Requirements for Quick Network Construction Mechanisms for the On-Site Emergency Rescue Activity

Keiichi Shima* Yojiro Uo*
*Internet Initiative Japan Inc., Chiyoda-ku, Tokyo 101-0051, Japan

Abstract

When a disaster happens in an area where people live in and there are victims at there, a rescue team is organized and sent to save the victims. Traditionally, the rescue parties run a risk of their own lives to save them. We believe that recent progress of robotics technologies and networking technologies can help the situation. We propose the idea of the autonomous network construction system and the remote investigation system of the disaster area by robots. In this paper, we propose a new research area for the dynamically extended and autonomously maintained network by robots. We define the disaster situation assumed in this area and state the requirements to realize the solution for the new kind of network.

1 Introduction

The primary purpose of rescue activities at the area stricken by a disaster is to save victims left behind or unable to evacuate because of collapsed houses or fire caused by the disaster. Since such a stricken area is usually in danger, especially just after the disaster, we have to be careful not to cause secondary disasters when we perform rescue activities. In addition to natural disaster, we are in risks of artificial disasters like terrorism recently. In such cases, poisoned gas or bombs may be spread over the area and would be immediate causes of serious injuries on rescuers.

One possible way to avoid the secondary disaster is to send rescue robots instead of human parties. Rescue robots inspect the disaster area and collect information necessary for the later human rescue activities. By using such robots, rescuers can reduce the cost to search areas no victims exist and can avoid too dangerous areas for human rescuers. Many laboratories are researching such rescue robots [1].

However, operators still have to go to the disaster area with robots because most of them are short range remote controlled robots and operators have to control robots beside or very near from them. Since the current robot control methods are with direct communication devices such as a wired line or a single wireless connection only, operators cannot control robots from a distant place yet.

We think that combining the robotics technologies and networking technologies we can provide a safer way to do rescue activities. If we have a network that covers whole the disaster stricken area, we can use the network to support robot operation with no need of operators to run a risk to get into the area. This raises one question to us; how we can create such a network in the stricken area. If the rescue area is outdoor, then we may be able to utilize wide-area wireless communication technologies to construct that kind of network. However if the disaster occurs indoor such as airports, underground shopping centers or stations, it is difficult to use wide-area communication devices. These areas are usually complicated in shapes and radio wave cannot cover whole the area because they are divided by walls or obstacles. In such cases, we can use robots not only to inspect disaster areas but also to construct the network for rescue. We can extend the search area by enlarging the network by using the network itself and robots.

In this paper, we propose the requirements for this kind of dynamic self-extendable network using robots. We call such a type of network as "*Robohoc network*". Section 2 shows the basic idea of how we can construct and extend the Robohoc network. Section 3 discusses disaster situations and use cases of the Robohoc network, then defines requirements for the Robohoc network. Section 4 introduces some related works on this area and Section 5 concludes this paper.

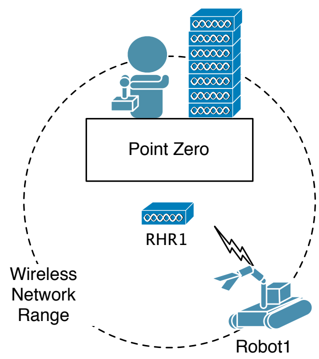

Figure 1: The initial Robohoc network topology.

2 Robohoc Network Construction Scenario

The Robohoc network is required because the target area where victims exist may be dangerous for human. Before sending a human rescue team, we need to examine the target area and collect information with robots using the Robohoc network.

With the Robohoc network, operators can initiate the rescue activity in the nearest safer place from the disaster stricken area. Robots and router nodes are launched from this base control point. In this paper we call the router node that constructs a Robohoc network as "*Robohoc-Router (RHR)*" and call the base control point as "*Point Zero*". Robots are connected to the Robohoc network via wireless communication between a robot and the nearest RHR. Figure 1 describes the initial status of the Robohoc network. In the initial state, there are only one RHR (RHR1) and one robot (Robot1). RHR1 is located at the Point Zero and Robot1 can move only inside the wireless communication range of the RHR1.

Robot1 will explore unexamined areas within the wireless access range to collect information of the neighbor area. For example, it checks the radio power of the RHR1 or existence of obstacles such as walls and doors. Operators can plan the following strategy of how to extend the Robohoc network efficiently. In some cases, Robot1 may be able to decide autonomously what it should do to extend the network.

Based on the decision of the operators and robots, the Robohoc network is extended by Robot1. Robot1 puts another RHR (RHR2) at the boundary of the wireless network range of RHR1 (Figure 2). RHR1 and RHR2 communicate each other and extend the Robohoc network. At this point, the Robohoc network includes two RHRs (RHR1 and RHR2) and one robot (Robot1).

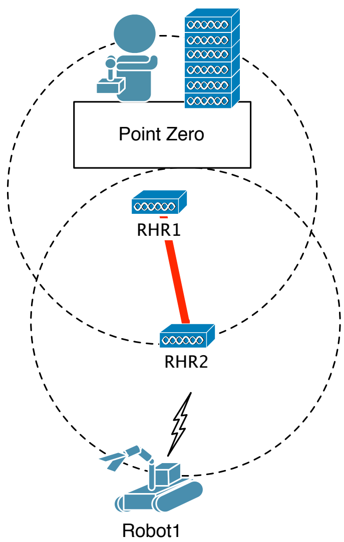

Figure 2: The second level rescue network topology.

Robot1 changes its attachment point to the Robohoc network from RHR1 to RHR2 and puts another RHR to extend the Robohoc network and so forth.

Figure 3 shows the fully expanded Robohoc network that can cover the whole disaster stricken area.

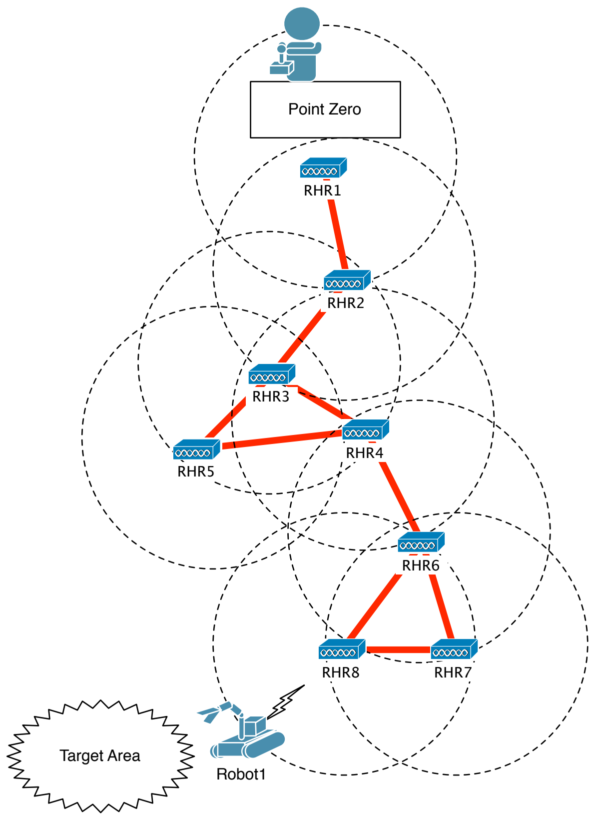

Figure 3: The fully expanded Robohoc network topology of this scenario.

Routing information in the Robohoc network is maintained by the extended IP routing protocols (for example, [2], [3], [4], [5], [6]). Thanks to the nature of the Internet constructed by autonomous systems and maintained with distributed processing methods, we can easily add a new access point to the existing network and can extend the infrastructure. What is important here is the robot activities also depend the network that is constructed by them.

The network construction scenario is similar to that of the mobile adhoc network (MANET). However the property of the Robohoc network is quite different from that of the MANET network. In the Robohoc network, most of the routers (RHRs) do not move. The main purpose of the Robohoc network is to provide the network infrastructure to the rescue robots. The RHRs are usually placed statically. The benefit of this approach is that the connectivity between RHRs is stabler than the MANET case that frequently changes the neighboring routers. We can achieve stable network delay and jitter and characteristics will provide less possibility of topology change events and more end-to-end bandwidth. Of course, we may need to relocate RHRs to fix the network, e.g. when a secondary disaster breaks some of core RHRs (see Section 3.3, 3.6 and 3.10). To make the Robohoc network robust, we have to have some moving RHRs in the Robohoc network. The proportion of the number of RHRs that can move out of all RHRs depends on the possibility of the network failure. We need more practice on how we can define the proper value.

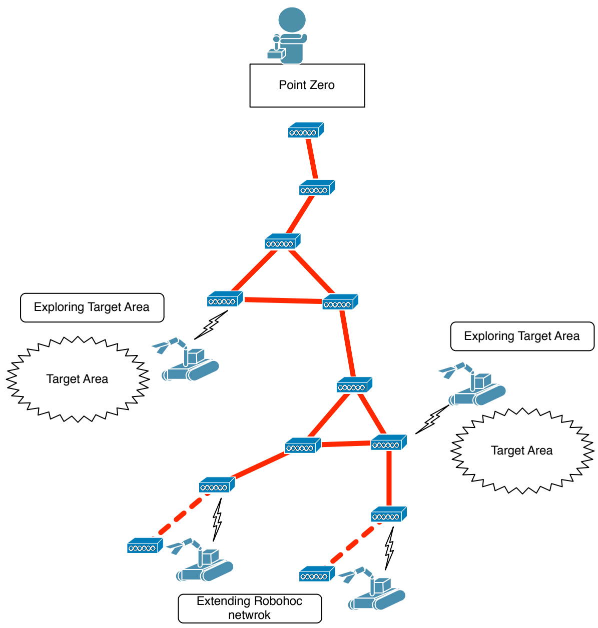

Figure 4: Concurrent search and expansion with multiple robots.

The number of robots is not restricted in this mechanism. Operators can launch any number of robots to extend a Robohoc network quickly, or to search victims in a wider area. Figure 4 shows an example topology for wider operation. In Figure 4, there are four concurrently operated robots. Two of them are extending the Robohoc network to reach frontier areas and the rest are looking for victims or examining the target area to collect information. The collected information is delivered to the rescue team via the network and they will use it for further rescue actions.

After the rescuers get enough information from the robots, they can go to save victims with detailed information of the stricken area collected by the robots and it will make them safer than they go to there without any information.

The constructed Robohoc network is also useful during the rescue activities by human teams. For example, it can be used as a communication channel between teams, in the case that the existing communication infrastructure is damaged in a disaster situation. In addition, resident people may use the Robohoc network in a recovery period from the disaster as an alternative communication method until a more stable communication infrastructure becomes available.

3 Use Cases and Requirements

In this section, we describe properties of the Robohoc network constructed as discussed in Section 2.

Before defining requirements for the Robohoc network, we have to understand the assumed disaster situation and its base requirements. The disaster we assume is the urban disaster. For example, the cases that a big earthquake hits a city or an explosion accident. In these situations we have to explore collapsed buildings or underground stations where many partitioning walls and collapsed obstacles are there. We cannot assume that a wide-range wireless communication device can be used in such a situation. We need to construct the network as a set of small wireless cells. When defining the size of the disaster area, we referred to the Yaesu underground shopping mall (about $73,000m^2$), that is one of famous underground shopping malls in Japan. The size fits most of the in-house disaster situation.

There are requirements those come from robot operation technologies too. The network delay gives a serious impact to a robot operator. The well known fact is that 1-second delay is the maximum delay to operate robots in real-time. If the delay is more than that, the real-time control becomes unrealistic but as long as the robot know the surrounding environment and the network assures the fixed delay and jitter, the operator can still control the robot using the predictive control mechanism. Thus, robots need to have some interface to know the current environment (such as geographical information or building map information provided from the operator) and the network have to provide stable communication between robots and the operator.

3.1 RHR Distribution Property

We assume the Robohoc network constructed area is disaster stricken. Victims are usually isolated in broken houses/buildings or underground structures like underground shopping centers or subway stations. There should be many walls or objects broken by the disaster and inside aisles are not wide. For these reasons, access point routers cannot be located uniformly. Figure 5 illustrates the situation. When there are many obstacles between the Point Zero and the target area, the density and the path length between nodes will have big deviation.

3.2 Communication Distance

The size of the disaster stricken area is usually unknown until the initial exploration completed. The distance between Point Zero and robots may vary from a few dozens of meters to a few kilometers. Moreover, this parameter depends on the disaster level. For a small size disaster, such as a fire accident or explosion in a building, the distance would be a few dozens meters to a few hundreds meters. For a large disaster, like an earthquake in the metropolitan area, the collapsed area may spread a few dozens kilometers or more. We assume the distance between teleoperators and robots will be from a few hundreds meters to about 1 kilometer, because the exploration area can be divided into small pieces even in a large-scale disaster.

3.3 Network Partitioning

When exploring the stricken area, we may face subsequent unexpected accidents. A RHR may stop working in the middle of an operation, or it may be broken by an object fallen onto it since the surrounding environment is still unstable. In such cases, the constructed Robohoc network may divide into two or more sub-networks. The Robohoc network must have a property to recover from unexpected partitioning.

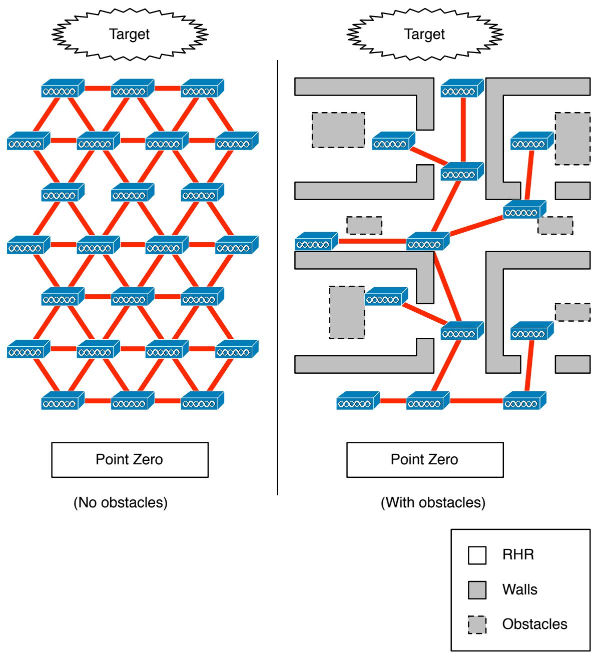

Figure 5: The network nodes cannot be located uniformly.

3.4 Real-time Robot Control

In the teleoperation situation, quality requirements to the network vary depending on the control theory of the system including robots, controller and teleoperators. Moreover, the system designer should select the appropriate control theory according to the amount of network delay.

Generally some kind of compensation mechanism is required in the long latency environment, because the more the latency of network communication increases, the more the difficulty of teleoperation grows. To avoid network latency problems in the teleoperation, various techniques, such as the prediction and preview display and the supervisory control system are proposed and applied [7].

We have to consider the robot operation model for the Robohoc network to decide the network parameters.

A bilateral control theory is popular when the teleoperators require feedback from robots. It is generally known as difficult to make a stable controller in the case communication delay exists in the control/feedback loop. The scattering transform method partly solves the problem [8] if the delay is known and stable. However, the method cannot directly be applied to the Internet environment because the latency and the jitter change dynamically, especially in the multi-hop wireless network. Some techniques are proposed ([9], [10]) for this problem, but it is still under addressing yet for the large fluctuation of jitter and long delay. Therefore, in the situation where the bilateral teleoperation is required, the network has to offer the communication assuring the upper bound of the jitter and latency.

If teleoperators need no bilateral feedback, some other control theories like a prediction display can be applied. The usability of this kind of teleoperation mechanism mainly depends on the skill and human characteristic of the teleoperator. With a well-designed teleoperation system, a teleoperator can manipulate robots over a few-seconds delay of visual feedback [11]. It is well known that an ordinary person can operate up to 1-second visual feedback delay.

Based on the previous fact and discussion, we decide a target upper bound of latency as $400ms$ (RTT: $800ms$). This value is delivered from the human factor of visual feedback delay. However, it is almost impossible to guarantee a small value against the upper bound of the latency because the Robohoc network consists of several RHRs and we cannot know the actual size of the network. There is a technology to control remote object even if the latency is not very small. In this case, though, the network must provide constant or predictable communication latency.

3.5 Supporting Type of Service

In the Robohoc network, various types of data would be sent; for example, messages to control robots, live streaming movies from robots, location data of robots and RHRs collected by sensor devices equipped with robots or RHRs, or geographical data to create the up-to-date disaster area map. The requirements from each kind of data vary depending on the traffic property. For example, a live streaming data requires a high bandwidth channel but geographical data does not; control messages should require low latency and low bandwidth communication channel. Therefore, the Robohoc network has to support various communication properties based on the data types used in the network ([12], [13], [14]).

3.6 Topology Information Sharing and Storing

The Robohoc network has to know its topology information. To recover from a partitioned situation, both robots and teleoperators need the network and geometric topology information. Both network components (RHRs and robots) have to share this kind of information. For example, when a Robohoc network is partitioned into two sub-networks A and B, and one of them (A) is connected to the Point Zero, teleoperators can control inside of the sub-network A. The other sub-network (B) is not connected to the Point Zero and has to be reconnected to A. Because the robots can modify the Robohoc network, it may be possible to re-connect these sub-networks autonomously if B has some robots. To recover the network, it has to inform robots of the broken link.

3.7 Bootstrap and Auto-Configuration

The rescue activity is a kind of fight against time. The construction of a Robohoc network and the collection of necessary data for the following rescue activities have to be done quickly. The RHRs and Robots need to be launched as soon as possible. To avoid the configuration of these nodes become complex, every node has to be configured automatically with a minimal manual configuration ([15]).

3.8 Hop Counts

In this paper, we assume that this technology is used in the urban disaster situation. The assumed size of the stricken area varies from one building/station to one town. The network communication tool should be a wireless network device since construction of a wired network is hard because of the weight of wire and possible obstacles on the path.

Considering that the range of one RHR is $50m$ (we can obtain this range with the current 802.11a [16] technology without any hindrances) and the size of the stricken area is $300m \times 300m$, we need 36 nodes when there are no radio wave disturbing objects. Because the wireless range will reduce when there are obstacles, we have to add some margin for the range. At this point, we assume that we can enjoy the half range size of the best case. Of course we have to verify the assumption in real environment. About the size of the target area, the size of the

Yaesu underground mall in Tokyo Japan is about $73,000m^2 \approx 270m \times 270m$ for example. The size of $300m \times 300m$ seems a good approximate value. Assuming that the range is $25m$, we need 144 RHRs if we put them as a grid layout, and the maximum hop counts will be 24 hops. That means the Robohoc network must work in a situation that there are more than 100 nodes and the hop counts between two nodes are more than 20 hops.

3.9 Layer 2 Information Utilization

When constructing a Robohoc network, we have to adapt the environment of the target area. In the previous section, we assumed the range of a RHR is about $25m$. however, it depends on the layout of obstacles and walls. To adapt the actual environment, all RHRs and Robots need to have a function to monitor the radio wave quality. The routing protocol which runs on RHRs and creates the logical Robohoc network topology has to consider the advantage or weakness of the links to get a better performance and reduce service disruptions. These information have to be shared by all RHRs and Robots to optimize the total throughput of the network and to utilize the strategy to extend the network to reach further unexplored areas.

3.10 Fault Tolerance

The Robohoc network has to be fault tolerant in case of network failure. It is highly possible that the constructed network is broken by some accident when performing extension of the network or performing any rescue activity. In principle, the network must not have a single point of failure. The topology should be designed redundantly. However, we cannot ensure that the network can always be redundant. In case of big accident that cannot be covered by the redundant topology, the Robohoc network should be recovered either by teleoperator's recovery procedures or automatically by robots. For example, if robots know the topology of the Robohoc network and they can get any failure information from the network, they may be able to move to the failure point to fix the broken link. This kind of approach requires the intelligent network, that is, the network has to know its topology and have a capability to detect the broken link in case of accident. In addition, the network and robots must have capabilities to exchange the location of the point and to re-construct a new topology that can reconnected to the other partitioned network.

4 Related Works

[17] discusses an efficient algorithm to explore frontier areas by robots forming an adhoc network. In this proposal, robots are trying to avoid their network range conflict and spread to the frontier. [18] proposes a self-healing mechanism of a wireless network using cross-layer information exchange between the network layer and the application layer. These research focus on completely autonomous system that human interaction is not necessary. In our research, we take the opposite approach. We utilize human resources as much as possible since in rescue activities, the experience of rescue experts are sometimes useful. We are trying to give help to the people so that they can do better jobs than before.

5 Conclusion

Rescue teams are looking for new ways to perform rescue activities safer and more efficiently than those done only by human parties. Using helper robots for rescue activities is one of new approaches. Recently, high functional robots, which can run over rough roads broken by disasters or which can go stairs up and down, are intensively being researched and developed. However, as long as the robots are controlled by short range communication devices, such as wires or direct wireless connections, we cannot expand the exploration range drastically. The networking technology can help on this problem. We propose a new rescue network architecture (the Robohoc network) which can be dynamically extended and adapted by either human operated robots or autonomous robots. On this network, we can construct a temporary rescue network adapting various disaster situations. Though

Required property	*Description*
RHR distribution	RHRs and robots cannot be located uniformly. The Robohoc network must support the non-flat node distribution. (Section 3.1)
Communication distance	The distance between teleoperators and robots is from a few hundreds meters to about 1 kilometer. (Section 3.2)
Network partitioning	The Robohoc network may be partitioned while constructing the network or operating rescue activities. The network must have a property to recover from partitioning. (Section 3.3)
Real-time robot control	For real-time robot control, the network latency has to be less than $400ms$. Robots can be controlled even the latency is more than $400ms$ using however, in that case, the latency has to be predictable and stable. (Section 3.4)
Type of service support	The Robohoc network must be able to provide different traffic properties for different contents, for example, the real-time delivery for the robot control and the wider bandwidth for the live streaming. (Section 3.4)
Topology information sharing and storing	When recovering from partitioning, teleoperators, RHRs and robots have to know the topology of the network to find the failure point. The topology information must be shared and stored in every node. (Section 3.6)
Bootstrap and auto-configuration	The network construction and rescue activities must be started as soon as possible. Every node must start with minimum manual configuration and must have an auto-configuration property. (Section 3.7)
Hop counts	The number of RHRs in a Robohoc network may be more than 100. The average hop count in this case would be more than 20. To support a wider area, the number of hops and average hop count will increase. (Section 3.8)
Layer 2 information utilization	The Robohoc network uses a wireless communication media to create the network. Each RHR has to monitor the link quality of their connections and utilize the information for better performance. (Section 3.9)
Fault Tolerance	The Robohoc network must not have a single point of failure. The network must be able to recover from partitioning either by the human intervention or by autonomous recovery actions of robots. (Section 3.10)

Table 1: The summary of the requirements for the Robohoc network.

the usefulness is clear, there have been few research activities in this area. We propose the basic idea of the Robohoc network and the requirements to satisfy the properties necessary for rescue activities.

We are planning to design the router, routing protocol and robots which satisfy the requirements and verify that the requirements are adequate through the implementation of such nodes and the operation in a real environment.

Acknowledgement

The authors thank Dairoku Sekiguchi, Masahiko Inami and Shinsuke Ohara for their valuable inputs related to robotics and teleoperation technologies. We also thank Fumio Teraoka, Masaaki Sato, Yuki Kawamura and Satomi Fujimaki for the valuable discussion on this new research area.

References

[1] B. Shah and H. Choset, "Survey on Urban Search and Rescue Robots," Journal of the Robotics Society of Japan, Vol.22, No.5, pp.582–586.

[2] S. Deering and R. Hinden, "Internet Protocol, Version 6 (IPv6)," Technical Report RFC2460, IETF, December 1998.

[3] G. Malkin and R. Minnear, "RIPng for IPv6," Technical Report RFC2080, IETF, January 1997.

[4] D. Ferguson and J. Moy, "OSPF for IPv6," Technical Report RFC2740, IETF, December 1999.

[5] C. Perkins, E. Belding-Royer and S. Das, "Ad hoc On-Demand Distance Vector (AODV) Routing," Technical Report RFC3561, IETF, July 2003.

[6] T. Clausen, C. Dearlove and P. Jacquet, "The Optimized Link-State Routing Protocol version 2," Technical Report draft-ietf-manet-olsrv2-02, IETF, June 2006.

[7] T. B. Sheridan, "Space Teleoperation Through Time Delay: Review and Prognosis," IEEE Transaction of robotics and automation, Vol.9, No. 5, pp.592–606, October 1993.

[8] R. J. Anderson and M. W. Spong, "Bilateral Control of Teleoperators with Time Delay," IEEE Transaction on Automatic Control, Vol.34, No.5, pp.494–501, May 1989,

[9] Kazuhiro Kosuge and Hideyuki Murayama, "Teleoperation via Computer Network," Transaction of IEE Japan, Vol.117-C, No.5 pp.521–527, 1997.

[10] Y. Yamashita and H. Nishitani, "Compensation of transmission delay and packet-loss in nonlinear remote-control system," The 10th IFAC/IFORS/IMACS/IFIP Symposium on Large Scale Systems: Theory and Applications, 627/632, 2004.

[11] W. S. Kim and A. K. Bejczy, "Demonstration of a High-Fidelity Predictive/Preview Display Technique for Telerobotic Servicing in Space," IEEE Transaction of robotics and automation, Vol.9, No.5, pp.698–702, October 1993.

[12] K. Nichols, S. Blake, F. Baker and D. Black, "Definition of the Differentiated Service Field (DS Field) in the IPv4 and IPv6 Headers," Technical Report RFC2474, December 1998.

[13] K. Ramakrishnan, S. Floyd and D. Black, "The Addition of Explicit Congestion Notification (ECN) to IP," Technical Report RFC3168, September 2001.

[14] R. Braden, Ed., L. Zhang, S. Berson, S. Herzog and S. Jamin, "Resource ReSerVation Protocol (RSVP) – Version 1 Functional Specification," Technical Report RFC2205, September 1997.

[15] A. Williams, "Requirements for Automatic Configuration of IP Hosts," Technical Report draft-ietf-zeroconf-reqts-12, September 2002.

[16] "Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: High-speed Physical Layer in the 5GHz Band," IEEE Std 802.11a-1999 (R2003), June 2003.

[17] J. Vazquez and C. Malcolm, "Distributed Multirobot Exploration Maintaining a Mobile Network," Proceedings of 2004 2nd International IEEE Conference, Vol.3, pp.113–118, Intelligent Systems, June 2004.

[18] M. Smith and B. Freisleben, "Self-Healing Wireless Ad Hoc Networks Based On Adaptive Node Mobility," Proceedings of the First IFIP International Conference on Wireless and Optical Communications Networks, Muscat, Oman, pp.121–124, IFIP, 2004.