

Autonomous Directional Antenna Control for Delay Tolerant Networking based Disaster Information Network System in Local Areas

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Abstract

When there was the East Japan Great Earthquake in 2011, many areas were isolated by the high congestions and the disconnection of cellular phones or Internet. DTN (Delay Tolerant Networking) is one of effective methods for Disaster Information Network System, but the delivery rate and latency are pointed out of the problems of DTN. Besides, since there are fewer roads or pedestrians in local area, it is considered that these problems become worse than the urban areas. In this paper, we introduced DTN with autonomous directional antenna control for wireless network based Disaster Information Network System, and the simulation is held by the map of a Japanese local area. The results show the improvement of DTN in local areas, and they are discussed for the future studies.

Keywords: Disaster Information Network System, Delay Tolerant Networking, Wireless Network, Autonomous Directional Antenna Control, QoS

1 Introduction

Recently, the development of communication network has realized many noble services, and it has greatly influenced to our life styles. However, because the current communication networks rely on the connection, their communication is not suitable for the congestion or the disconnection of networks. Therefore, it is necessary to consider the resiliency when there are high congestions or wide area cable disconnections by such as disasters [9, 14]. In fact, when there was the East Japan Great Earthquake in 2011, many areas were isolated by the high congestions and the disconnection of cellular phones or Internet [9]. Besides, since many aspects of our life style came to rely on these communication networks, it greatly influenced to the delay of rescue, seeking missing people, and delivering rations such as water and food [14]. Moreover, in case of local areas, residential areas are more likely isolating than the urban areas because of the less equipment.

In case of Disaster Information Network System (DIS), there are some considerable approaches to make the network more resilient according to the previous researches[8, 2, 12, 13]. The wireless network system is one of the methods because of its robust connection and quick reactivation from the damages [8]. However, when the directional antenna is required for the longer distance to communicate, it is necessary to adjust the direction of the antenna before getting started. Besides, it is not suitable for vehicle-to-vehicle wireless network because the nodes are always moving. Also, in case of local areas, directional antenna control is necessary since the residential areas are widely spread out.

DTN (Delay Tolerant Networking) is considered to be one of the possible approaches for the disaster use. The DTN approach is based upon the “store-carry-forward” protocol for the sake of carrying data

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packets under disconnected networks [2]. Thus, if mobile nodes such as smart phones or wireless cars have the DTN functions, it is supposed that significant disaster information would be able to transfer to the destination node.

However, since local areas have fewer roads, cars, and pedestrians than those of urban areas, the possible delivery data of DTN would be less. Thus, it is necessary to consider additional effective functions when DTN is applied for the Disaster Information Network System in local areas (DIS-LA). Especially, according to our previous studies [12, 13], the distance of wireless transmission is pointed out as one of important factors for improving the delivery rate or latency, thus the usage of directional control method is considered be effective for DTN.

In this paper, we introduced DTN with directional antenna control for IEEE802.11a/b/g/n based wireless cars, and the simulation is held by the map of a Japanese coastal town that was severely damaged by the East Japan Great Earthquake. Then, the results are discussed for the future studies of DTN for vehicle-to-vehicle communication based DIS-LA as well as DTN usages for DIS-LA.

2 Disaster Information Network System

The proposed DIS-LA is shown in Figure 1. The disaster headquarters and the evacuation shelters are connected by wireless networks, and these wireless interconnected nodes are consisted of fixed stations such as evacuation shelters or residents, and mobile nodes such as wireless cars, cellular phones, or mobile PCs. Also, fixed nodes equip the satellite system for the connection to the central government.

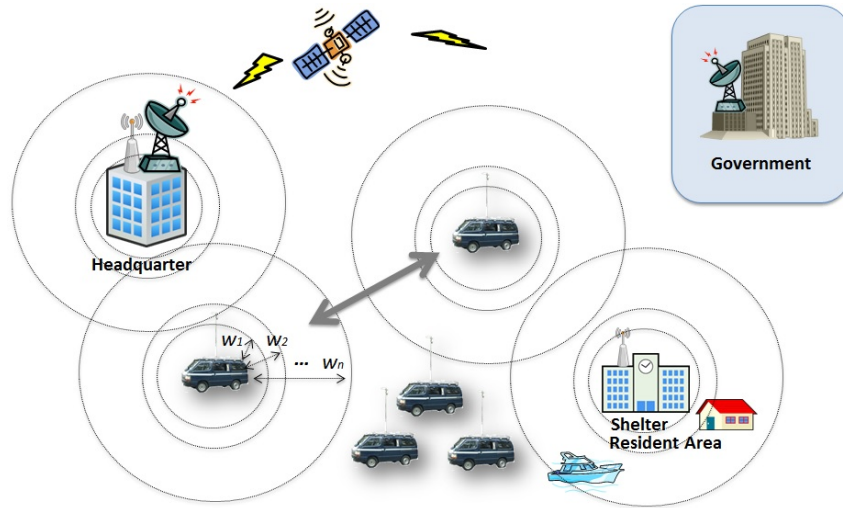


Figure 1: A Proposed Disaster Information Network System

Each node has multiple heterogeneous wireless interfaces such as IEEE802.11b/g/j/n/ac and amateur radio, and one of the interfaces is selected by the network conditions such as electric field strength, throughput, and packet loss rate. Moreover, each fixed and mobile nodes are supported by the DTN methods under inoperable conditions. Thus, the transmitted data is firstly stored in each nodes when there is no transmittable node nearby, and then the data is duplicated when mobile nodes come closer.

Then, since the proposed system is supposed to use in local areas, directional antenna control is introduced to each mobile nodes. When the radio communications system is used at an emergency in local area, the communication range of an electric wave is important. Mobile stations are operated to a stricken area just after the disaster to quick recover the communication means so that anyone can communicate anywhere anytime without any license and approval from authoulized organaization. However,

especially since such the output signal power of the wireless network is very low and its communication distance is limited particularly when the non-directional antenna is used. Those problems can be cleared by controlling the direction of directional antenna automatically by considering the GPS data and electric power density, packet loss rate, delay time. The details will be discussed in the following chapter 4.

3 Delay Tolerant Networking

DTN (Delay Tolerant Network) is the approach of “challenged computer network” that provides interoperable communication where continuous end-to-end connectivity cannot be assumed [4]. Although the current TCP protocol needs the end-to-end connectivity to establish network communication, DTN has been designed for the environment even if end-to-end communication cannot be available such as heterogeneous networks, interplanetary, military, and disaster networks.

In the DTN method, 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. In Figure 2, node 1 holds the message data M1, when there is no available node nearby. When node 1 comes closer to node 2, data M1 is duplicated in node 2. Then, data M1 will be duplicated to other nodes as the same way until M1 reaches to a goal node.

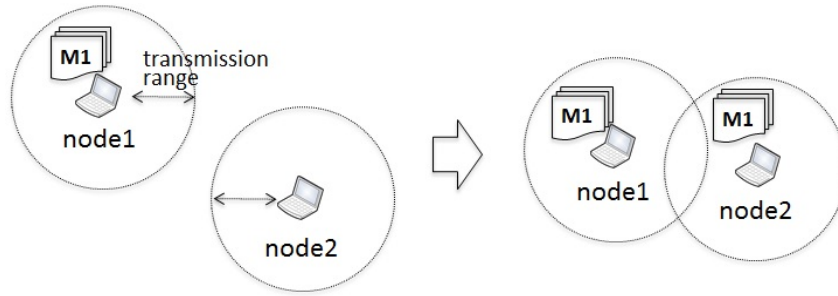


Figure 2: The Example of The Epidemic Routing

This basic typed DTN protocol is called the epidemic model, but there are some problems of the protocol such as the delivery rate, the latency, and the node’s resources.

First of all, there 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 especially limited being only able to hold a certain volume of copies of messages. In the case of epidemic routing, the oldest data is abandoned if the capacity of a node’s volume becomes full. Second are the delivery rate and the latency of messages. Unlike end-to-end connection model, the delivery rate and the latency are extremely high by using DTN. SIR model [4], which is the model of spreading virus, is widely applied to the simulation of the epidemic routing. By SIR model, when “X” is the available nodes to receive a copy of message, “Y” is the nodes that are holding and carrying a message, and “Z” is the unavailable nodes to receive or transmit a message, the mathematical DTN model can be expressed as the following equations.

$$\frac{dX(t)}{dt} = -\beta X(t)Y(t) \quad (1)$$

$$\frac{dY(t)}{dt} = -\gamma Y(t) + \beta X(t)Y(t) \quad (2)$$

$$\frac{dZ(t)}{dt} = -rY(t) \quad (3)$$

In the equations (1) (2) (3), the parameter β is the transmittable parameter and represents the rate of contacts between two nodes. The parameter γ is the non-transmittable rate and represents the rate in which nodes already have the messages. Also, the equation (4) is derived from the equation (1)(2)(3).

$$\frac{d}{dt} (X(t) + Y(t) + Z(t)) = 0 \quad (4)$$

The paper [3] reported the calculation results of the SIR model, and it takes more than 10,000 seconds to spread a message with 100 nodes in 8 x 8 km area.

To improve these considerations, there are some different approaches to improve the QoS (Quality of Service) such as Spray and Wait [10], MaxProp [1], and PROPHET [6]. Spray and Wait attempts to gain the resource efficiency by setting an upper limit of copies per message in the network. It is supposed to be effective for the low resource environments such as a low storage of mobile nodes. This DTN routing method “sprays” a number of copies into the network, and then “waits” till one of these nodes meets the destination. MaxProp is the flooding-based routing as well as the epidemic routing, but it determines which messages should be transmitted first and which messages should be dropped first. 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. 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 over previously existing protocols.

Also, the authors previously discussed about the usage of cognitive wireless DTN methods [12] for DTN. In the approach, the wireless nodes are consisted of multiple interfaces such as IEEE802.11a/b/g/n or amateur radio, and one of the interfaces is selected by the network conditions such as throughput, latency and PER (packet error rate). Although the results show the results, it was considered that the improvements was not enough because the delivery rate shows about 95 percents and the latency was about 2,000 seconds in the local areas. Besides, the single amateur radio network was almost same as the proposed cognitive wireless approach, and so it became to consider the transmission range is more important than other network conditions such as throughput.

If DTN is applied for DIS-LA or severely damaged areas, there should be more effective methods for the delivery rate or the latency. Although most of DTN protocols such as Spray and Wait or MaxProp are mainly considered about the resource efficiency or the transmission routes, in case of local areas, transmittable nodes such as cars or pedestrians are less than the urban areas. Besides, residential areas are widely spread in the area. Thus, this paper approaches to improve DTN efficiency by the transmission range making longer, and DTN with directional antenna control is proposed for improving the QoS of DTN.

4 Directional Antenna Control

Our previous study [11] discussed about the directional control for Disaster Information System. This proposed system is operated by connecting a GPS receiver, a pan/tilt actuator control unit for directional antenna, and a wireless LAN access point to PC, and executing application. The system configuration of the prototype system is shown in Figure 3.

The location of the node is acquired by GPS, and these positioning messages are communicated with other nodes through 3G or amateur radio network that the connection is assumed to be always provided in this paper. Those positioning messages are used for the computational calculation of the proper angle

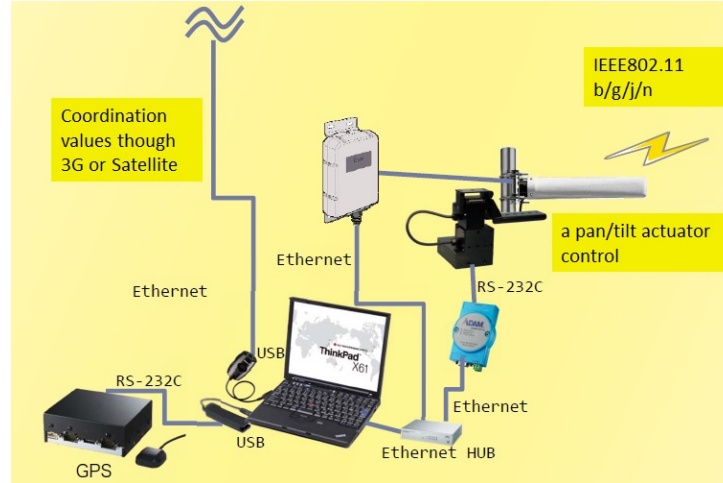


Figure 3: The System Configuration of Prototyped System

of the directional antenna, and it used for the pan/tilt actuator control through RS-232C. Then, after adjusting the angle of an antenna using coordinates and direction information, it is necessary to tune finely in the optimal position adjustment using electric power density, round trip time (RTT) and packet loss rate (PLR).

Figure 4 is the picture of the prototype system, and Figure 5 is the experimental results of the system.



Figure 4: The Prototype Directional Antenna Control System

5 Experiments

First of all, in order to evaluate the efficiency of the current DTN protocols in local areas, the experiments of the Epidemic Model are carried out by the GIS map of Taro area, Iwate, Japan. Taro is one of the severely damaged towns by the East Japan Great Earthquake, and the population in 2011 was 3951, and the area is 101.15km^2 .

The Opportunistic Network Environment Simulator (the ONE) [7, 5] was modified, and it was used for the computational calculation. The seven evacuation shelters were set as the fixed station in the GIS map, and 20, 40, 60, 80, and 100 wireless cars as mobile nodes were experimented for the effectiveness of DTN in local areas. The more details of the experiment are shown in Table 1.

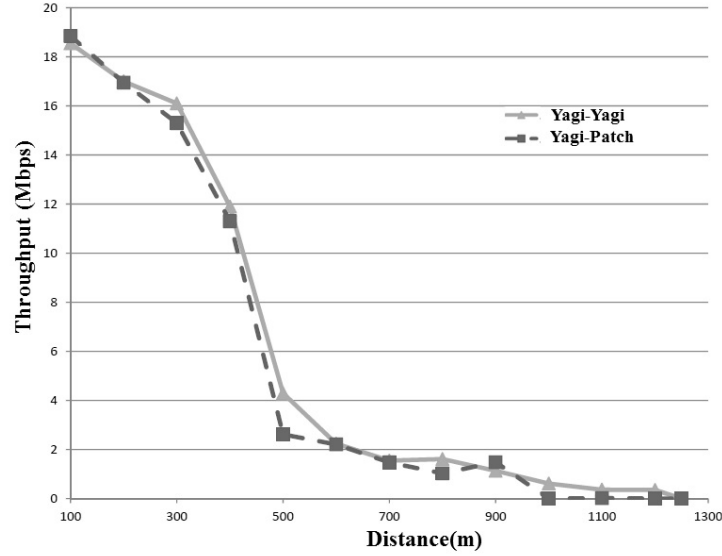


Figure 5: The Prototype Directional Antenal Control System

Table 1: Simulation Senarios

Fixed Wireless Station	Taro: Seven buildings (City Hall and evacuation shelter designed by city) (IEEE802.11b).
	Taro City Hall, Green Peer Taro, Joun Temple, Taro First Elementary School, Kashinai Community Hall, Road Station Taro, Settai Kaizen Center .
Mobile Nodes	Wireless cars (IEEE802.11b/g).
	The numbers of cars are 20, 40, 60, 80, and 100.
	ShortestPath Model
	Speed 10-50 km/h
DTN protocol	Epidemic Routing
Wireless Interfaces	IEEE802.11b (11Mbps, 100m, 2.4GHz)
	IEEE802.11g (22Mbps, 50m, 2.4GHz)
	Non-directional Antenna, RTT (43200sec)
	To switch interfaces, it takes 5 seconds for password identification and DHCP configuration.
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.
Nodes	2GB storage.
Duration	12 hours (43200 seconds).

The experimental result of the delivery rate is shown in Figure 6., and the latency is in Figure 7.

The graph of IEEE802.11b in Figure 6 demonstrates the sharp rise by 40 mobile nodes, and then the probability is kept constant at around 80 percents. The result is supposed to match the mathematical SIR model for epidemic routing as mentioned before. On the contrary, IEEE802.11g does not show like the SIR model. That is because mobile nodes did not have enough time to duplicate since the mobile nodes ran so fast. Because mobile nodes ran fast from 10 km/h to 50km/h randomly, there was no enough time after 5 seconds duration of PWD identification and DHCP preparation. That is why IEEE802.11g showed the poor results. Figure 7 of the latency also indicate that only IEEE802.11b interface is effective for the simulation scenario.

Secondly, we had the experiment for the comparison of the proposed DTN with antenna directional control, the Epidemic, and the Spray and Wait routing. According to the first experiment, the

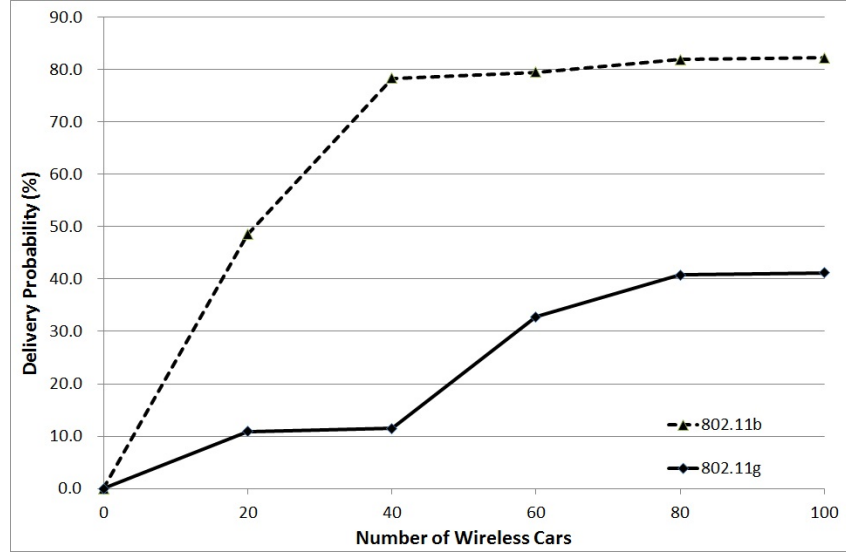


Figure 6: The Delivery Rate under the Epidemic Routing

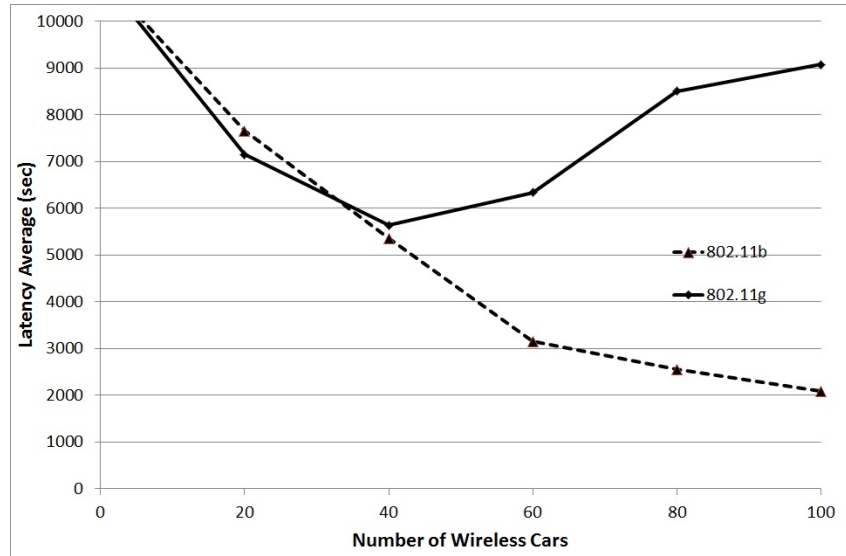


Figure 7: The Latency under the Epidemic Routing

IEEE802.11b/g for the proposed method are compared with IEEE802.11b of the Epidemic and Spray and Wait routings because of non-directional antenna of IEEE802.11g did not work in the simulation scenario. In this experiment, our previous experiment results in Figure 5 is used for the parameter setting of the ONE, and 17 seconds duration is needed for the adjustment of antenna control before the data transmission. The maximum pop of Spray and Wait is also set as six. The results are shown in Figure 8 and 9.

According to these results, first of all, our proposed directional antenna control method is effective than other DTN protocols. Both the delivery rate and latency are greatly improved than the Epidemic and the Spray and Wait routings. Therefore, it is necessary to consider about the transmission ranges of wireless nodes when DTN is applied for the DIS-LA, and the proposed directional control method is the proper approach for DTN.

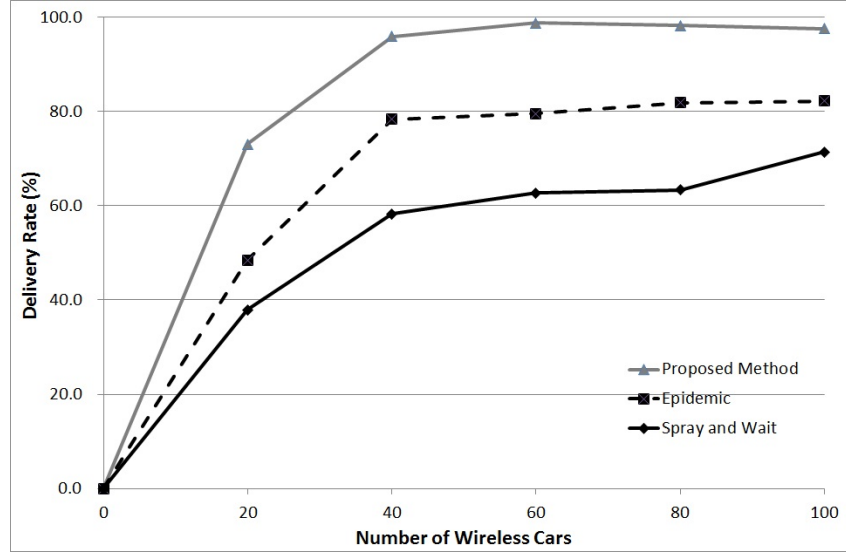


Figure 8: The Delivery Rate under the Proposed Method

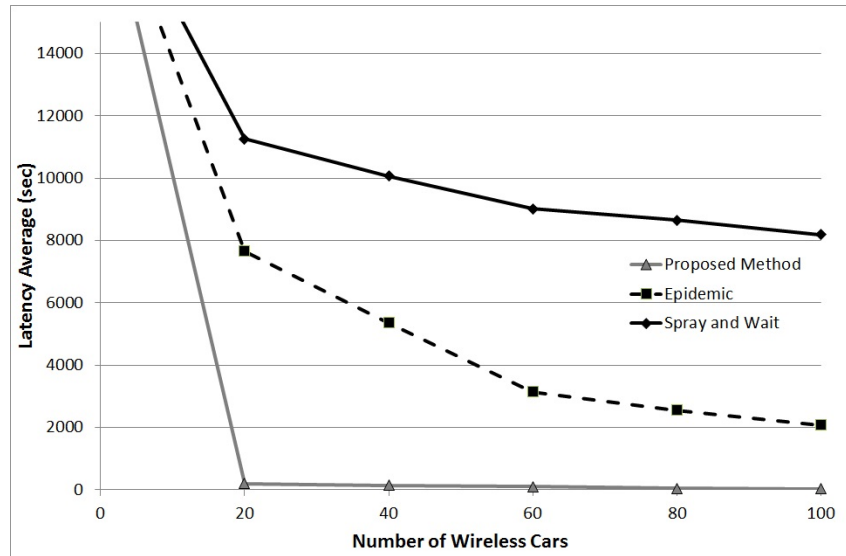


Figure 9: The Latency under the Proposed Method

Secondly, the Spray and Wait protocol did not show the improvement of DTN. It is supposed that the simulation scenario had enough 2GB storage to store the messages. Currently, with the developments of IT, cellular phones or smart phones have enough HDD storage and memory. Therefore, the DTN approach considering node's resources such as the Spray and Wait may not be suitable any more according to this simulation.

6 Conclusion and Future Study

It is considered that DTN is a possible method for DIS to transmit data because it is suitable for interoperable communication. However, the previous studies have pointed out the problems of node's resources,

the delivery rate, and the latency of DTN. Moreover, if DTN is introduced in local areas, it is obvious that these problems would be worse. That is because the local areas or disaster areas consist of fewer roads, pedestrians, and cars than in urban areas.

Therefore, this paper introduces DTN with directional antenna control for DIS-LA. The simulation was held by the GIS map of Taro that is severely damaged area by the East Japan Great Earthquake, the results shows that the proposed method is effective for the DIS-LA. For the future studies, we are now planning to conduct field experiments by the proposed method, and additional DTN protocols to improve QoS for DIS-LA. In detail, they are Data Triage method under DTN, message priority protocols, and the dynamic message error correction method using Reed Solomon Coding in order to improve the delivery rate and the latency with fewer mobile nodes.

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Author Biography



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