Construction Strategy of Wireless Sensor Networks with Throughput Stability by Using Mobile Robot

Kei Sawai
Department of Information and Communication Engineering, Tokyo Denki University
Tokyo, Japan

Yuta Koike
Department of Information and Communication Engineering, Tokyo Denki University
Tokyo, Japan

Shigeaki Tanabe
Technical Support Department,
Technology Institution of Industrial Safety (TIIS)
Sayama city, Japan

Ryuta Kunimoto
Department of Information and Communication Engineering, Tokyo Denki University
Tokyo, Japan

Hitoshi Kono
Department of Information Communication and Media Design Engineering, Tokyo Denki University
Tokyo, Japan

Tsuyoshi Suzuki
Department of Information and Communication Engineering, Tokyo Denki University
Tokyo, Japan

***Abstract*—We propose a wireless sensor networks deployment strategy for constructing wireless communication infrastructures for a rescue robot with considering a throughput between sensor nodes (SNs). Recent studies for reducing disaster damage focus on a disaster area information gathering in underground spaces. Since information gathering activities in such post disaster underground spaces present a high risk of personal injury by secondary disasters, a lot of rescue workers were injured or killed in the past. Because of this background, gathering information by utilizing the rescue robot is discussed in wide area. However, there are no wireless communication infrastructures for tele-operation of rescue robot in the post-disaster environment such as the underground space. Therefore, we have been discussing the construction method of wireless communication infrastructures for remotely operated the rescue robot by utilizing the rescue robot. In this paper, we evaluated the proposed method in field operation test, and then it is confirmed that maintaining communication connectivity and throughputs between End to End of constructed networks.**

Keywords*—Wireless Sensor Networks; Rescue Robot Tele-Operation; Maintaining Throughput

I. Introduction

Gathering information in disaster areas is very important for assessing the situation, avoiding secondary disasters, and managing disaster reduction [1]-[8]. In general, bird's-eye image information gathered by unmanned air vehicles (UAVs) and artificial satellites is useful for understanding post-disaster situation. However, in an underground space in the city part where such UAVs etc. cannot gather information, it is difficult to ascertain the extent of the damage, which is important for avoiding secondary disasters. Also, rescue teams cannot organize a suitable rescue plan for underground spaces because sufficient information is not gathered. Under such a situation, the rescue team must go into the underground spaces directly to gather disaster information, and the information should be shared within the teams by communication between above ground and underground space for efficient and cooperative rescue works. However, when the communication infrastructure is broken due to damage, rescue teams cannot cooperate closely because of communication disconnection. Therefore, the rescue team has to work in the underground space with being unable to know the situation correctly, and they face the added risk of secondary disasters. For example, in the underground disasters in Korea in 2003, a lot of rescue workers were sacrificed because of smoke damage. The rescue teams could not expect the smoke damage because they could not gather enough information about post-disaster situation in underground space, thus many lives were lost. This is a typical case of underground disaster damage due to secondary disasters that has triggered because the rescue teams entered underground areas without adequate information.

From discussions based on past accidents analysis, researchers have recently focused on a disaster information gathering method using a wireless sensor network (WSN) and a rescue robot in closed areas. The WSN consists of spatially distributed sensor nodes (SN) to cooperatively monitor the environmental conditions such as temperature, sound, vibration, pressure, motion, etc. Then, the WSN is enabled to provide the wireless communication function in place without existing infrastructure. The WSN in closed area is constructed by rescue robot. Therefore, an information gathering method by constructing the communication infrastructure to disaster area by using the WSN has been discussed.

One of them, a SN deployment strategy by utilizing the rescue robot is very important to the performance evaluation of adaptability in closed space. Many SN deployment strategies have been discussed in the WSN research field. In these strategies, deployment methods have been proposed based on evaluation scales that consider factors such as packet routing, energy efficiency, power saving, and coverage area. Several SN deployment methods using mobile SNs and mobile robots to construct the WSN have been developed. Parker et al. proposed the WSN construction method using an autonomous helicopter for environmental monitoring and urban search and rescue [9]. Umeki et al. proposed an ad-hoc network system, Sky Mesh, using a flying balloon for targeted disaster rescue support [10]. Also, deployment methods have been developed based on virtual interaction between the SNs based on several physical models; such as the potential field model and the fluid flow model [11]-[17].

A great deal of effort has been made on SN deployment strategy. However, what seems to be lacking is the strategy that is considered the specification of underground space and the construction method of with concerning a throughput quality for expanding the area where is able to operate remotely the rescue robot. There are a lot of shielding materials of electrical wave. Then a discussion of the construction method of the WSN with concerning specification of underground space is important to prevent a network disconnection. Then to expand the network with stable throughput is important to maintain the information gathering system, it is necessary to prevent the secondly disaster.

Therefore, we have been discussing the information gathering system that is considered these important matters (Fig. 1) [18]-[21]. In this paper, we proposed the novel SN deployment strategy to construct the WSN with the stability of communication connectivity by utilizing the rescue robot. Then we evaluated the availability of the proposed method in field operation test.

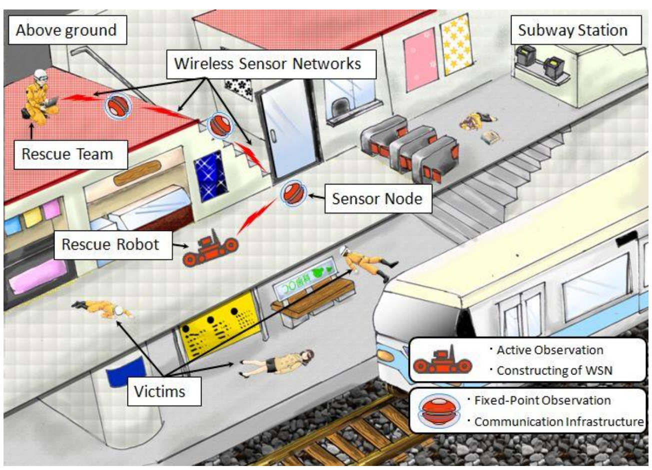


Fig. 1. Gathering disaster area information by utilizing wireless sensor networks and rescue robot

II. Deployment Strategy For Maintaining Communi-Cation Connectivity By Utilizing Rescue Robot

A. Prior Conditions

In our proposed system, the WSN is constructed by utilizing rescue robot to deploy SNs. In the construction environment that is deployed SN, we assume the place that has entrance stairs and the first basement floor.

First of all, the entrance stairs in under-ground is required to set up at intervals 30 [m], and passage way is built in line in Japanese building standard low. Therefore, in our proposed system gathers this area's information. Then we discussed the WSN construction method by utilizing rescue robot in this area. In the wireless communication of this WSN, IEEE 802.11 series are adopted for wireless communication between SNs including the rescue robot, which has been used as proven communication in many studies of mobile robot and the WSN [22]-[26]. Then in our proposed method, we treat a rescue robot as a SN in the WSN. Heterogeneous networks that are involved some SN and various mobile robots are difficult to manage the system control. Especially, the maintaining the stability of the system control is not easy by occurring secondly disaster in underground spaces. In this environment, to construct the stable system is necessary to simplify the network structure. Therefore, we simplified the network structure by treating a rescue robot as a SN. From here onwards, the communication system of the rescue robot is adopt the IEEE802.11 series as same as the SN.

In our SN deployment method for constructing the WSN, we adopt the method that the rescue robot delivers the previously wireless connected SNs. The rescue robot deploys the SN in the own passageway. Then the WSN is expanded, the operator is able to control the rescue robot by utilizing the communication infrastructure of the WSN. In the network topology of this WSN, it is linearly connected each SNs to prevent the error of routing control. Generally, the WSN is able to decide the routing path of data transfer automatically by utilizing the RSSI between each SN, throughput of End to End or the rate of packet loss. The routing pass of the WSN is reconstructed by changes of these communication qualities.

However, the reconstruction of the routing pass repeatedly occurs the situation that is the disconnection and reconnection in between SNs. This situation is a problem for the system with tele operating the mobile robots. The tele-operating with abeyance of wireless communication degrades an operability of rescue robot and the performance of the gathering disaster area information. Then the change of the communication qualities is often occurred in disaster area by the damage of secondly disaster, the routing path is repeatedly reconstructed in the WSN. Therefore, we adopt the network topology that is linearly connected SNs, and it refers to the previously determined routing path to prevent the lowering of mobile robot activity.

B. Requested Specifications

IEEE 802.11 series, it is necessary to keep the throughput that is more than 1.0 [Mbps] in between the operator and the rescue robot (End-to-End communications) (Add the references). Then in the construction of the WSN by utilizing the rescue robot, the throughput between End-to-End communications has to be maintained in the environment that is constructed the WSN. The construction length of the WSN is required 50 [m] by concerning the distance of first basement floor 30 [m] and entrance stairs 20 [m]. However, the communication connectivity of IEEE802.11 series is characterized by decreasing in turn area covered with concrete material such as the underground space. Thus in our proposed system for constructing WSN, we should consider this communication characteristic that has a risk of network disconnection.

In the communication system of the SN and the rescue robot, it adopt IEEE802.11b as the system that has the high connectivity in the environment where has a lot of obstacles. The theoretical values of throughput by utilizing IEEE802.11b are 11.0 [Mbps], and then the actual measurement values are lowered around 7.0 [Mbps] by the efficiency of the various factors in the real environment. Then this wireless LAN protocol provides the communication distance that is 100 [m] as on the straight line. The throughput is satisfied with the required specification that is more than 1.0 [Mbps] to operate the mobile robot and the high connectivity. Therefore, we adopt IEEE802.11b to our proposed system. And then the throughput we defined is the amount of packet transferred per unit time in the networks.

When IEEE802.11b is adopted in the ad-hoc networks, the number of SNs that is able to maintain is more than 1.0 [Mbps] is 4 nodes in the situation that the entire throughput between each SN is more than 6.0 [Mbps]. In the function of ad-hoc networks constructing the WSN, the delay of data transfer is occurred with an increasing amount of the hop number in between the source and the destination of the network. Whence to linearly connect the SNs for expanding the WSN with maintaining the throughput, the number of the SN is required to decide for constructing the network in advance. Then this method provides the high connectivity in turn area covered with concrete material such as the underground space by deploying the SN as communication relay device to construct WSN. Also the constructed network consists of a source SN, three SNs that are deployed and a rescue robot regarded as the SN (Fig. 3).

III. SN Deployment Method To Construct Lineally Networks

Our proposed SN deployment strategy is required the communication quality parameters to construct lineally networks. The communication qualities are measured the electrical field density (RSSI) and the throughput for the decision of SN deployment place. The lower of the packets throughput is occurred by the efficiency of various factors that is the multipath facing of the radio waves, the packet collisions, changing RSSI …etc. Thus it is difficult to construct the WSN with maintaining the throughput over 1.0 [Mbps] in the section of End to End. Therefore, our proposed method constantly monitors these parameters for the construction of stable communication infrastructure.

The rescue robot mounts three SNs, and then it expands the WSN by deploying these SNs. The entire SNs mounting on the rescue robot is linearly connected by reference the routing plan in advance. Then, SN is deployed by the state of network connection. The deployment with connecting the adjacent SNs has no steps that involving the reconstruction of connection by adding to the WSN. The reconstruction of WSN need to momentary disconnect the adjacent SNs of deploying SN, whence the operator cannot control the rescue robot in that split second. The rescue robot with the status of uncontrolled tele-operating has the risk which is the occurring the losing of the rescue robot and the secondly disaster. Therefore, we adopted the method that connecting the entire SNs in advance.

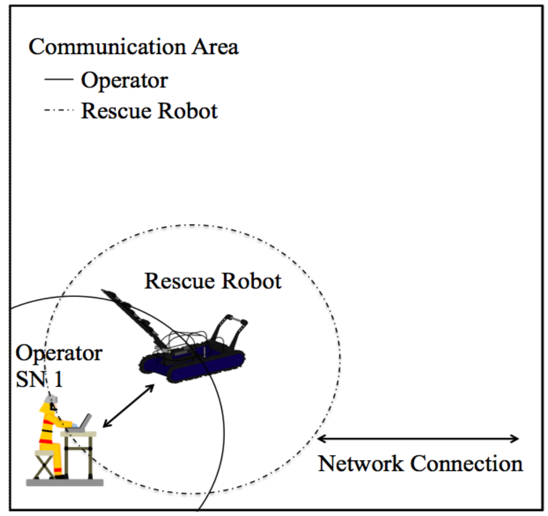


Fig. 2. Existing approach of wireless tele-operation

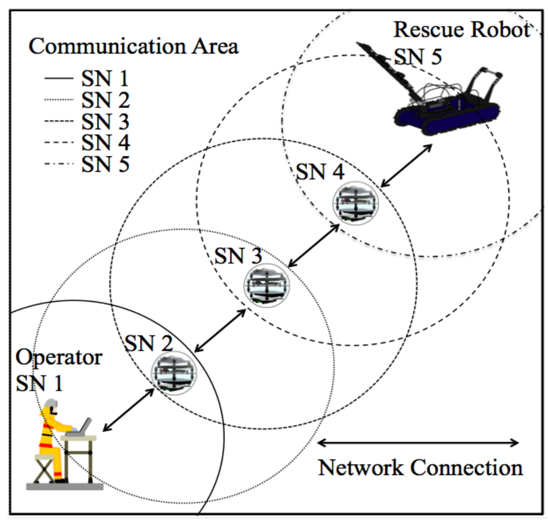


Fig. 3. Constructing method of wireless sensor networks by utilizing rescue robot

To keep the throughput to over 1.0 [Mbps] in End to End, it requires maintaining the two communications qualities of between each adjacent SN. The RSSI in between two adjacent SNs (1 [Hop]) requires over -86 [dBm]. A wireless LAN module that controlling the throughput speed constantly refers the RSSI for stability of the network connection. If the RSSI value get down to under -86 [dBm], the wireless LAN module controls the throughput speed to under 6.0 [Mbps]. Whence our proposed method also should measure the RSSI to predict the throughput speed control of the wireless LAN module. Throughput requires the value more than 6.0 [Mbps] in between the deploying SN and the adjacent SNs on the condition that maintaining the throughput over 1.0 [Mbps] in between end to end. Moreover in the decision of deployment position, measuring the End-to-End throughput is required to evaluate the communication quality between the operator and the rescue robot.

Therefore, our proposed algorithm requires the repetitive measurement of communication quality and the movement of rescue robot. The rescue robot in decided place deploys the SN. Fig. 4 shows the workflow of this deployment strategy. In the workflow, *N* is parameter of previously deployed SN ID, *M* is the next deployment SN. The workflow is outlined below.

1) Rescue robot deploys the first SN in the point of 0 [m], the deployed SN is numbered the ID "N" (initial value = 1). The secondary SN is numbered the ID "M" (initial value = 2).

2) After the moving of the rescue robot, the operator constantly observes the RSSI between SN "N" and "M" in interval at 1.0 [m].

3) If the RSSI of between "N" and "M" is higher than -86 [dBm], the operator measures the throughput of between the End-to-End communications. Moreover if the throughput is more than 1.0 [Mbps], the rescue robot keeps task to construct the WSN.

4) If the deployed SN ID is "N= 1" in the situation that the RSSI is lower than -86 [dBm] or the throughput is not enough 1.0 [Mbps], the rescue robot goes back the place where is kept the communication qualities.

5) After the movement, the rescue robot evaluates the throughput between End to End. If the throughput is stable, the rescue robot deploys the SN of ID "M". After the action of deployment, the value of "N" and "M" are changed to "N"=2 and "M"=3. The number of "N" and "M" are incremented a value after deployment of SN. (N=N+1, M=M+1)

6) Then the rescue robot repeats above deployment action (2) - (5) until the number of "M" is incremented 5. Our proposed SN deployment strategy constructs WSN by utilizing above workflow.

IV. Communication Quality Evaluation Of Constructed Wireless Communication Infrastructure By Using Proposed Model

A. Experimental condition

actually constructing the WSN composing the SNs and the rescue robot. Then, the rescue robot deploying the SNs constructed the WSN in this experiment. In the evaluation, evaluation item was targeted at the extended distance and the throughput in between End to End of the WSN.

To construct the WSN, we adopt the developed SN device shown in Fig. 5 in our previous studies. This SN mounts the CPU board, memory device, CompactFlash disc, IEEE 802.11b/g wireless LAN module, a digital camera, an A/D converter, and a battery. Then these devices of the SN are controlled by Linux OS (Debian). It enables to construct the WSN by utilizing the "AODV-uu" of the application connecting Ad-Hoc networks. Table 1 shows the specification of our developed SN.

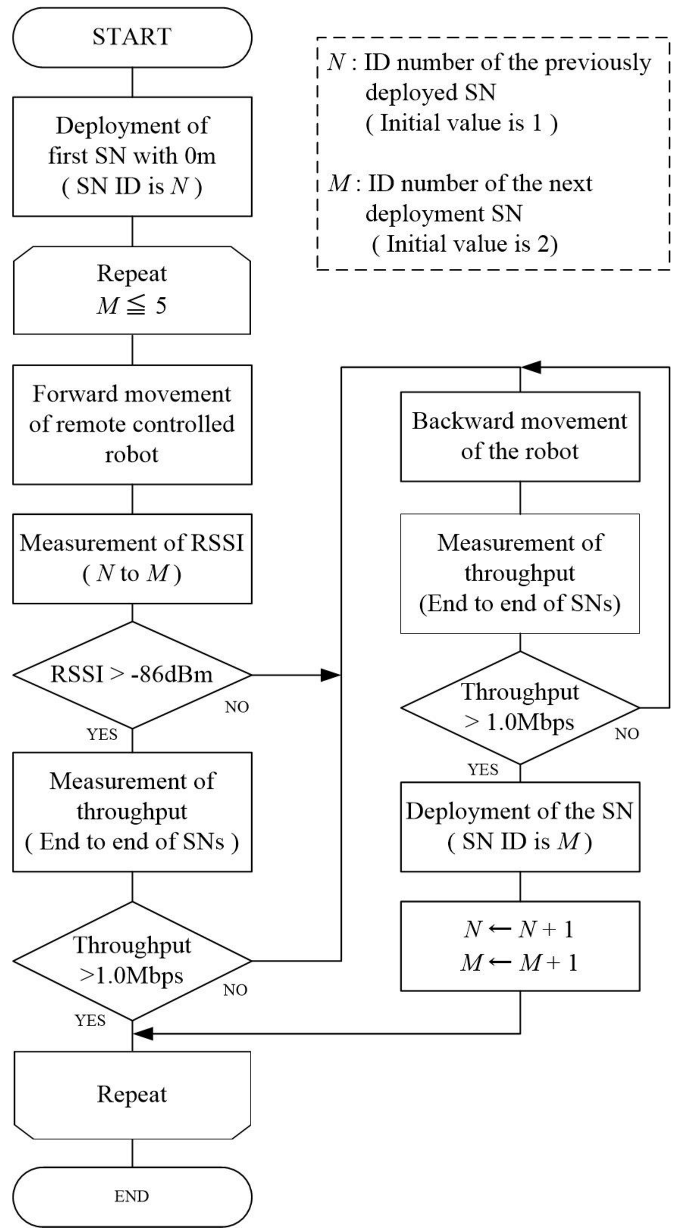


Fig. 4. Workflow of SN deployment method

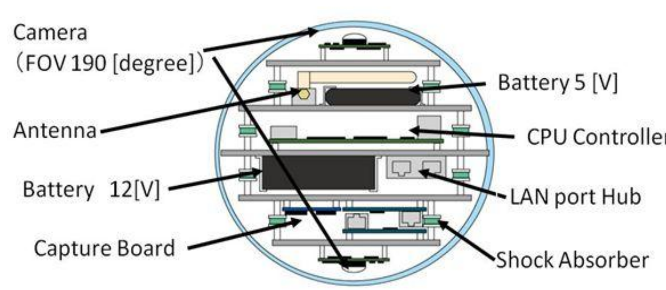


Fig. 5. Developed wireless sensor node

TABLE I. SPECIFICATION OF WIRELESS SENSOR NODE

Sensor Node	
Operating system	Linux Kernel 2.6 (Debian)
CPU board	Armadillo-300 (ARM 200[MHz])
Web camera	Axis 207MW
Fish eye lens	Nissin 4CH190 (AOV 190[deg])
Weight	1.5 [kg]
Height×Width×Length	225 [mm] × 180 [mm] × 380 [mm]
Battery No. 1	Output : 5 [V], 1.8 [A]
Battery No. 2	Output : 12 [V], 2.1 [A]
Operating time	3 [hour]

The crawler-type mobile robot,"S-90LWX" (TOPY INDUSTRIES, LIMITED), in Fig. 7 is adopted as the rescue robot in this experiment. The SN deployment mechanism was developed for the WSN construction and installed to the rescue robot, which can mount up to five SNs using five solenoid-operated locks. Figure 6 shows the framework of this mobile robot with the SN deployment mechanism. The mobile robot and the entire SNs are named IP address in this system. Then, the operator can operate the crawler robot and the deployment mechanism remotely by utilizing the TCP/IP and UDP.

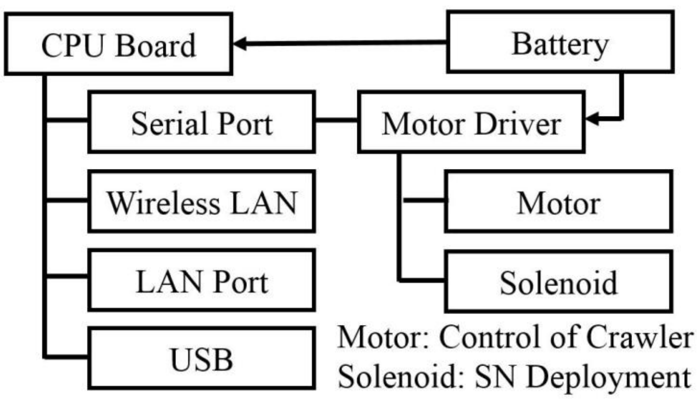


Fig. 6. Configuration of Mobile Robot

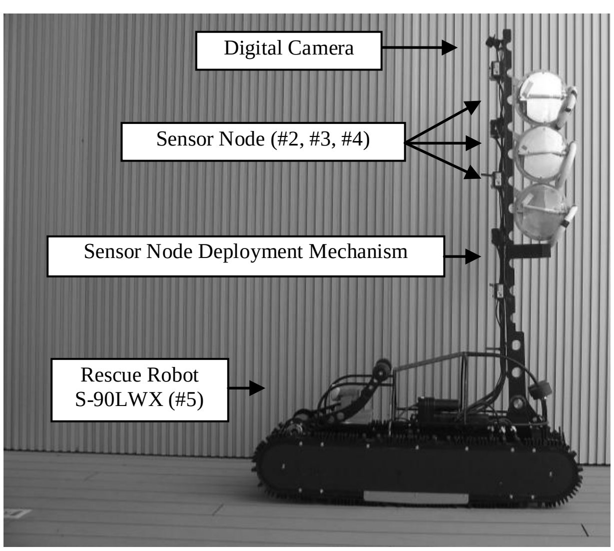


Fig. 7. Rescue robot mounting sensor node

B. Measurement Method

The operator linearly advances the mobile robot in a straight way. In this experiment, the RSSI and the throughput are measured to 10 times at every 1.0 [m] interval, and calculated the average at each measuring point. The throughput is measured in the between deploying SN and the adjacent SNs, and the End to End. Generally, a wireless communication quality in physical layer level is measured using the spectrum analyzer in anechoic chamber. For the RSSI measurement in this experiment, however, we used "iwlist" command contained in the Linux wireless tools package because we aimed to evaluate the transport layer level communication. To measure the packet throughput, "utest" (NTTPC Communications Ltd.) was used.

The experiment is performed in the passageway with a length of 300 [m] or more in Tokyo Denki University, and the rescue robot constructed WSN by utilizing our proposed algorithm in this environment (Fig. 8 and 9). Then we evaluated the distance that the mobile robot moved the without the SN deployment for the cooperative evaluation. In the experiment without the SN deployment, the mobile robot is controlled in area that keeping the throughput to over 1.0 [Mbps].

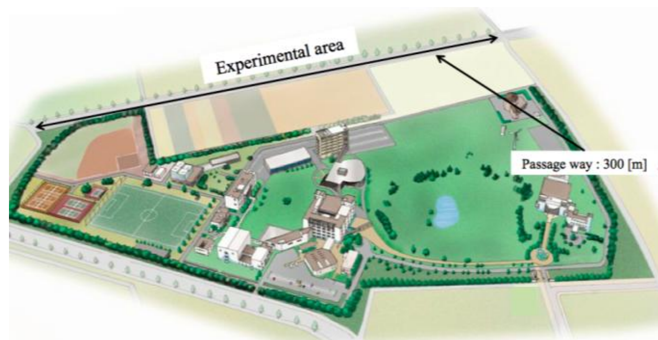
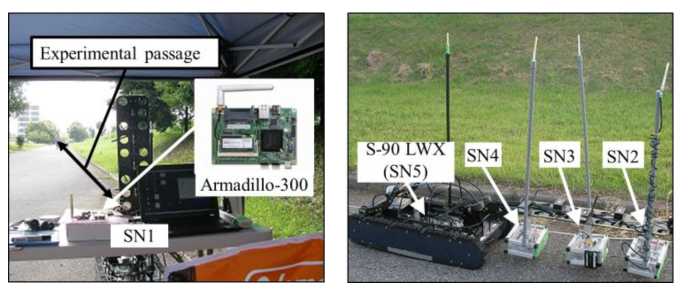


Fig. 8. Experimental environment



(a) Experimental place (b) S-90LWX with SNs

Fig. 9. Overview of experimental environment

C. Experimental Results

Figure 10 shows the results of the average of through-put between End to End communications, the value of the RSSI and the extending distance by utilizing our proposed algorithm. Arrowed lines on the graph indicate the SN deployment point and the extended distance. In the results, the extended distance with maintaining the throughput over 1.0 [Mbps] was 252 [m].

Then the distance without the extending method was 140 [m] that the remit keeping the throughput to 1.0 [Mbps].

Therefore, we confirmed the extended distance for the WSN construction with keeping the throughput of 1.0 [Mbps] is over the theoretical distance of the networks at this experimental situation.

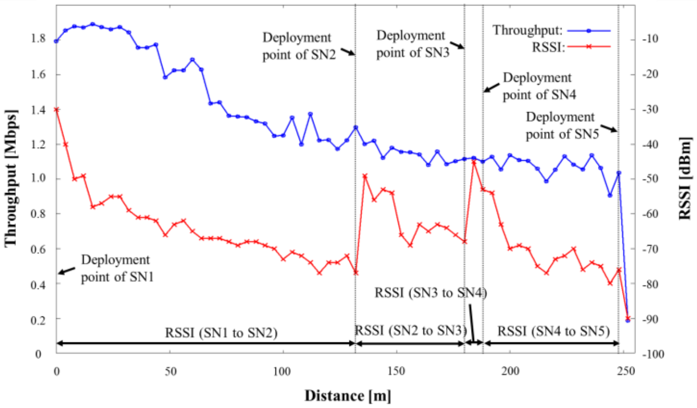


Fig. 10. Experimental results of measured RSSI and throughput

V. Discussion

In this communication quality evaluation, we confirmed the WSN that has the maintenance capability of throughput between End to End communications was constructed by utilizing our proposed method. Throughput between the End to End was stable over 1.0 [Mbps] to the point of 252 [m] from the point of 0 [m]. The deployment point of SNs was 130 [m] (SN2), 180 [m] (SN3), 192 [m] (SN4) and 252 [m] (Rescue robot as SN5). Decreasing throughput was 0.7 [Mbps] at most in between SN1 and SN2, however, it was maintained over 1.2 [Mbps] in entire measurement point. It is assumed that this reduction of the throughput was occurred as a result of increase of communication distance.

Thus there was no significant decrease of throughput in between SN2 and SN3, SN3 and SN4, SN4 and Rescue robot (SN5). Then it was stable in between End to End. These experimental results is caused by the SN deployment point interval was short, thus the throughput was not affected by the attenuation of radio wave. In the reason that SN deployment intervals was short, it was caused by the environment there are various noises. However, the throughput was stable to more than 1.0 [Mbps] in this environment, it was confirmed the availability of our proposed method in this field test.

VI. Conclusion

This paper proposed the WSN deployment strategy that maintains throughput more than 1.0 [Mbps]. The proposed strategy maintained communication conditions such that the throughput between End to End communications in the WSN enables smooth tele-operation of the mobile rescue robot in a post-disaster underground space. Experimental results showed the effectiveness of the proposed strategy that is enable to construct the WSN in the field test.The rapid implementation of actions to reduce secondary disasters in disaster areas requires the stable referral of disaster information. Therefore, this strategy which constructs WSN that maintains the throughput stable by utilizing rescue robot is effective for gathering disaster area information in actual disaster scenarios. We will apply the proposed strategy to WSN deployment in practical underground space in the future.

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