data cannot be received, stop moving the node 3, put down the node 1 on the ground and wake up it, then shift the address of the node 3.

Step 3: Move the node 3 and the node 2 from Site B to Site C, and check the data the node 0 receives. Once the data cannot be received, stop moving the node 3, put down the node 2 on the ground and wake up it. Finally, shift the address of the node 3.

Step 4: Move the node 3 from Site C to Site D, and check the data the node 0 receives.

In the process of the experiment, the node 3 would transmit the data packet, including 32 bytes, to the controller computer 50 times when the node 3 is moving between two sites, and the controller computer will transmit no less than 5 instructions to the node 3, which also includes 32 bytes in each packet. And the node 3 will change the data packet as an answer packet to the node 0, then

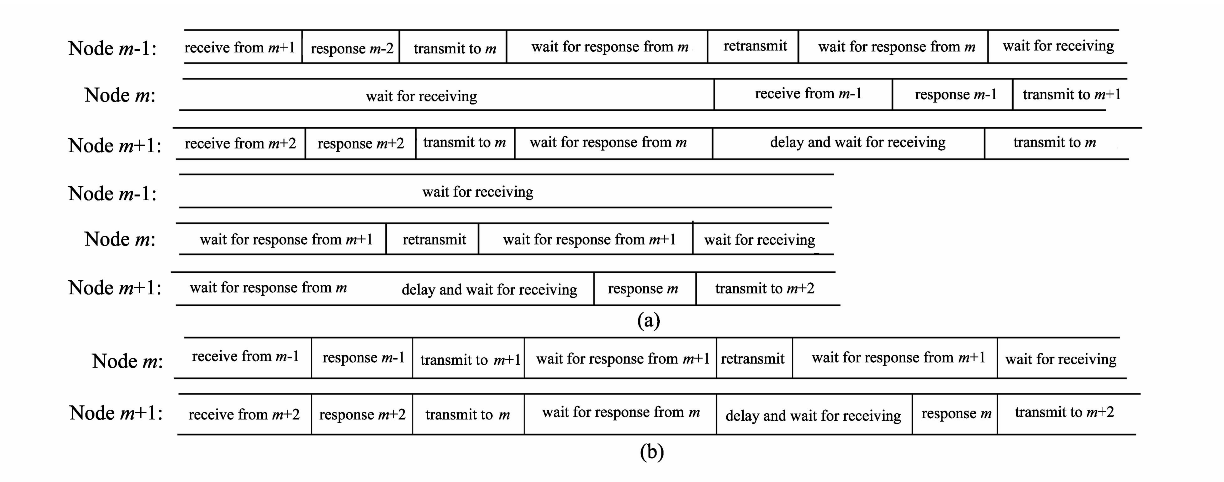

Fig. 2 (a) Timing diagram when the collision happens on the signal node, (b) Timing diagram when the collision happens on the two nodes

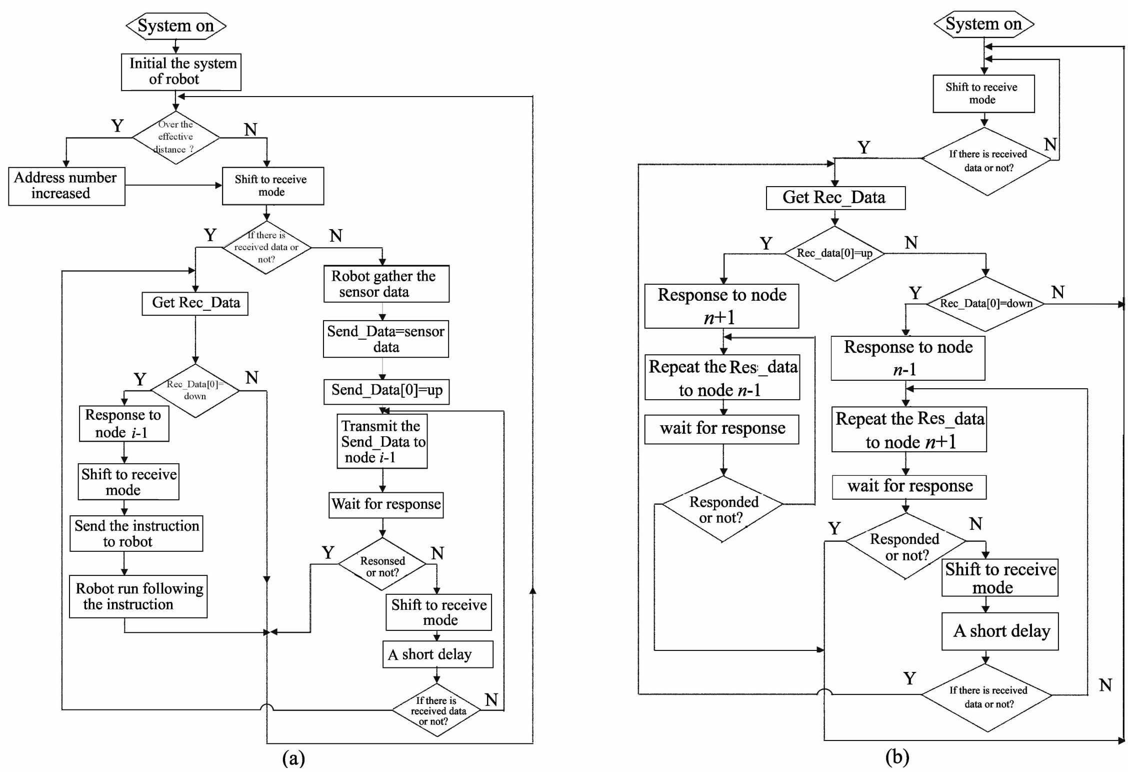

Fig. 3 (a) Flowchart of the robot node, (b) Flowchart of the node i

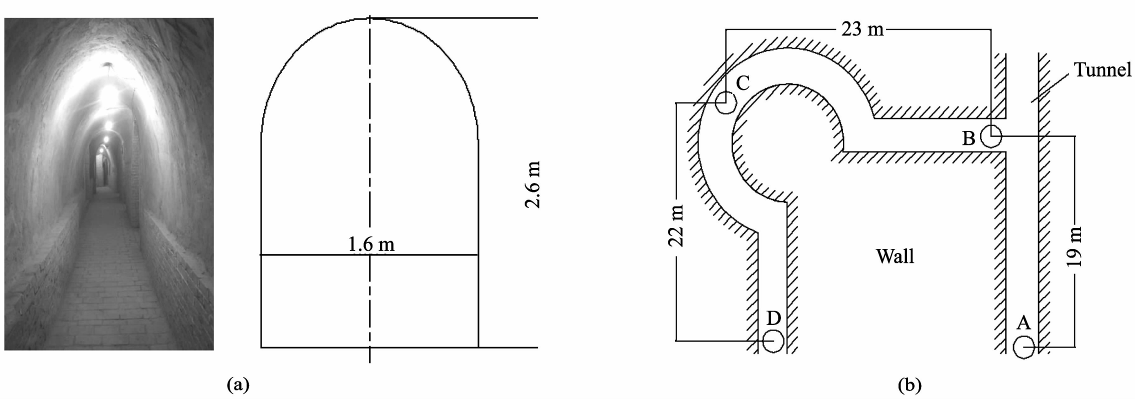

Fig. 4 (a) Structure and size of the tunnel; (b) Map of the tunnel

operator can know whether the instruction reaches the node 3 or not, through what the node 0 receives.

4 Results and Discussion

The results of the experiment are shown in Tab. 1, and "Success" means that the error rate of the data packets from the node 3 to the node 0 is less than 10%, the instructions from the node 0 can reach the node 3, and the delayed time is less than 1 s.

The analyses of the results show that the robot node 3 and the node 0 can keep connected in the complex tunnel where the radio wave cannot pass through the thick wall, by dynamically putting some repeater nodes down at the turns when the robot passes; And with the priority of the communication direction and response signal, the node 0 can transmit the instruction to the node 3 while the node 3 is transmitting data to it, ensure the efficiency of the two-way communication in a single channel.

Tab. 1 Communication status when the node at different locations

Location of the node 3	No repeater	With the node 1	With the node 2
Between Site A and Site B	Success	Success	Success
Between Site B and Site C	Fail	Success	Success
Between Site C and Site D	Fail	Fail	Success

5 Conclusion

For the problem, in which the Underground Search and Rescue robot cannot run effectively for the restriction of communication once a mine accident happens, a multi-hop communication method is proposed, and an experiment is carried out to verify its efficiency. This method can increase the communication distance between the USR robot and the controller, even in a complex tunnel with L-turns and U-turns where the radio wave cannot pass through the wall. It allows the robot to have access to the deep place of the mine, and improves the usefulness of a USR robot in a rescue action when an accident happens underground.

References

[1] Hua Zhu, 2007. Current status and technical problems in the research of coal mine rescue robot. *Journal of Xuzhou Institute of Technology*, (6): 5-8.

[2] Xiao-po Dong, Xu-ben Wang, 2007. Development of rescue robot technology and its application in disaster. *Journal of Disaster Prevention and Mitigation Engineering*, (1): 112-117.

[3] Zhong-min Wang, Jun Liu, Zhi Dou, 2007. Research and application status and development of search and rescue robot for mine disaster. *Coal Mine Machinery*, (11): 6-8.

[4] Robin Murphy. Robot-Assisted Search and Rescue: A Grand Challenge Problem for Computing System. University of South Florida. Center for Robot- Assisted Search and Rescue.

[5] De-qiang Cheng, Wei Liu, Jian-sheng Qian, 2007. Wireless communication technology in coal mine and its deveolopment trend. *Industry and Mine Automation*, (5): 72-76.

[6] Ji-pin Sun, Zi-jian Tian, Liang Liang, 2003. A new networking method of underground wireless communication. *Industry and Mine Automation*, (2): 17-19.

[7] Wei Yang, Shi-xin Cheng, Ji-ping Sun, 2001. The mine wireless communication and frequency source utilization. *Journal of China Coal Society*, (5): 634-637.

[8] Yi Zhang, Yuan Luo, Tai-xiong Zhen, 2007. Mobile Robot Technology and It's Applications. Publishing House of Electronics Industroy.

[9] I. F. Akyildiz, Zhi Sun, M. C. Vuran, 2005. Signal propagation techniques for wireless underground communication networks. Physical Communication, (3): 337-342.

[10] L. Li, M. C. Vuran, I. F. Akyildiz, 2007. Characteristics of underground channel for wireless underground sensor networks. Proc. IFIP Mediterranean Ad Hoc Networking Workshop (Med-Hoc-Net'07), Corfu, Greece.

[11] Patrick Herhold, Ernesto Zimmermann, Gerhard Fettweis, 2005. Cooperative multi-hop transmission in wireless networks. *Computer Networks*, (49): 299-324.