Delay Tolerant Networks on Vehicle-to-Vehicle Cognitive Wireless Communication with Satellite System for Disaster Information System in a Coastal City

Noriki Uchida* [1], Norihiro Kawamura[2], and Yoshitaka Shibata[3]

[1] Dept. of Informational Social Studies
Saitama Institute of Technology
1690 Fusaiji, Fukaya, Saitama 3692093 Japan
uchida@sit.ac.jp

[2] TAC Engineering Co.,LTD.
2320, Tsushidanishi, Morioka, Iwate 0200836 Japan
Nor.kawamura@tac-e.co.jp

[3] Faculty of Software and Information science
Iwate Prefectural University
15252 Sugo, Takizawa, Iwate 0200193 Japan
shibata@iwate-pu.ac.jp

Abstract

This paper introduces new Disaster Information System based upon Delay Tolerant Network (DTN) in Taro, Miyako, and Iwate Prefecture in Northern Japanese coastal towns which are the severely damaged by the East Japan Great Earthquake in 2011. This paper reports and discusses about the network conditions in disaster area by using our prototype network. Then, the computational experiments of the DTN by using cognitive wireless cars in those towns are discussed. The results show that the proposed cognitive wireless network (CWN) under the Spray and Wait Routing can work effectively. Finally we conclude that 25 wireless cars are expected to need for Disaster Information System with DTN in the town of Taro.

Keywords: Disaster Information Network System, Delay Tolerant Network, Cognitive Wireless Network, QoS

1 Introduction

It has been already two years since there was Great Earthquake at the Eastern Japan in 2011. Many Northern Japan coastal cities were severely damaged by the catastrophic earthquake and tsunami. It brought various problems such as a great number of victims, isolation of areas, and nuclear crisis. There are still so many problems including political problems for the reconstruction. However, in recent, disaster related works are also being carried out for the reconstruction of the damaged cities. This paper deals with the field experiments of network conditions in Taro, Miyako, Iwate, Japan, and discusses about

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*Corresponding author: Tel: 81-48-585-6876

the DTN based Disaster Information System which employs cognitive wireless cars and satellite system based fixed stations in the town.

The Great East Japan Earthquake caused not only destructions of many buildings but also disconnections of communication networks [15]. The communication networks such as Internet, cellular phones, and land phones were unavailable after the earthquake. Moreover, there was a wide blackout spread over the northern and central Japan. In addition, the disconnection came with various problems such as the delay of rescue and the isolation of the cities. In result, the cities are still suffering from the poor network conditions.

According to our previous reports about the ultra large scale earthquake [11, 16], wireless networks such as satellite system or wireless LAN were effective in reactivating the communication network in the disaster area. However, it is not the case to the satellite system, which have some problems such as a large jitter and PER (Packet Error Rate) for the Disaster Information System. Besides, if the disaster area was wider, it is not easy to cover the entire area by using Satellite System only. That is, even if some evacuation shelters in the area have a robust connection by Satellite System, it is necessary to carry the significant information data to whole shelters at least. DTN is one of the communication methods suitable for these problems. DTN is the “challenged computer network” approach originated from the Interplanetary Internet. Its data transmission is based upon the “store-carry-forward” protocol in order to carry data packets under the condition of poor connections such as space [7]. If mobile nodes such as wireless cars with smart phones or mobile PCs are used with the DTN methods, it is supposed to be able to communicate each other even during disasters. However, in the case of using DTN in local areas such as Taro town, the probability of delivery data would be less than the urban areas because the number of roads, cars, and pedestrians are fewer than these of the urban areas.

In this paper, we propose DTN based Disaster Information System which consists of cognitive wireless cars as mobile nodes and Satellite System as fixed stations in Taro, Miyako City, Iwate Prefecture, Japan, which was severely damaged by the East Japan Great Earthquake. For the first, this paper reports about network conditions based upon the satellite system in Taro City Hall resulted by the field experiments, and deals with DTN with CWN which consists of multiple wireless interfaces proposed by a Disaster Information Network System in order to set up in local areas. Then, considering the actual usage of DTN in local areas, the simulation is accomplished according to the map of Taro Town. In the experiments, vehicle-to-vehicle communications with single wireless interfaces such as IEEE802.11b/g and amateur radio was simulated, and then a proposed CWN method was simulated by GIS map of Taro. The results are discussed for the future works of DTN usages for Disaster Information Network System in local areas.

In the followings, the East Japan Great Earthquake and its network conditions are explained in section 2. System configuration and architecture of our proposed Disaster Information System by DTN and Satellite System are explained in section 3 and section 4, respectively. The field experiments in the town are reported in section 4. DTN on Vehicle-to-Vehicle CWN and it performance evaluations are described in section 5. Finally, the conclusions and future works are summarized in section 6.

2 The East Japan Great Earthquake in Taro, Japan

On March 11, 2011, the East Japan Great Earthquake hit the wide Northern and Middle parts of Japan as shwon in Figure 1 [13], and it caused severe damages such as blackout and nuclear crisis.

There are still many issues for the reconstruction of cities and the disaster prevention system even now, and to do this, a few works are being carried out. For example, as shown in Figure 2, Iwate Prefectural University in Japan opened the Disaster Reconstruction Support Satellite Office in Taro in October 1, 2012. The office aims to support not only various recovery activities such as volunteers,

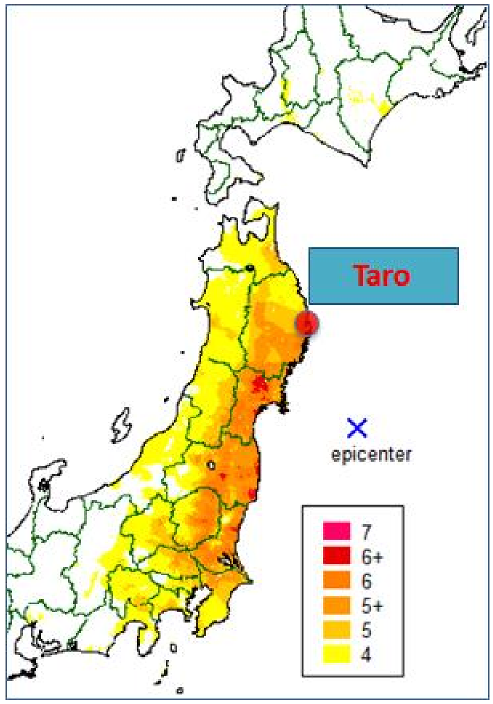

Figure 1: JMA Scale (Shindo) in the East Japan Great Earthquake.

education, and economic revitalization, but also diversity of research including information technology. In this satellite office, many researchers are also studying about the Disaster Information Network System including DTN, resilient network, disaster cloud computing system, SDN (software defined network) to be applicable for new disasters, the disaster content system, and so on.

Figure 2: Disaster Recovery Support Satellite Office in the Taro City Hall by Iwate Prefectural University.

Taro is a coastal resident area in Miyako City which is located in the middle of Iwate prefecture in Japan. It was originally called Taro Town, and the town was merged with the expanded Miyako City in 2005 and became a part of the city[2]. The population in 2011 was 3951, and the area is 101.15km2. The main industry is fishing such as sea urchins, abalones, and producing seaweed. The town also provides a rich fishing place widely known as “the town of salmon” in Japan. And the town is located in the “Sanriku ria coast” that is the National Park, and the magnificent sight of the coast is well known as a famous sightseeing place in Iwate.

However, Taro is also known as of "the tsunami and disaster prevention town." That is because the town has the tragic history severely damaged from three times of large scale disasters[17]. The first one is the Keicho Sanriku Earthquake on December 2, 1611. The magnitude of the earthquake was expected to 8.1, and it was said that the village disappeared under a 15 to 20m high tsunami according to their ancestral records. The second one is the Meiji Sanriku Earthquake on June 15, 1896, and a 14.6m high huge tsunami after the 8.5 magnitude earthquake destroyed the town area and there were 1,859 dead out of a population of 2,248. The third one is the Showa Sanriku Earthquake on March 3, 1933. The tsunami after the 8.4 magnitude earthquake killed 911 persons out of a 2,248 population. The height of tsunami at this time was recorded as 38.2m in the Village near Taro. Therefore, Taro built the biggest breakwater along the seacoast in 1966, which has 10m high walls and 2,433m length. These disasters ledthe town to declare "the tsunami and disaster prevention town" in 2003, and they have tried various disaster prevention events such as annual tsunami drills and disaster educations for all people in the town since the declaration.

Figure 3: A Breakwater in Taro after the East Japan Great Earthquake

However, the East Japan Great Earthquake brought severe damage again as shown in Figure 3 even for this well-prepared town. A massive 9.1 magnitude earthquake caused huge tsunami, and the estimated 15m high tsunami passed over the biggest breakwater in the world and destroyed the town like the previous disasters did. The damaged buildings were recorded up to 1,091 [10], and some buildings in the town disappeared. Fortunately, the victims were 166 dead out of the 3,951 population in the area, and the reason was assumed that their previous prevention activities saved many lives while the earthquake was quite serious like the number of buildings were damaged.

However, the disconnection of communication network made this town isolated from the other areas. Researchers reported about the terrible confusion caused by isolation and how our network reactivating activities worked well by Satellite System [15, 11, 16]. Although a few weeks passed after the tsunami, the disconnection of cellular phones, land phones, and internet made difficulty for the rescue of missing people. Even in developed countries like Japan, there must be some possibility of isolation from other areas because of the disconnection of the communication network. Thus, a robust network connection method has been focused on as one of the significant issues of disaster related research in the world, not only in Japan.

3 Proposed Methods and Prototype System in Taro

According to the experiences of network reactivations in the coastal cities such as Taro, we propose the DTN based Disaster Information System by Vehicle-to-Vehicle Cognitive Wireless Communication with Satellite System described in Figure 5. The system consists of fixed stations such as a disaster

Figure 4: Network Reactivation by Satellite System in Taro

headquarters, evacuation shelters, and residents, and mobile nodes such as wireless cars, cellular phones, and mobile PCs in the system.

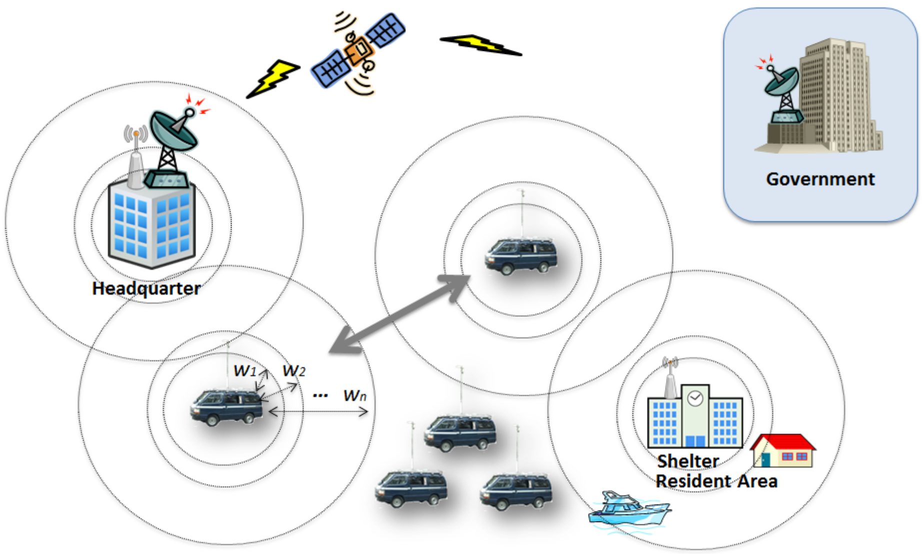

Figure 5: Proposed Disaster Information System with DTN and Satellite System

Major fixed stations have Satellite System to communicate with outside of disaster area such as governments, and self-productive energy such as solar power system. Moreover, all nodes have multiple heterogeneous wireless interfaces such as IEEE802.11a/b/g/j/n, Wimax, amateur radio, and so on (w1,w2, ..., wn). Then, mobile nodes such as wireless cars delivers these data to the inside of disaster area. These wireless interfaces are automatically selected according to the network conditions, nodes, movements, message priorities, and user policies under disaster for the sake of improving the message delivery rate and the latency by DTN. Figure 6 shows the prototype system implemented in the Taro Office. The system has multiple wireless gateways such as Satellite System, Wimax, 3G mobile system, and Wi-Fi (IEEE802.11a/b/g/n). Also, there are Wi-Fi routers for the communication with wireless cars and mobile terminals. Under such implementation, we are researching how DTN works effectively by these mobile nodes. In this paper, we evaluate our prototype systems by using the network simulator based on the map of Taro.

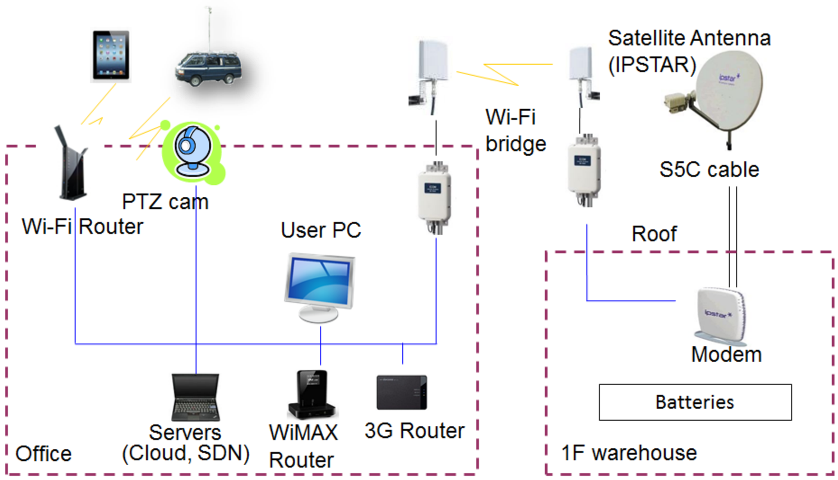

Figure 6: Network Configuration of Prototype System in Taro

4 Delay Tolerant Network

DTN is the approach of "challenged computer network" that provides interoperable communication in where continuous end-to-end connectivity cannot be assumed [9]. Although the current TCP protocol needs the end-to-end connectivity to establish network communication, DTN has been designed for the environment of that end-to-end communication cannot be available such as heterogeneous networks, interplanetary, military, and disaster networks.

DTN is originally designed from Interplanetary Internet such as the communication between an earth and the planet Mars[7]. In case of interplanetary network, interplanetary links are considered to be extremely troublesome in the current TCP/IP architecture. In the environment of extrememly longer distance of wireless data transmission, the important subjects mean extremely large latencies, bidirectional communication on each connection, continuous end-to-end connectivity, intermittent scheduled connectivity by relay orbiters, low data rates, and so on. Therefore interplanetary network needs new network protocols designed for such an interoperable communication.

To achieve the interoperable communication in poor network environment, DTN generally takes into account "store-carry-forward" protocol for its routing. That is, each node stores the transmission data if there is no available node nearby, and the data are duplicated when a node comes closer to be transmitted. Figure 7 shows an example of data duplication by DTN. Node 1 holds the message data (M1) when there is no available node nearby. If Node 1 comes closer to Node 2, M1 is copied into Node 2. Then, M1 will be carried to other nodes as the same way until the data is reached to a destination node.

However, the epidemic routing of DTN has some considerations to apply for the actual case of adhoc computer network. One is the limitation of a node's resources such as storage volumes, battery, and bandwidth. If a node is assumed as a cellular phone, the data volume is significantly limited so it is only able to hold a certain volume of copies of messages. In the case of epidemic routing, the oldest data is abandoned when the capacity of a node's volume is full. The second is the delivery rate. There are many considerable subjects to carry the messages such as the number of encounters, the delivery distance, the network condition, and the node's movements. If one of these factors is not enough, it is hard to deliver all messages by the epidemic routing. The last is delivered time (latency) from a sender

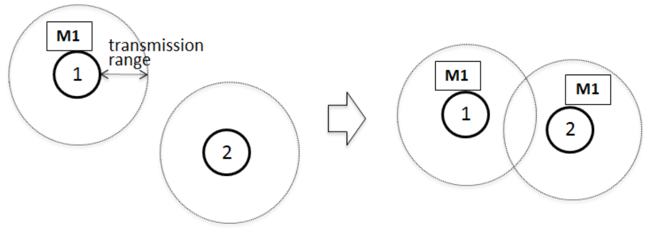

Figure 7: Deprecation by DTN

node to a destination node. Since the mobile nodes carry messages, DTN is not suitable for the real-time contents. Also, some other factors such as encounters, distance, and network conditions are supposed to affect the latency.

To solve these considerations, there are some different approaches of DTN routing such as Spray and Wait, MaxProp, PROPHET, and RAPID. Spray and Wait [12] attempts to gain the resource efficiency by setting an upper limit of copies per message in the network. This is effective for the low resource environments such as a low storage of mobile nodes. MaxProp is the flooding-based routing as well as the epidemic routing. This method determines which messages should be transmitted first and which messages should be dropped first. And the priorities are based on the path likelihoods to peers according to historical data and also on several complementary mechanisms, including acknowledgments, a head-start for new packets, and lists of previous intermediaries [5]. PROPHET (The Probabilistic Routing Protocol using History of Encounters and Transitivity) is a probabilistic routing protocol by using history of node encounters and transitivity to enhance performance of the previous protocols [9]. RAPID which is an acronym for Resource Allocation Protocol for Intentional DTN routing is based on flooding method like MaxProp, and attempts to replicate all packets if network resources allow. RAPID includes the effective algorithm that is intentionally minimizing one of three metrics: average delay, missed deadlines, and maximum delay [4].

However, if DTN is applied for a Disaster Information Network System in local areas or severely damaged areas, there should be more considerations to improve the delivery rate or the latency. In the case of Taro, like other local areas, the main transportation is car and pedestrians are rare. Public transportation is also less than that of urban areas, and it is likely to stop after a disaster. Besides, available roads and cars are supposed to be fewer than that of urban areas. Since these factors affect the delivery rate or latency of DTN routing, additional functions are necessary to apply for the Disaster Information Network System in local areas. In this paper, DTN with CWN consisting of multiple wireless interfaces is proposed for the improvement of QoS (Quality of Service) of DTN.

5 Experiments

5.1 Evaluations of the Prototype System

First of all, the network conditions in this office were evaluated by the field experiments. Although it has been already two years after the earthquake, most of internet cables are still not available around the office. Thus, our experiments were held by the ping data and the video conference system between the Taro office and University of Shizuoka away about 500 km from Taro. Figure 8 shows the actual experiment environment of video conference.

In the experiment, our results show 1.62Mbps by the Satellite System and 1.41Mbps by WiMax in the average throughput. However, the quality of the video conference with the Satellite System was worse than that of WiMax because of the poor resolution and high latency. In details, the 32 bytes ping

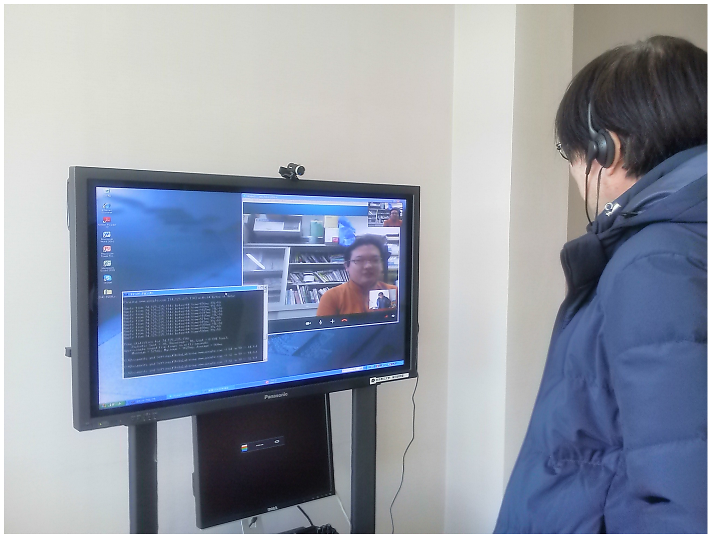

Figure 8: The Video Conference between Taro and University of Ahizuoka

results show 785ms RTT (Round Trip Time) and 567ms jitter by the Satellite, although that of Wimax was 109ms RTT and 42ms jitter. Besides, large packets more than 64 bytes were unable to communicate by the Satellite. Figure 9 is the capture image delivered by the Satellite and Figure 10 is by the Wimax.

Figure 9: The Image under Satellite System

Therefore, we concluded that real time contents such as video confernce or VoIP are not suitable for the communication with disaster area, and the packet size is also an important factor to maintain QoS under the proposed system.

5.2 Evaluations of DTN on Vehicle-to-Vehicle Cognitive Wireless Communication

Next, for the DTN simulation, the ONE (The Opportunistic Network Environment Simulator) [3, 8] is used. Also, for the purposes of the simulation scenarios, we modified some modules such as the experimental wireless interfaces, the GIS map, and the DTN routing. Figure 11 shows the modifications of the ONE's modules for the experiment.

The simulation scenario is shown in Figure 12. The seven evacuation shelters which are designated by Miyako City are located in the map, and wireless cars as mobile nodes are also implemented in

Figure 10: The Image under Wimax

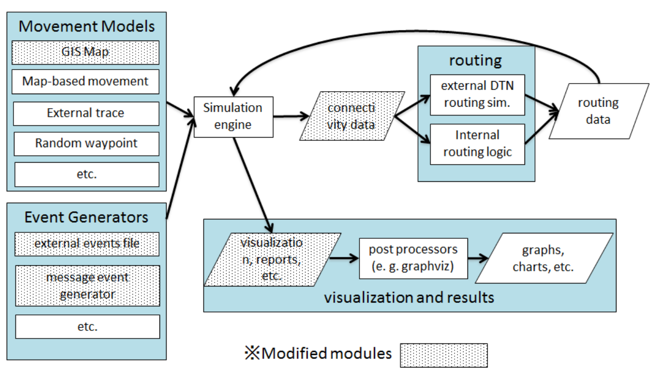

Figure 11: Modified Modules in the Experiments

the map. Table 1 also shows the details of simulation scenarios. Three types of wireless interfaces (IEEE802.11a, b, and g) were experimented by the different numbers of mobile nodes. The message data is assumed as text contents such as life safety information or damage information after a large scale disaster, and 0.5 - 1.0MB data is created at the Taro City Hall in every 50 - 60 seconds and carried to the Green Peer Taro that is a major evacuation shelter in the town. Then, the message delivery rate and the latency were calculated in each case.

The results of the Epidemic Routing are shown in Figure 13 and 14. Figure 13 is the results of message delivery rate in each wireless interface and CWN. The graph of IEEE802.11b demonstrates dramatic increase until 50 mobile nodes, and then the probability is kept constant at around 80%. Also, amateur radio shows the sharp rise by 50 mobile nodes, and then the probability is kept constant at around 60%. That is because amateur radio has only 128kbps throughput, and this is not enough to carry the whole data by the Epidemic Routing.

Figure 12: The Simulation Map in the Experiments

On the contrary, IEEE802.11a did not show any data delivery, and IEEE802.11g shows the poor results. That is because mobile nodes did not have enough time to duplicate the message data. Since mobile nodes goes fast from 10 km/h to 50km/h randomly and transmission range is extremely short as 50m, transmittable mobile nodes have already passed by after 5 seconds duration for PWD identification and DHCP preparation even if transmittable nodes come closer.

However, the proposed CWN methods do not work efficiently as we expected. Although the probability rises up by 25 mobile nodes, it kept constant at around 60%. There are two considerable reasons why the proposed methods are worse than the single IEEE802.11b. First of all, because of the better data transmission, more messages are possible to duplicate and these many messages are not easy to get the destination node. In fact, the results showed that many redundant messages were copied among various nodes even after the messages were already reached to the destination. Therefore, old messages should be minimized after the reach of the message. Secondly, time duration of changing wireless interfaces affected the probability. Since it takes five seconds to change the interfaces, the messages are not carried efficiently.

Figure 14 indicates the results of delivery latency in each wireless interface. However, as the same results as Figure 13, the proposed CWN and amateur radio did not work well for the same reason.

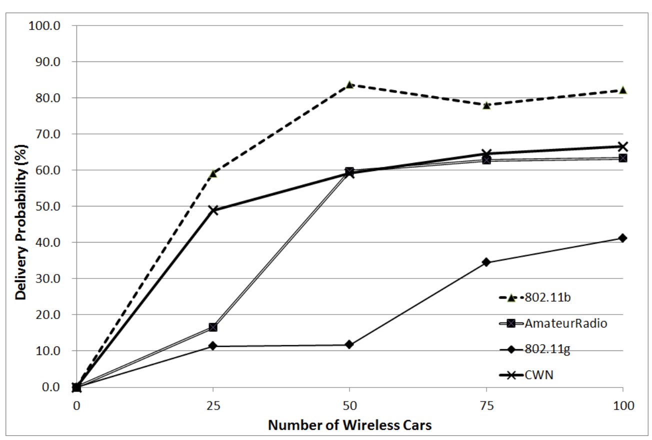

Figure 13: The Experimental Results of Delivery Probalilites

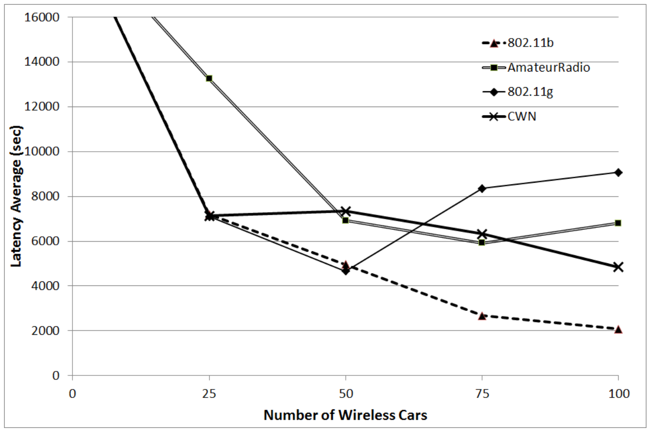

Figure 14: The Experimental Results of Delivery Latency

Fixed Wireless Station	Seven evacuation shelters (IEEE802.11a/b/g/amateur radio). Taro City Hall Green Peer Taro Joun Temple Taro First Elementary School Kashinai Community Hall Road Station Taro Settai Kaizen Center
Mobile Nodes	Cognitive Wireless cars (IEEE802.11a/b/g/amateur radio). (1) 25 cars (2) 50 cars (3) 75 cars (4) 100 cars ShortestPath Model Speed 10 - 50 km/h
DTN	(1) Epidemic routing (2) Spray and Wait (maximum pop is 6)
Wireless Conditions	- IEEE802.11b (11Mbps, 100m, 2.4GHz) - IEEE802.11a (25Mbps, 25m, 5.2GHz) - IEEE802.11g (20Mbps, 50m, 2.4GHz) - Amateur Radio(128kbps, 1000m, 430MHz) - Cognitive Wireless Network (automatic selection by SNR) Non-directional Antenna RTT (43200sec)
Data	- Data are carried from Taro City Hall to Green Peer Taro. - 0.5 – 1.0 MB data are created in every 50 – 60 seconds.
Network Connection	- 5 seconds duration is needed before the link connections in order to such as PWD identification and DHCP.
Node	- 2GB storage.
Duration	One day(43200 second)

Table 1: Simulation Senarios

Then, the results of the Spray and Wait Routing are shown in Figure 15 and 16. Figure 15 indicates that the proposed CWN demonstrates the sharp rise by 25 mobile nodes, and then the probability is kept constant at around 95%. This is better results than the Epidemic Routing, and that is because the upper limit of copies makes the network resources efficiently.

Figure 16 also indicates that the proposed method works properly, and the latency is available to make below 2,000 seconds by 25 mobile nodes.

In conclusion according to the experiments, the proposed methods under the Spray and Wait Routing work effectively, and about 25 wireless cars are expected to be necessary for Disaster Information System with DTN on viecle-to-viecle communication in the town of Taro.

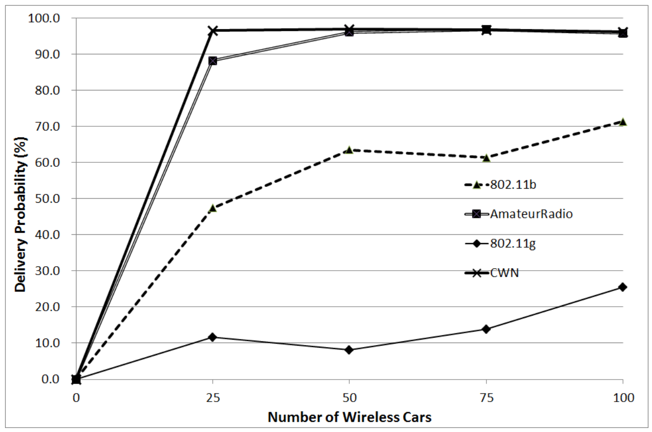

Figure 15: The Experimental Results of Delivery Probalilites

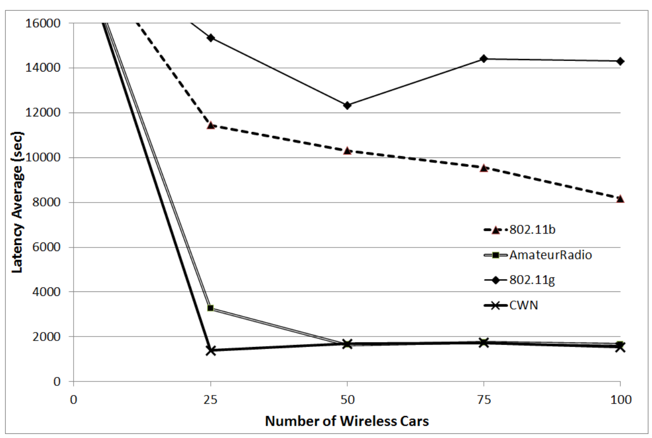

Figure 16: The Experimental Results of Delivery Latency

6 Conclusion and Future Study

This paper introduced our approach for Disaster Information System in the town of Taro in Iwate prefecture, Japan, which is one of the severely damaged areas by the Great East Japan Earthquake.

DTN and Satellite System are considered as a useful method to transmit data by interoperable communication. However, DTN for the Disaster Information Network System in local areas such as Taro was not easy for the simulation based on fewer roads, pedestrians, and cars than those of urban areas. So that is still remained as a future work.

Therefore, this paper carried out the evaluation of network conditions in disaster areas and its simulations by GIS data of Taro. The results indicated that the proposed CWN under the Spray and Wait Routing can work effectively, and about 25 wireless cars are expected to be necessary for Disaster Information System with DTN in the town of Taro.

Now we are studying new DTN protocols to improve QoS for improvement of Disaster Information Network System in the coastal cities in Iwate, Japan. In detail, we are trying to find an automatic link and route selection methods in CWN, an automatic controls of directional antenna in a wireless car, message priority protocols, and a DTN routing protocols with coding such as Reed Solomon Coding in order to improve the delivery rate and the latency with fewer mobile nodes.

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Author Biography

Noriki Uchida received the B.S. degrees from University of Tennessee in 1994, M.S. degrees in Software and Information science from Iwate Prefectural University in 2003, and Ph.D. degree degrees in the same University in 2011. Currently he is an associate professor in the Saitama Institute of Technology. His research interests include Cognitive Wireless Networks, QoS, and Heterogeneous Network. He is a member of IEEE, Information Processing Society of Japan (IPSJ), and Institute of Electronic and Communication Engineering in Japan (IEICE).

Noritaka Kawamura received the engineering degrees from Chiba Institute of Technology in 1994, M.S. degrees in Software and Information science from Iwate Prefectural University in 2004. Currently he is a enginner in TAC Engineering Co., LTD. His research interests include Geographic Information System for local goverments, and Digital Terrain Modeling by 3D Laser Data.

Yoshitaka Shibata received his Ph.D. in Computer Science from the University of California, Los Angeles (UCLA), U.S.A. in 1985. From 1985 to 1989, he was a research member in Bell Communication Research, U.S.A., where he was working in the area of high-speed information network and protocol design for multimedia information services. Since 1998, he is working for Iwate Prefectural University, Japan as an executive director of Media Center and a professor of Faculty of Software and Information Science in the same university. He is a member of IEEE, ACM, Information Processing Society of Japan (IPSJ) and Institute of Electronic and Communication Engineering in Japan (IEICE).