

Never Die Network Based on Cognitive Wireless Network and Satellite System for Large Scale Disaster*

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Abstract

The Great East Japan Earthquake caused many casualties and radiation contamination from the Fukushima nuclear power plant, and many problems still remain in the disaster area. The communication network was severely affected by the earthquake. The network disconnection greatly delayed the rescue work and isolated many residential areas. This lack of robust network connection has become one of the major topics for any discussion of a Disaster Information Network System. This paper proposes a Never Die Network (NDN) which will consist of a Cognitive Wireless Network (CWN) and a Satellite Network. The best possible wireless links and routes are selected out of multiple wireless networks. This proposal, first of all, puts forward a cognition cycle which has a continuous network and user changing environment. Secondly, the optimal link selection will adapt the extended Analytic Hierarchy Process (AHP) method by a change of network environment and user policy during a disaster. Then, if the network environment or user environment can be changed, a proper route selection method can be conducted by the proposed extended Ad Hoc On-Demand Distance Vector (AODV) method with Min-Max AHP values. The simulation described in this paper contains an evaluation of the proposed methods by comparing a single ordinal wireless network system and a CWN for the disaster situations. The probable effectiveness of the proposed methods is discussed in this paper.

Keywords: Disaster information network, cognitive wireless network, never die network, QoS

Journal of Wireless Mobile Networks, Ubiquitous Computing, and Dependable Applications, volume: 3, number: 3, pp. 74-93

*This paper is an extended version of the work originally presented at the 26th IEEE International Conference on Advanced Information Networking and Applications (AINA'12), Fukuoka Institute of Technology (FIT), Fukuoka, Japan, March 26-29, 2012 [10].

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1 Introduction

There have been many serious disasters such as earthquakes, tsunamis, or typhoons in the world recently. Especially, in the Japanese archipelago which mainly consists of mountains and coastal areas, there is always a possibility of some areas becoming isolated if such severe disasters occur. In fact, the Great East Japan Earthquake caused serious damage to a wide area of northern Japan on March 11, 2011. In the event, the shock of the earthquake and tsunami in Japan had an enormous impact on the whole world, not only in Japan. What is of global significance is the nearly complete disconnection of the communication network, as well as the potential for a nuclear fallout crisis and major energy problem. The lack of information and communication caused the complete isolation of many Japanese cities, and it also affected the rescue work, evacuation of people, and food supplies. After the earthquake, most land phones, cellular phones, and internet services were unable to be used because of high congestion in the communication network. This breakdown of the network devices affected a much wider area. For example, the Kanto region which includes Tokyo was similarly affected. Through the experience of this large scale disaster, it will be argued that a robust network connection should be the focus for the design of a Disaster Information Network System.

The authors have been studying the Wide Area Disaster Information System based upon a wireless network system that will enable a quick reactivation of the network system by avoiding the problem of broken cables and blackouts [1, 2]. In our previous studies, we proposed methods such as the optimal transmission control of the Cognitive Wireless Network (CWN) and a ballooned network system with a self-energy production powered by the solar system, as a part of a Disaster Information Network System. However, in the case of a large scale disaster such as the Great East Japan Earthquake, it is necessary to consider a more resilient connection system enabling a quicker recovery than in March 2011. Therefore, we propose the Never Die Network (NDN) [3] from what we have learned from this disaster.

In our proposal of the NDN, a Satellite Network and Cognitive Wireless Network will consist of multiple wireless interfaces such as IEEE 802.11a/b/g/n at first. The Satellite Network System is considered to be the most efficient method to realize NDN, because it is supposed to work even after a serious disaster [4]. In fact, the communication network can be quickly reactivated by using the Satellite Network System developed by the authors while dealing with the situation following on from the earthquake of March 2011[4]. Figure 1 shows about our activities. However, this Satellite Network has some problems in terms of its Quality of Service (QoS): The throughput is low, the latency is large, the data transmissions are not sent and received at the same speed, and the cost is expensive.

A wireless network system such as IEEE802.11a/b/g/n is also proposed as a very effective method of reactivating the network after a disaster. The single ordinal wireless communication has the following problems. First, the physical characteristics of wireless frequency may cause a lack of QoS. When using a high-frequency band radio, high bandwidth communications like video contents are suitable only for a short distance. A high-frequency band radio is also highly affected by obstacles such as buildings and trees. On the other hand, a low-frequency radio communication is more suitable for long distance communication and has a lower interference from obstacles such as trees, but it is not suitable for the transfer of a large volume of contents. Secondly, because of the rapid spread of wireless LAN devices in recent years, there is a concern about the interference on the same radio waves caused by other users. For example, IEEE802.11b/g is very commonly used in ordinary households, offices, and other business premises, as a result, there is the possibility of these devices actually interfering with rescue services operating on the same frequency.

Moreover, network congestion is particularly acute just after a large scale disaster. In the case of the Great East Japan Earthquake, network traffic increased enormously just after the earthquake, and it caused cellular phone and internet access to be almost impossible [4]. Thus, a normal network control method such as the best effort connection is not suitable for a Disaster Information Network System.

Instead, it is important to use the network resources more effectively by taking into account the local network environment and user requirements during the emergency period.

Therefore, our proposed methods suggest that the heterogeneous wireless networks are used in the construction of a robust network connection, and they are selected to engage with the interface between the user and local network environment.

In Section 2, the preferred forms of communication during a disaster have to be responded to in terms of the proposed NDN. The network model and system architecture of our proposed communication method are defined in Section 3. Sections 4 and 5 deal with our proposed methods. The cognition cycle consists of three stages. The first stage is observing network parameters and user policy. The second stage is to decide on an optimal link and route selection by first using the Extended AHP method and then the Extended AODV with the Min-Max value method. The final stage is the reconfiguration of the network by changing wireless links and routes. Section 6 explains the function of the Satellite System during the disaster. In Section 7, we introduce a new type of simulation of a specific rural area as a model for the calculation of how effective the suggested control method actually may be. In this new simulation, a randomly transient set of wireless cars is factored into this study of the coastal region of Iwate in northern Japan. Finally, Section 8 sets out our conclusions and possible future research.



Figure 1: Network Reactivation by Satellite Network in Taro, Miyako

2 Never Die Network

2.1 Requirements from the Great East Japan Earthquake

The Great East Japan Earthquake on March 11, 2011 caused severe damage over the wide area of Northern Japan. A massive 9.0 earthquake destroyed many buildings and equipment, and a devastating tsunami swept over the cities and coastal areas. This tragedy shocked the world, and there were 15,868 dead, 2,848 missing, and 6,109 injured persons reported until August 2012 [5]. Compared with major earthquakes in world history, it was the fourth largest earthquake next to the Great Chilean Earthquake in 1960 (M9.5), the Great Alaskan Earthquake in 1964 (M9.2), and the Indian Ocean Earthquake and Tsunami in 2004 (M9.1) [6].

As a result, the Great East Japan Earthquake caused blackouts throughout a wide area of northern and middle Japan, lack of food and fuel. Moreover, the disconnection of the communication network caused great confusion in today's highly developed IT society. Shibata et al have written about the problems caused by malfunctioning network devices and system overload, and also reported on their own network reactivating initiatives in the coastal area of Iwate Prefecture [7, 8].

The paper also reports the internet condition as worsening to 100 - 150ms in Round Trip Time (RTT) and 20 - 50 % in Packet Error Rate (PER) according to the ping results from the university to google.com as shown in Figure 2. Therefore, it is a very bad network condition as judged by the requirements of the Disaster Information System.

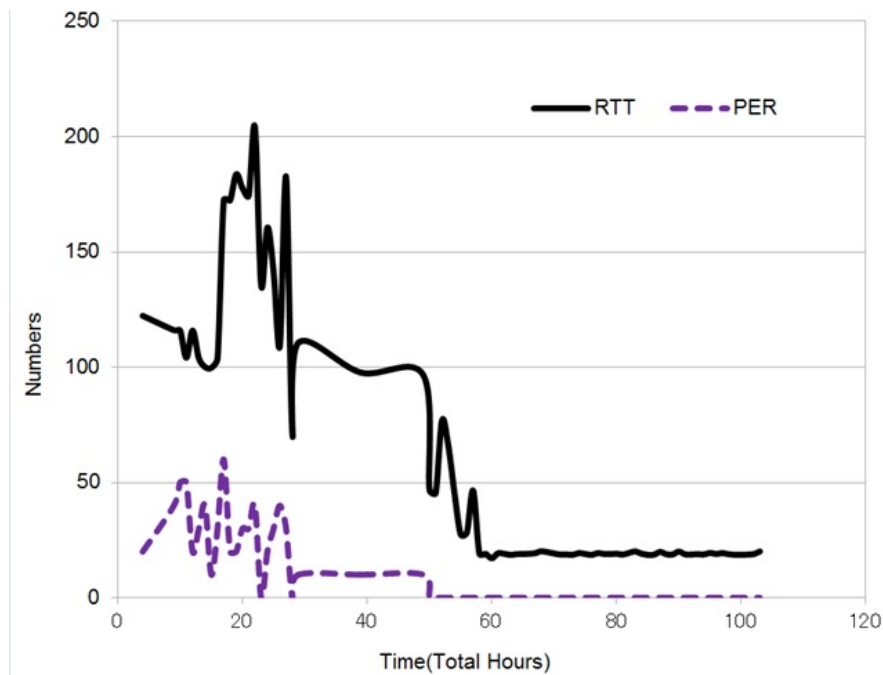


Figure 2: Network Conditions during disaster

Moreover, the network congestion during the emergency situation must be considered in setting up a new network. In other words, the proper wireless interface and network route should be selected for “what kind of information is needed during a disaster”. From the investigation of previous large natural disasters [9], the required information is varied according to what happened after a disaster as shown in Table 1.

In Figure 3, a forecast is required during the term t_1 , while evacuation information is not yet impor-

Subjects	Required Information / Elapsed Time	t_1	t_2	t_x	t_3	t_4	t_5	t_6
Victim (Inside of the Disaster area)	Disaster Prevention	△	○					
	Evacuation		○		⊙			
	Safety				⊙	⊙	○	△
	Stricken Area				⊙	○		
	Traffic				○	⊙	⊙	
	Relief Supplies					⊙	○	
	Public Service					○	⊙	
	Lifeline					○	⊙	
	Local Government					○	⊙	
Relatives Volunteer (Outside of the disaster area)	Safety				⊙	⊙	○	
	Stricken Area				⊙	○	△	
	Relief Supplies					○	⊙	

	Period	Activity
t_1	Ordinal	
t_2	2 weeks before ~ Disaster	Indication, rumor
t_x	Occurrence of Disaster	evacuation
t_3	Disaster ~ 2 days	Rescue, evacuation, safety information
t_4	3 days ~ 2 weeks	Relief materials, safety information
t_5	3 weeks ~ several months	Restore lifeline, residences
t_6	Ordinal	

Figure 3: Information Required during a Disaster

tant. Then, when there are indications such as news or rumor about the disaster at t_2 , evacuation and disaster prevention then become significant. After the disaster happens at t_x , the rescue, evacuation, and safety status of individuals come to be critical. During the term of t_3 , the disaster evacuation, residential safety and disaster status information are now needed. Just after the disaster, it is considered that the data connectivity is the most important factor while the other network factors such as data volumes are not so important. That is because the information during this term is devoted to the saving of human life, and the Disaster Information Network should provide the minimal data connections for this purpose even if some network faculties are broken and the network quality such as Throughput or PER have become worse. Besides, the text data based on information given on web pages are likely to include a list of the evacuated people as well as a report of stricken areas by the Disaster Information System.

2.2 Never Die Network

The Never Die Network (NDN) is a robust network method proposed by Shiratori et al [3], and it is proposed as an effective network control method in a Disaster Information System. The paper indicates that an NDN is defined as a robust network which will be unaffected by any changes in the environment such as a sudden degradation or fluctuation of quality of network capability. To realize an NDN, they proposed the network control method by an infra-depend mode and an autonomous mode [3]. Once a disaster has happened, the network should go into an autonomous mode. In an autonomous mode, the network condition is observed, and a new administration node is selected for a route reconstruction. However, in an actual severe disaster case, a single wireless network might be disconnected. Network

congestion should be also considered in the setting up of an NDN. Therefore, the authors extended their proposal and now discuss the NDN as using a CWN and a Satellite Network System [4, 10].

In the case of our newly proposed NDN, the data connection is robustly guarded as shown in Figure 4. In Figure 4, a wired network is easily influenced by a disaster. The connection of a wireless network or a CWN is stronger than a wired network, but the connection can be disconnected according to the scale of a much stronger earthquake. On the other hand, an NDN keeps the data connection even if the transmission quality is lower than usual as shown in Figure 4.

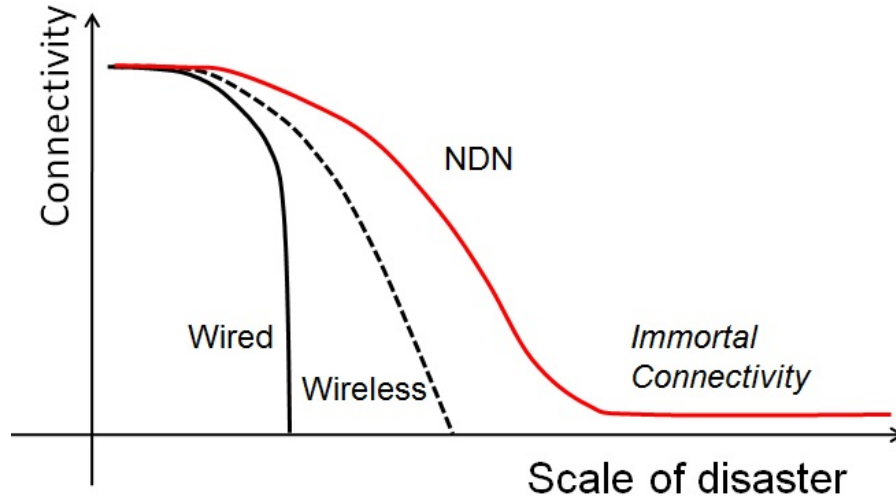


Figure 4: System Connectivity by Scale of Disaster

Figure 5 shows our proposed Disaster Information Network System by the NDN. Our proposed system consists of a combination of the CWN and the Satellite System, and the CWN is based on heterogeneous wireless networks including IEEE802.11b/g/j/n, WiMaX, FWA, and the Satellite Network. They are connected by fixed and mobile inter-stations between the disaster headquarters and the evacuation shelters. The satellite system is also used for temporal data transmission and network configuration if a disaster happens.

3 Network Model and its Architecture

3.1 Network Model

Figure 6 shows our suggested network configuration. Mobile wireless nodes connect a user and a content server, and the nodes consist of multiple heterogeneous wireless interfaces such as IEEE802.11a/b/g/n or WiMax. A Satellite System also supports the temporal connections if there is a severe earthquake, and it also has some functions such as checking whether a node is alive, and a parameter transmission for the network reconfiguration as a control link (link 0).

Wireless nodes are supposed to be wireless terminals, and they have routing, ad-hoc, and multi-hop functions. Also, the antenna of each node is supposed to be non-directional. Moreover, network conditions are changed over time by a node's movement or radio interference like trees or buildings. A data transmission is carried out by ordering a user request from a server to a user terminal.

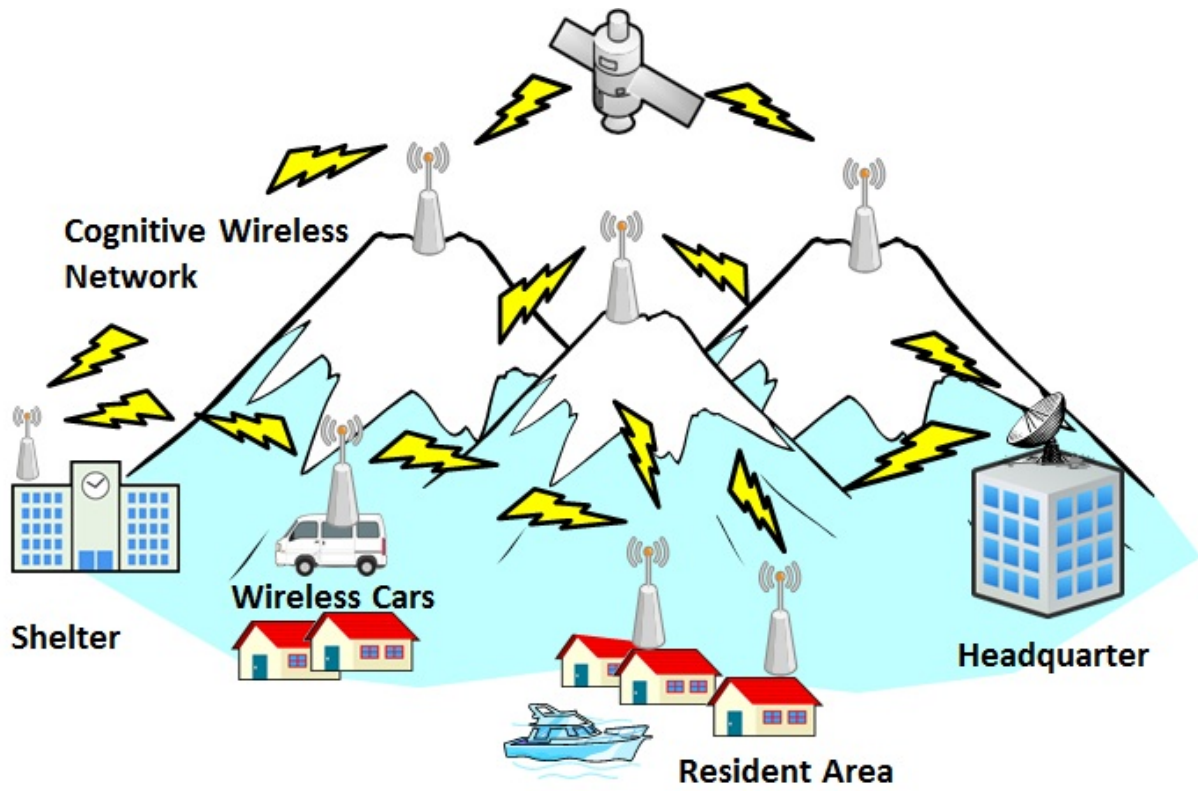


Figure 5: The Proposed Disaster Information Network

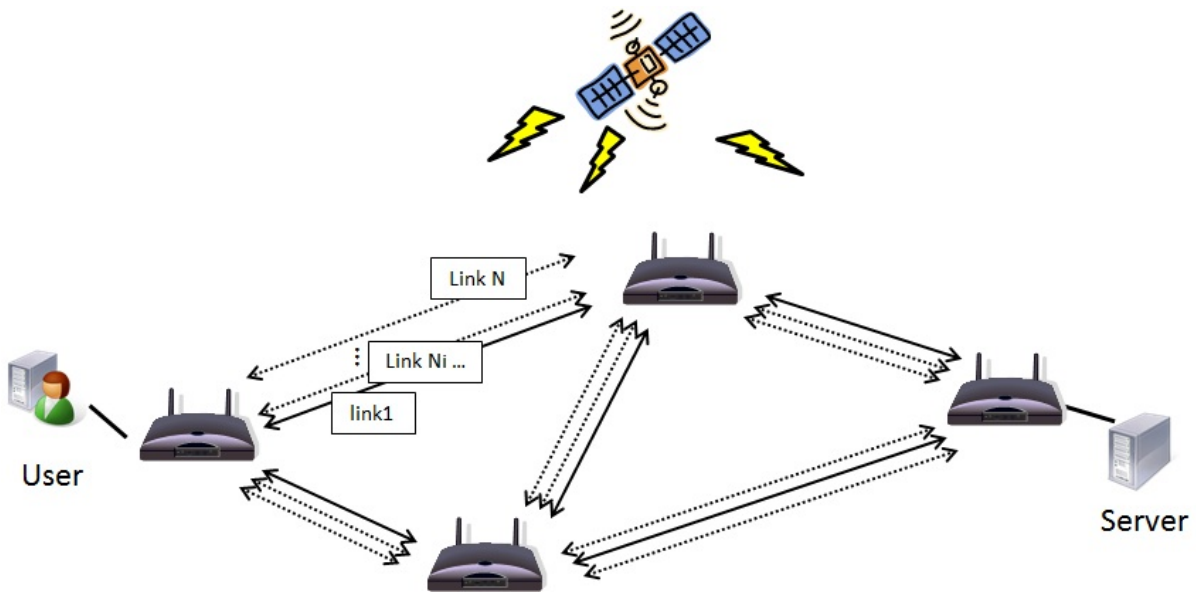


Figure 6: Wireless Network Configuration

3.2 System Architecture

The system architecture is organized into three layers, which include the network layer, the system layer, and the application layer in Figure 7. When transmission data are sent from a sender to a receiver, the network data from each layer are observed.

In the application layer, the individual user policy is detected. The user policy is assumed from various types like video, VoIP, text, and connectivity priority. These policies are used for the decision formula of the Extended AHP method in the system layer in Figure 7. The network layer also observes network conditions such as the value of PER, throughput, delay, jitter, BER, and electric field strength.

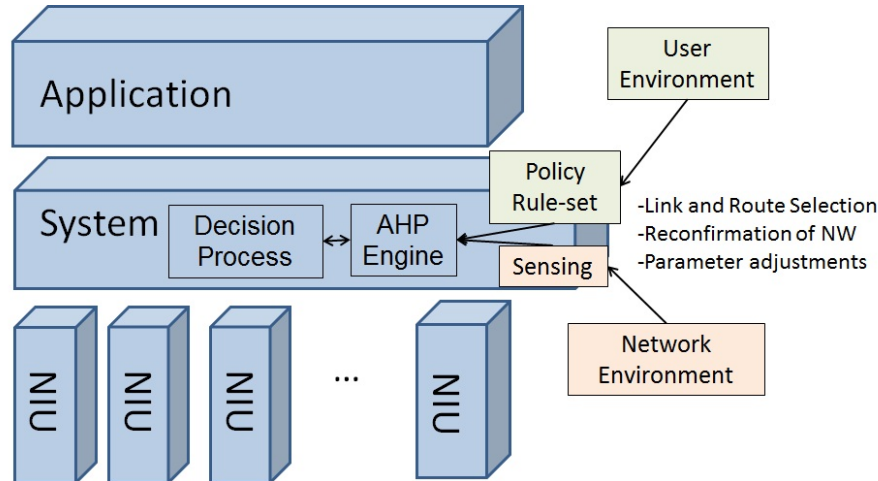


Figure 7: System Architecture

Network data from each layer are observed, and the decision making is held within the system layers. Then, the message of the preferred link or route is sent through a control link (link 0) in Figure 7, and a reconfiguration procedure is acted at both sender and receiver nodes.

4 Cognition Cycle

As the previous research on CWN shows [11, 12], the cognition cycle is introduced into our proposed method. However, the authors propose a simple cognition cycle [13], which consists of three stages: the observation stage, the decision stage, and the acting stage in Figure 8. Each stage is continuously cycled in order to perform link or route configuration. Therefore, load averages of each wireless node become less than in the previous research, and the new proposed method is suitable for the actual usage of CWN during a disaster.

Network data are continuously observed through each layer at this observation stage. The wireless network condition varies depending on the movement of nodes or radio interference. Therefore, CWN needs to parse these stimuli to select the available solution for assessing the performance from user requests.

In this paper, our supposed system observes application types in order to decide user policy that depends on the specific services or media. Also, physical characteristics like PER (packet error rates), Throughput, Delay, Jitter, BER (bit error rates), and electric field strength are observed. These parameters are used for understanding stimuli from the user environment.

At the decision stage, the optimal wireless link and route of each node will be selected. When the network condition is changed, the proposed system will seek a suitable link and route by calculating

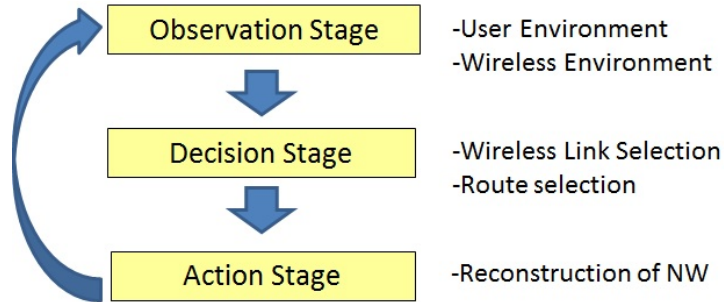


Figure 8: Proposed Cognition Cycle

from the values of network characteristics like user policy, Throughput, BER, and so on. We introduce the Extended AHP method for the calculation of the link. The extended AODV with Min-Max AHP values method can now be used for making a decision on a suitable route. Those proposed methods are discussed in Section 5 of this paper.

After the optimal link or route has been decided, the reconfiguration occurs in the action stage in Figure 8. In the proposed system, a wireless control link (link 0) is used for the transmission of the control information. In this paper, a control link is set up using a satellite system, and a node sends the calculation results to the next node through link 0. Then, both nodes change the link at the same time. A route change also acts in the same way as a link change.

Then, the cognition cycle goes back to the observation stage after the action stage, and it works relative to the link or route change.

5 Wireless Link and Route Selection Methods

5.1 Wireless Link Selection Method

In the decision stage of the Cognition Cycle, the Extended AHP is proposed for the optimal wireless link selection in our proposed method. AHP (Analytic Hierarchy Process) is one of the multi-attribute decision making and structured techniques for dealing with complex decisions. T. L. Saaty developed it in the 1970s [14]. By structuring a decision problem hierarchy, the AHP provides quantifications of its elements and evaluations of alternative solutions. Sugimoto et al also used the AHP method for the wireless link selection of hand-over in previous studies [15]. The authors propose the Extended AHP method by considering these previous studies [13]. In our proposed method, user policies are adopted for the weight values of the criteria, and the observed network condition values are used for the calculation of alternatives unlike the survey-based process. Therefore, the decision process can proceed dynamically with the changing of user policies and network conditions.

For example, this paper deals with the AHP as shown in Figure 9. The hierarchy of the problem is first structured. That is, a goal (to decide the suitable link between wireless nodes), criteria (network characteristics such as Delay, PER, Throughput, and so on) and alternatives (wireless links such as IEEE802.11a/b/g/n, IEEE802.16e, satellite system, and so on).

Then, paired comparisons of criteria and alternatives are calculated for the priority value on the AHP. Assuming that we are given n as the number of criteria, and w_1, w_2, \dots, w_n as the weight of each criteria, and paired comparison of each element are expressed as $a_{ij} = w_i/w_j$. In this paper, the weight of criteria w_n , is determined by the scored level from 1 to 9 by considering user policies during a disaster, and then the weight of criteria w_n is used for a calculation of a paired comparison of criteria [16]. These paired

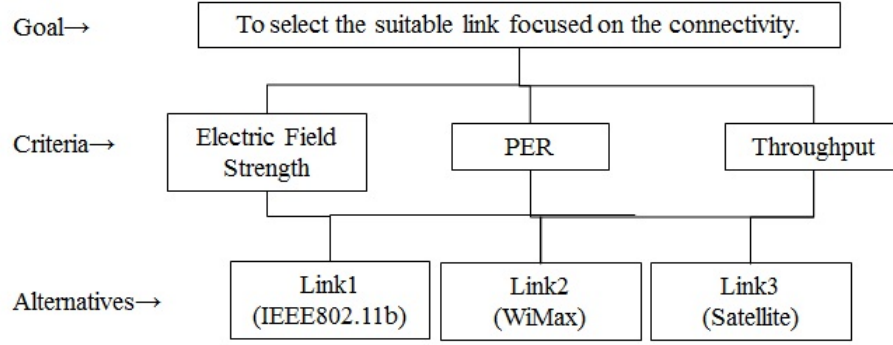


Figure 9: Example of Hierarchy on AHP

comparisons are expressed in the comparison matrix A shown in the formula (1).

$$A = \begin{bmatrix} \frac{w_1}{w_1} & \dots & \frac{w_1}{w_j} & \dots & \frac{w_1}{w_n} \\ \dots & \dots & \dots & \dots & \dots \\ \frac{w_i}{w_1} & \dots & \frac{w_i}{w_j} & \dots & \frac{w_i}{w_n} \\ \dots & \dots & \dots & \dots & \dots \\ \frac{w_n}{w_1} & \dots & \frac{w_n}{w_j} & \dots & \frac{w_n}{w_n} \end{bmatrix} \equiv \begin{bmatrix} a_{11} & \dots & a_{1j} & \dots & a_{1n} \\ \dots & \dots & \dots & \dots & \dots \\ a_{i1} & \dots & a_{ij} & \dots & a_{in} \\ \dots & \dots & \dots & \dots & \dots \\ a_{n1} & \dots & a_{nj} & \dots & a_{nn} \end{bmatrix} \quad (1)$$

Then, normalized A_{norm} is defined as:

$$A_{norm} = \begin{bmatrix} b_{11} & \dots & b_{1j} & \dots & b_{1n} \\ \dots & \dots & \dots & \dots & \dots \\ b_{i1} & \dots & b_{ij} & \dots & b_{in} \\ \dots & \dots & \dots & \dots & \dots \\ b_{n1} & \dots & b_{nj} & \dots & b_{nn} \end{bmatrix} \quad (2)$$

When:

$$b_{ij} = \frac{a_{ij}}{\sum_{k=1}^n a_{kj}} \quad (3)$$

Then, priority value is defined as:

$$p_i = \frac{\sum_{l=1}^n b_{il}}{n} \quad (4)$$

For example, the vector of w_n is set up (Electric field strength, PER, Latency, Throughput) = (3,1,1,5) as a user policy. This is because the higher Throughput is usually important in this case. Therefore, Throughput is the highest weighted, while PER and Latency are moderately weighted. On the other hand, the vector of w_n is set to (3,3,5,1) in VoIP focused policy. When a user uses VoIP, Latency is usually the most significant among these conditions. Therefore, the Latency is the highest weighted while Throughput is more important than any other condition. Also, the vector of w_n is set up (3,5,3,1) as text priority, because PER is more important while Throughput is moderate in the case.

Then, the observed network conditions such as Throughput by Packet Probing Method [17] and Latency are introduced to the weight of alternatives w_n , and each priority of alternatives is calculated in our proposed method. At this time, the observed network values are calculated on the same scale rate from 1 to 9 as the following equations in order to acquire a network environment for the alternatives [18].

$$\begin{aligned}
S_i &= \left\lceil \frac{n_i - l_i}{u_{\max} - l_i} \times 10 \right\rceil ; l < n_i < u_i \\
&= 1 ; n_i \leq l_i \\
&= 9 ; n_i \geq u_i
\end{aligned}
\quad (\text{In case of Throughput}) \quad (5)$$

$$\begin{aligned}
S_i &= \left\lceil \frac{n_i - l_i}{u_i - l_i} \times 10 \right\rceil ; l < n_i < u_i \\
&= 1 ; n_i \leq l_i \\
&= 9 ; n_i \geq u_i
\end{aligned}
\quad (\text{In case of Electric Field Strength}) \quad (6)$$

$$\begin{aligned}
S_i &= \left\lceil \left(1 - \frac{n_i - l_i}{u_i - l_i}\right) \times 10 \right\rceil ; l < n_i < u_i \\
&= 1 ; n_i \geq u_i \\
&= 9 ; n_i \leq l_i
\end{aligned}
\quad (\text{In case of PER, Latency, and so on}) \quad (7)$$

In the above formula, S_i is the weight of each alternative, u_i and l_i are the upper and lower limits of the alternative, u_{\max} is the upper limit of all alternatives, and n_i is the observed value from the network. Next, the priority values of the alternatives are calculated by the equations (2) (3) and (4) as the same as the criteria.

Finally, the total value of the AHP is calculated by each priority value of criteria and alternatives. Here, the total value of the alternative is calculated by the alternative priority multiplied by the criteria priority value for video. The link with the largest value will be decided as the best suitable link.

5.2 Wireless Route Selection Method

Our proposed system would change the network route if the suitable link is not found or user policies are not satisfied. When a network route needs to be changed, we introduce the extended AODV for deciding on a suitable route. Here, the Extended AODV with Min-Max AHP values is introduced for a route decision.

AODV (Ad hoc On-demand Distance Vector) is a routing protocol for mobile ad hoc networks (MANETs) [18]. It is a reactive routing protocol, which means that it establishes a route to a destination only on demand base. Therefore, the connection is slower than proactive routing protocols like OLSR or TBRPF [18]. But AODV is superior when the network condition does not change so often or changes more slowly [19]. Because network conditions caused by disasters do not happen so often, AODV is a more suitable way than the proactive protocols and is selected for the base theory for our proposed method.

AODV builds routes using route request (RREQ) and route reply (RREP). When a source node requires a route to a destination of which it does not have a route, the source node broadcasts RREQ packets across the network. When the neighbor nodes receive those packets, they update their route information with the source node in the routing table. The RREQ contains the source node's IP address, current sequence number, broadcast ID, and the most recent sequence number for the destination node. A node receiving the RREQ may send RREP packets if it is either the destination or it has a route to the destination with corresponding sequence number greater than or equal to that contained in the RREQ. If this is the case, RREP packets are sent back to the source node with a relative setting to the routing tables.

Our proposed method is extended to hold the link values by AHP calculations for RREQ and RREP packets, and those are set to work in the routing tables as shown in Figure 10.

The Min-Max processes are as follows.

- (1) With each possible route from the source node to the destination node, AHP values of links are listed at the destination node.
- (2) Each minimal AHP value is selected and listed as the Min AHP table at the destination node. For

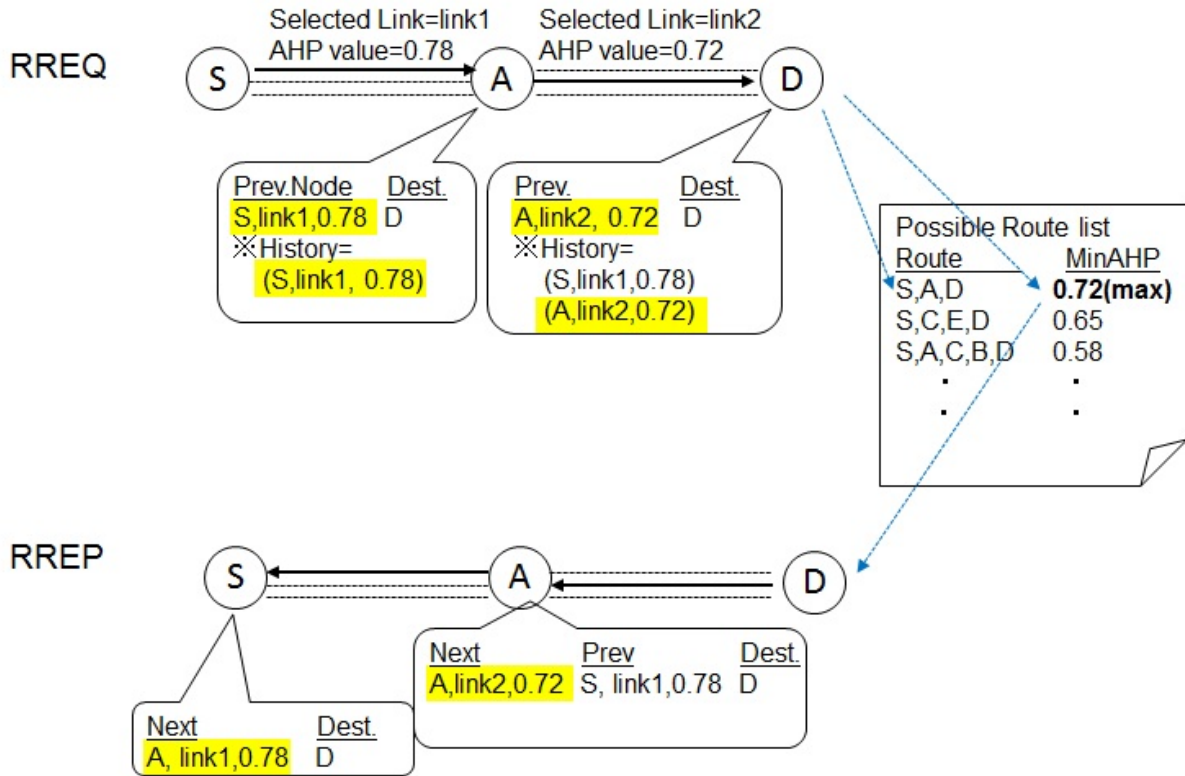


Figure 10: Min-Max method by AHP results

example, 0.72 is selected as Min AHP among 0.78 and 0.72 in the route SAD. Then, 0.72 is listed in the Min AHP table in Figure 10.

- (3) The max AHP value is selected among the Min AHP table, and the route that has the max AHP value is selected as the proper route. For example, 0.72 is selected among 0.72, 0.65, and 0.58 in the Min AHP table, and the route SAD that has the Max AHP value is selected as the proper route.

6 Satellite Network

The Satellite Network System is considered to be the most efficient method to realize the NDN, because it is supposed to be robust even after severe disasters. In fact, it was one of the effective methods for the authors' network reactivating initiatives [7] in the Great East Japan Earthquake. However, the Satellite Network has some problems for QoS (Quality of Service): Throughput is low, Latency is large, sending and receiving data transmissions are different, and cost is expensive. Thus, it is not suitable for the transfer of a large volume of multimedia content.

However, as for the previous discussion, the connectivity is very important especially just after a disaster, and so the life related information such as rescue or evacuation work will be facilitated with the Disaster Information System. Thus, a Satellite System is introduced in our proposed systems, and it has the following functions. First of all, parameters like observed network conditions or AHP results are transferred by a Satellite System as a communication link (link 0). The message of the preferred link or route is sent through link 0, and a reconfiguration procedure is acted on by both sender and receiver nodes. The location of every node is also collected by link 0. However, it is considered that the optimal

allocation by the satellite based scheduling would be one of the future topics for a study.

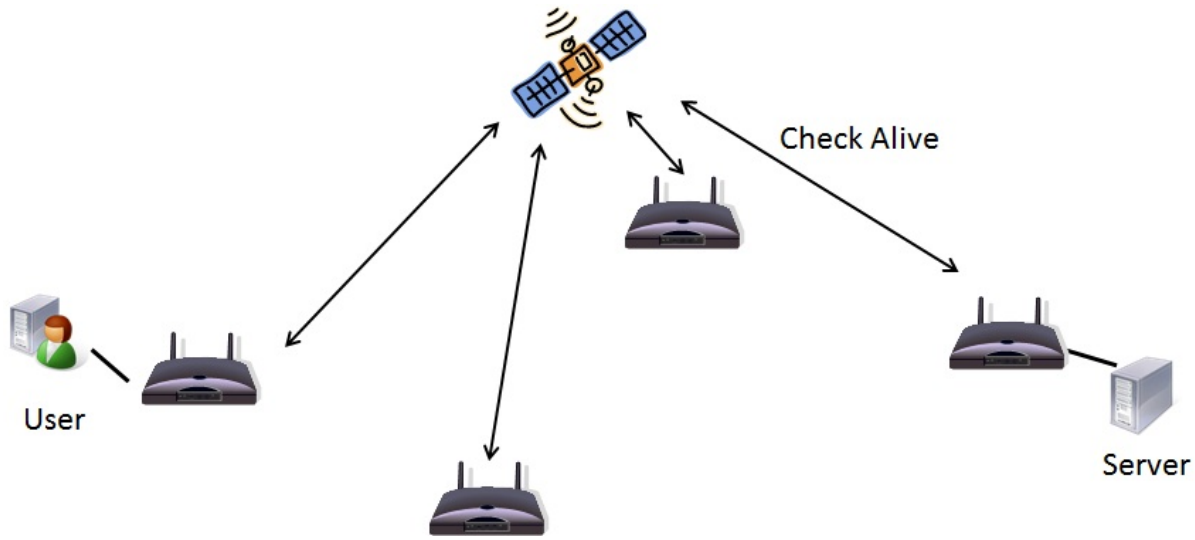


Figure 11: Check Alive Function

Secondly, wireless nodes are checked to see whether nodes are destroyed or not after a disaster by the Satellite System in Figure 11.

If some wireless nodes are destroyed by a severe disaster, a sender node collects all live information on the node, and then this information will be used for the reconstruction of the topology or alternative data transmission.

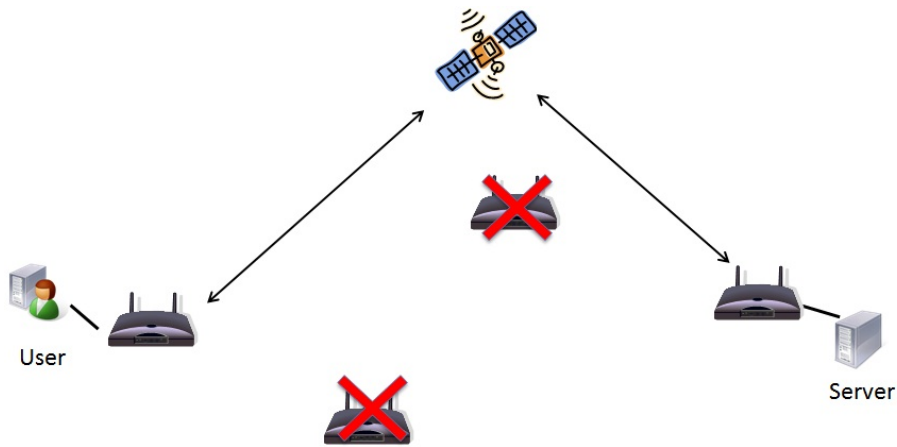


Figure 12: Min-Max method by AHP results

However, if the data transmission is not possible, the Satellite System alternates data transfer instead of wireless links as shown in Figure 13. Even if disasters are extremely severe, each node can use satellite transmission and so the probability of the network disconnection becomes extremely low. It makes the NDN more robust, and at least text contents will be able to be transmitted through the Disaster Information System. Therefore, the proposed network system makes it possible to send data like safety information concerning residents even if the Throughput is low until the topology is reconstructed.

7 Simulation

The simulation is to be evaluated for the effectiveness of our proposed methods. In the simulation, ns2 (Network Simulator 2) [20, 21] was used as the network simulator, and the scenario is for the actual field of Taro in Iwate Prefecture where there was severe damage caused by the Great East Japan Earthquake.



Figure 13: Location of Residential Area

In the case of a rural area shown in Figure 13 on the Google Map, the residential area is separated by mountain or sea, and our simulation should be concerned with the location of wireless nodes. Therefore, an evacuation shelter is set up as a sending node, and a disaster headquarters is set up as a destination node as shown in Figure 14. There are three residential areas located in the ns2 space, and each residential area has some distance from the other. A disaster headquarters and evacuation shelters are connected to each other with the fixed nodes, and each residential area has ten local nodes. Also, to evaluate a large scale disaster, all transmission nodes are stopped at once, and then some of the nodes are gradually recovered through time in the simulation.

IEEE802.11a (OFDM, 5.6GHz, 54Mbps), IEEE802.11b (DS-SS, 2.4GHz, 11Mbps), IEEE802.11g (OFDM, 2.4GHz, 54Mbps) are used as the wireless links [22, 23] and a satellite system is used as the link 0. Because this experiment's circumstance has heterogeneous wireless interfaces, it is considered that other wireless interfaces such as IEEE802.16e are also available to our proposed methods. UDP data transmission (320x240MJPEG, 15fps, 1/15 compressed) is held between an evacuation shelter (a sending node (0, 0)) and a headquarters (a destination node (1000, 1000)) by way of nodes in residential areas. There are three residential areas between a sending node and a destination node, and each residential area has ten fixed nodes at locations randomly selected from the residential area. All nodes in residential areas are stopped at 10 units of time, and then, after 20 units of time in the simulation, one node is randomly

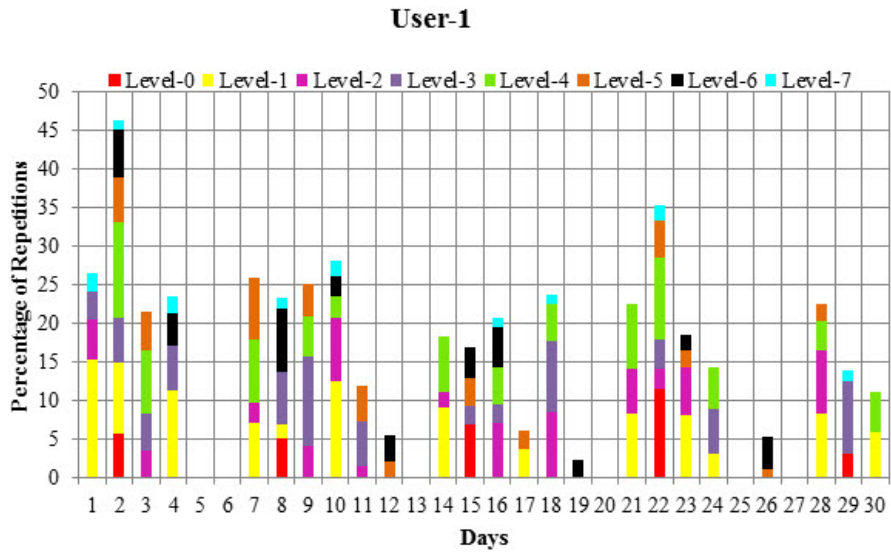


Figure 14: Simulation Scenario

selected and recovers transmission at each time phase until all nodes are recovered. Moreover, the actual field experiment data [24] used for the ns2 calculation because it is supposed to make a more accurate result than the equipped ns2 values.

First of all, the experiment considered the early stage of a disaster. In this experiment, the connectivity of data transmission is more focused than other network conditions as discussed in Section 2, and weight values on criteria are set up to (electric field strength, throughput, Jitter, PER, latency)=(3,1,1,5,1). These weight values on criteria are used for the Extended AHP calculations for CWN and NDN. IEEE802.11b is selected for the single wireless network in the experiments, because it has the longest distance connectivity and the least PER among IEEE802.11a/b/g according to the previous field experiments [24]. The result of Throughput is shown in Figure 15.

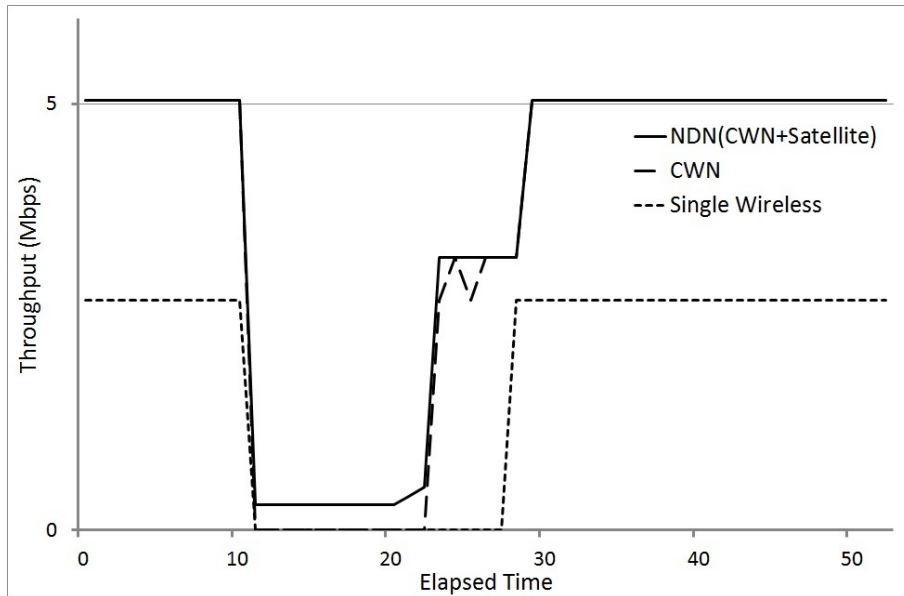


Figure 15: Throughput Results Focused on Connectivity

Figure 15 shows that the single wireless network, CWN, and NDN suddenly decrease the Throughput after 10 units of time because all inter-transmission nodes in residential areas are stopped. However, only NDN keeps minimal data connection because the alternative data transmission is done by the Satellite System. Also, NDN recovers network connection more quickly than the others with the recovery of inter-transmission nodes after 20 units of time. The results agreed with our model of NDN as mentioned in Section 2, and it is evaluated that our proposed methods work even after a large scale disaster.

In this paper, the simulation by mobile nodes in wireless cars is also assumed. In the actual fields, mobile nodes carried by wireless cars are useful alternative methods after disasters. Therefore, the mobile nodes that are moved by a random walk algorithm were introduced for the simulations in Figure 16.

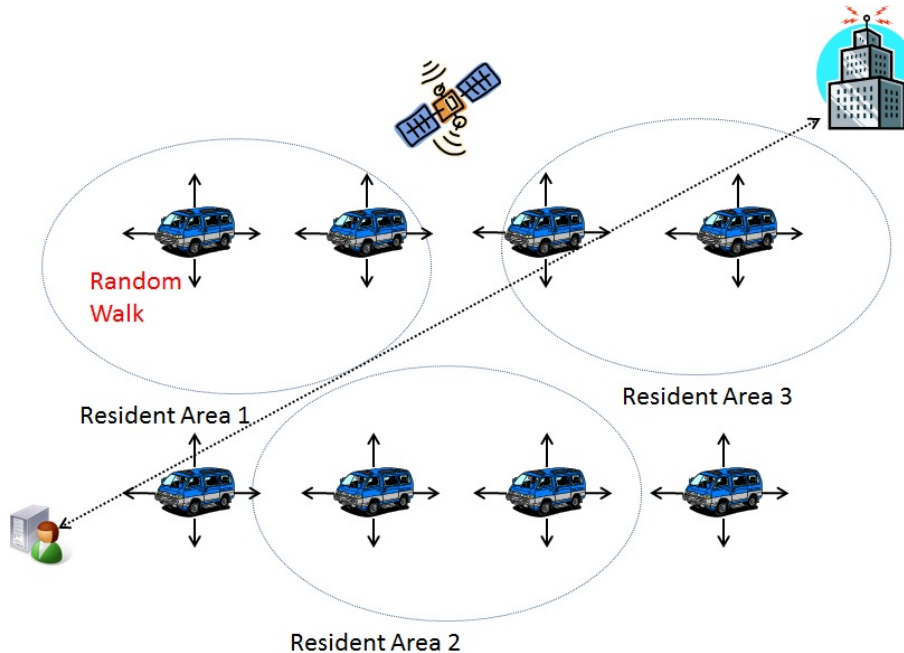


Figure 16: Simulation Scenario by Mobile Nodes

Figure 17 shows how the proposed NDN does not change under different circumstances with four mobile nodes in the simulation. Although the CWN and the single wireless network disconnect by the movements of mobile nodes, the NDN keeps the minimal connectivity.

Figure 18 shows the result of eight mobile nodes. In this case, all networks keeps the connection by the movement. However, the NDN shows the better result than single wireless network as the same as CWN.

The result of the simulation is that the changes of wireless and user environments can effectively switch the wireless link and route selection by our proposed method. That is, our method is designed to create a robust network connection in order to establish the NDN.

8 Conclusions

We have discussed how it is possible to deal with the disconnection of the communication network system in the case of another disaster on the scale of the Great East Japan Earthquake of March 2011. We have considered how the rescue services and disaster affected areas could be greatly assisted by a robust network connectivity that could form a new type of Disaster Information Network System. This

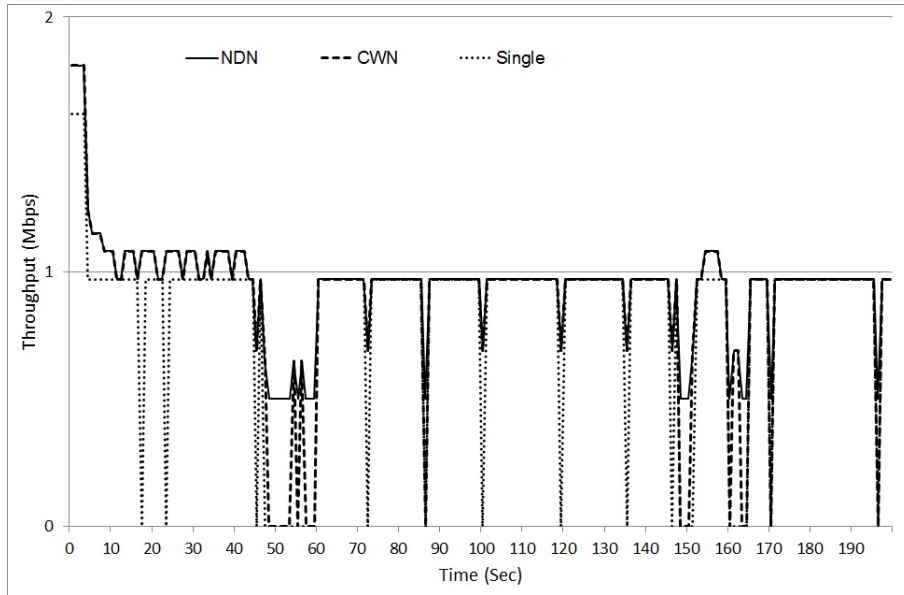


Figure 17: Throughput Results by Four Mobile Nodes

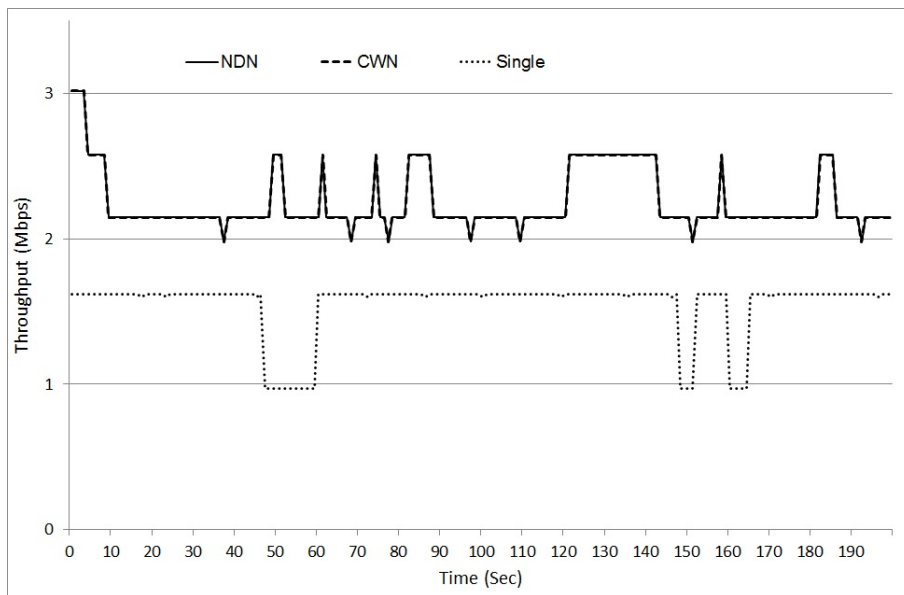


Figure 18: Throughput Results by Eight Mobile Nodes

paper proposes a Never Die Network that consists of CWN and a Satellite Network. A proper wireless link and route are optimally selected by taking proper account of network environment and the user’s particular requirement. In our proposed method, the cognition cycle will follow these particular factors. Secondly, for the optimal link selection, an extended AHP method will consider the respective change of network environment and user policy during a disaster. Then, if the network or user environment is changed, another route selection method will be conducted by the extended AODV with Min-Max AHP values.

For the sake of evaluating our proposed methods, the simulation compares an ordinal single wireless network system and a CWN in a hypothetical disaster situation. In this paper, mobile nodes such as

wireless cars are also considered in the experiments as well as fixed nodes. Figures 17 and 18 show how our proposed methods create robust network connectivity and a quick recovery in comparison with a single wireless network and a CWN. Therefore, we suggest that our proposed NDN is more effective as a Disaster Information Network System than previous models.

Now we are in the process of constructing a field experiment demonstrating how our proposed NDN could work in the coastal cities of Iwate Prefecture. Then, the local test-bed is planned to connect up with the New Generation Network (JGN-X) in order to simulate an additional experiment showing how a Software Defined Network (SDN) and an autonomous disaster cloud computing system (no acronym exists at the moment) can be used in combination for a future study of the proposed NDN.

9 Acknowledgement

We had the generous support of Prof. Nicholas Williams of Saitama Institute of Technology in the editing of this paper.

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