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Delay Tolerant Network for Disaster Information Transmission in Challenged Network Environment

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SUMMARY After the East Japan great earthquake on March 11, 2011, many Japanese coastal resident areas were isolated from other because of destruction of information infrastructure, disconnection of communication network and excessive traffic congestion. The undelivered disaster information influenced the speed of evacuation, rescue of injured residents, and sending life-support materials to evacuation shelters. From the experience of such disaster, more robust and resilient networks are strongly required, particularly for preparation of large scale disasters. In this paper, in order to respond to those problems, we introduce Delay Tolerant Network (DTN) for disaster information transmission application in challenged network environment. Message delivery by transport vehicles such as cars between disaster-response headquarter and evacuation shelters in challenged network environment is considered. A improved message delivery method combined with DTN protocols and cognitive wireless network is explained. The computer simulation for the actual rural area in Japan is made to evaluate the performance and effectiveness of proposed method.

key words: *DTN, disaster network, resilient network, disaster management*

1. Introduction

The recent social problems such as rapid decreasing population, aging and economical gaps between urban and rural areas have been serious in Japan. The gap of communication networks is also one of the problems, and the poor network circumstance in rural areas might affect not only the safety for natural disasters, but also the medical or welfare services. Since more than 70 percent of the Japanese land consists of the mountainous area, once natural disasters such as earthquakes, typhoon, heavy rain and snow occurred, those rural areas are likely to become isolate from others because of disconnection of communication cables or breakdown of network devices.

In fact, The East Japan Great Earthquake caused many problems in functions such as rescue, food distribution, and evacuation responses [1], [2]. Malfunction of the information network system was a part of major problems after the earthquake [3]–[5]. Many Japanese coastal resident areas were isolated from other because of destruction of information infrastructure, disconnection of communication network and excessive traffic congestion [6]. Especially, the lack of disaster information such as life safety for evacuated residents, damages scale and degree of houses, buildings, lands, roads, bridges and seaports brought much confusion of various activities [7]. The Table 1 summarizes various information networks and their functional conditions which Iwate Prefecture obtained through our network recovery activities [8].

Table 1 The state of communication means in East Japan Earthquake.

System	Condition	Details
Radio broadcasting	○	Local copmmunity FM stations functioned well
TV broadcasting	×	Could not function due to blackout
Fixed phone (voice)	×	Lines were disconnected and network devices were damaged
Cellar phone (voice)	×	Traffic was congested and base stations were damaged
Internet (wired,wireless)	△	Worked depending on communication lines
LANs in local government office	×	Power supplies were failured and network devices were damaged
Regional super highway	×	Line disconnection, power supply and network devices were damaged
Personal radio communication	○	Worked well among licensed users
WLAN & FWA	○	Quickly recovered information infracture after disaster
Satellite network	○	Quickly recovered information infracture after disaster

Many refugees could not communicate each other just after the disaster and even when staying in the temporal evacuation shelters. For this reason, the required disaster information between those shelters and other sites such as local government office, hospitals, clinics schools could not be delivered. Thus it is necessary to establish the robust and resilient emergency communication mean to prepare for unpredicted disasters in addition to the usual public communication network.

During disaster, situations sometimes arise where information delivery is more important than latency and long wait time are acceptable. DTN (Delay Tolerant Networks) [9], [10] is considered as one of the effective communication methods in such inoperable communication circumstances. DTN is defined as the "challenged computer network" approach that is originally designed from the Interplanetary Internet, and the data transmission is based upon the "store-carry-forward" protocol for the sake of carrying data packets [11]. Thus, if mobile nodes are used for carrying data by the DTN method, significant disaster information would be transferred each other.

Currently as mobile node during disaster period, Autonomous Flight Wireless node (AFW) such as drone [12]

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and Transport Vehicle Wireless node (TVW) are suitable. Drone is useful for disaster areas where the roads are disconnected and cannot be passed through. However, the fighting time of AFW is limited due to battery energy supply and long distance message carrying is difficult. Whereas the TVW can carry the messages in the disaster area as long as roads can be passed through. Thus, both multiple AFWs and TVWs are used depending on the degree of disaster and recovery of road to cover message delivery in the disaster areas. In our research, message carrying by multiple TVWs based on DTN routing protocol is considered.

In this paper, in order to improve the performance of the basic DTN, we propose cognitive wireless network(CWN) [21] as communication network interface, then evaluate the proposed system by computational simulation according to the GIS map of the actual area, Taro in Miyako City, Iwate in Japan, the severely damaged city in the East Japan Great Earthquake. The computational results are discussed for the future studies of DTN usages for Disaster Information Network System in rural areas.

In the followings, our disaster information delivery system is explained in Sect. 2. Next, basic DTN protocols are explained in Sect. 3. Then, our proposed method for DTN is shown in Sect. 4. Section 5 deals with the computational simulations of the proposed methods, and conclusion and future study are discussed in Sect. 6.

2. Information Delivery System in Disaster Area

Figure 1 illustrates information delivery system in the disaster area. It is assumed that all of the public communication networks are damaged and disconnected and temporal wireless local networks are recovered. There are a Disaster-response Headquarter or local government office, evaluation shelters and TVWs as mobile nodes. Each communication device of those consist of a computer, a storages and a wireless communication device which has DTN transmission function. Disaster-response Headquarter has external network access such as Internet. On the other hand, the direct communication among the evacuation shelters and the Disaster-response Headquarter cannot be possible although

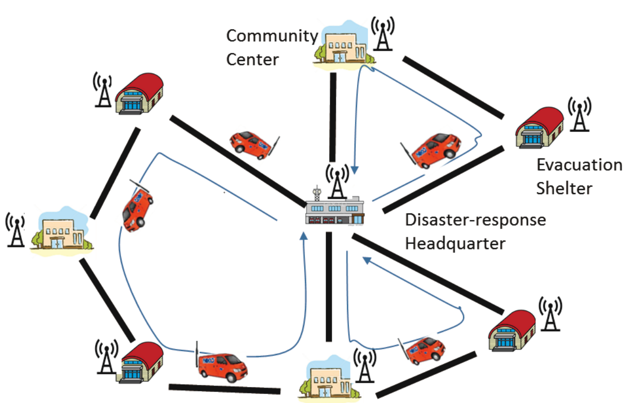

Fig. 1 Information delivery system after disaster.

the communication inside the shelters can be possible. Then using DTN, a TVW goes around the disaster area and delivers information at the evacuation shelter. At the same time, the information stored at the evaluation shelters is collected and delivered to other shelters or Disaster-response Headquarter. There are multiple number of TVWs which move around different routes each other in the disaster area. When the two TVWs encounter on the road, the information is exchanged using vehicle-to-vehicle communication. Thus by repeatedly delivering and exchanging information by TVWs among Disaster-response Headquarter and evacuation shelters, the information delivery can be attained. In this situation, the information delivery sometimes involves a low delivery rate and long delay due to the inherent characteristics of basic DTN. Therefore, the improvement of the network performance of information delivery should be considered as explained in the Sect. 4.

3. Delay Tolerant Network

In order to deliver information among the Disaster-response Headquarter and those shelters in challenged network environment, DTN protocol is used. DTN provides "store-carry-forward" typed protocol for the 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.

There are widely applicable DTN protocols. Epidemic routing protocol [14] is a basic protocol and applies a flooding mechanism. When the node which has message encounters other, the node spreads the message like a disease in population. The received node repeats this flooding process until it encounters the destination node. The advantages of Epidemic protocol are to maximize the delivery ratio and to minimize the latency although the total resources are consumed in message delivery.

Several previous papers [15]–[17] pointed out that Epidemic routing of DTN has some problems for the actual case of ad-hoc 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 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 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. Third is the delivered time (latency) from a source node to a destination node. Since the mobile nodes carry messages by "store-carry-forward" method, DTN is not suitable for the real-time contents. Thus, Epidemic routing is affected by those node's resources and network conditions and should be improved.

To improve these problems, there are some different approaches of DTN routing such as Spray and Wait, MaxProp, PROPHET, and RAPID. Spray and Wait [15] is a routing protocol that attempts to gain the delivery ratio benefits of replication-based routing as well as low resource utilization. The Spray and Wait routing protocol is composed of two phase: the spray phase and the wait phase When a new message is created at source node, a number L is attached to this message in the network. During the spray phase, the source of message is responsible for "spraying", or delivering one copy to L distinct "relays". When a relay receives the copy, it enters the wait phase, where the relay simply holds this particular message until the destination is encountered directly. Thus, in the Spread and Wait routing protocol, the message is delivered from the source to destination nodes with at most 2 hops.

Moreover, MaxProp [16] 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) [17] is a probabilistic routing protocol by using history of node encounters and transitivity to enhance performance over previously existing protocols.

RAPID [18], which is an acronym for Resource Allocation Protocol for Intentional DTN routing, is flooding-based like MaxProp, and attempts to replicate all packets if network resources allow. RAPID introduces the effective algorithm by intentionally minimizing one of three metrics: average delay, missed deadlines, and maximum delay.

However, the recent developments of mobile nodes provide enough data storages or throughput unlike the previous environments. In fact, our previous papers [19], [20] evaluated the performance such as delivery probability and average latency between the source and destination nodes using the Epidemic routing. The performance results varied depending on the wireless network conditions. As results, the performance should be improved by selecting better DTN routing protocol and network conditions.

4. Proposed Method

In order to improve the performance of delivery rate and latency between the source and destination, one of possible way is to improve the connectivity between the neighbor mobile nodes. Generally as the reachable communication distance of the wave signal of the mobile node increases, the connectivity between the mobile nodes increases and the number of hops from the source to the destination nodes decreases, eventually the performance of delivery rate and latency can be improved. In usual ad hoc network, a single network interface such as Wi-Fi is used as a communication network. In this case, the reachable communication distance of wave signal is fixed depending on the Wi-Fi signal specification.

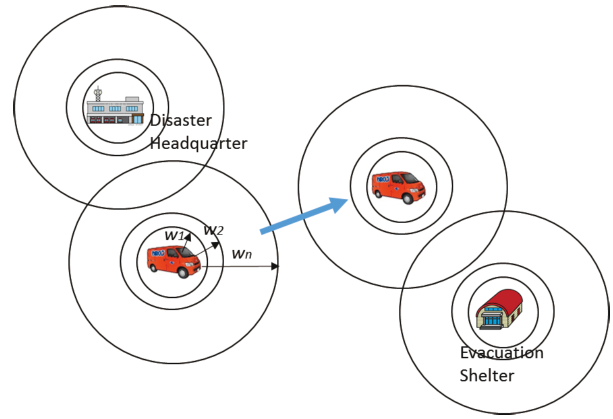

Fig. 2 Cognitive network based DTN.

Whereas, in our research, cognitive wireless network (CWN) technique is introduced as shown in Fig. 2. In CWN, multiple different wireless networks, $(w_1, w_2, \ldots, w_n)$ in Fig. 2 with different wave lengths or different central frequencies are introduced as communication means. For example, in our research, IEEE 802.11a (5.6 GHz), IEEE802.11b (2.4 GHz), IEEE802.11ah (920 MHz) are used at outdoor environment. Those networks have tradeoff in reachable communication distance and effective data transmission rate. That is, the wireless network signal with longer wave length can reach to the longer communication distance because of its wave wraparound characteristics whereas the effective transmission data rate of the wireless network signal with longer wave length is less than that of shorter wave length if the sending transmission power are both equal.

By integrating those different wireless networks into a CWN and automatically selecting the best wireless network among them based on the RSSI, throughput, latency and packet loss rate using Software Defined Network technology (SDN), a desired message transmission can be realized.

In fact, in our previous research [21], [22], we developed and implemented a resilient disaster network which is based on the CWN combined with multiple different 3G networks, Wi-MAX network and satellite IP network to maintain the network connectivity as much as possible before disaster even though the communication network means were seriously damaged and unstable after large scale disaster like the Great East Japan Earthquake. As result, the network connectivity by the CWN could be maintained even when the all of the public mobile networks on the ground were seriously damaged.

In our experiments of this paper, one of the wireless interfaces is selected by simply comparing all of the RSSIs among possible wireless interfaces as the CWS. That is, when another possible wireless interfaces appeared at a certain range of data transmission while one wireless interface is being selected, all of the RSSIs are compared and determined which network interface should be selected as a new wireless interface. The following section deals with the experimental simulation of the proposed DTN method with the CWN for comparing with various wireless interfaces.

5. Simulation Result

A computational simulation was held for the effectiveness of DTN routing. For the actual usages of DTN in Disaster Information Network System, the GIS map of Taro in Miyako city, Japan was introduced for the simulations as shown in Fig. 3. Taro in Miyako city was the one of the disaster-stricken areas and seriously damaged in the East Japan Great Earthquake. Now the city is developing the evacuation countermeasure plan against the future great tsunami. The results of this research are supposed to be reflected to this plan. The six evacuation shelters, which are designated by the city are located in the GIS map, and mobile nodes assumed as wireless cars were also set in it.

Table 2 also shows the details of simulation condition and parameters. A single wireless interface (IEEE802.11a 5 GHz, EEE802.11b 2.4 GHz, IEEE802.11ah) was initially experimented by the different numbers of mobile nodes. In order to avoid influence of power and to have fair simulation in terms of MAC layer functions and wireless characteristics. Those powers were equally set to 10 mv. Then, the proposed DTN with the CWN which is integrated by those three wireless interfaces is experimented by selecting a proper interface among these three types of wireless interfaces. Also, the simulation was held by the Epidemic routing and the Spray and Wait routing as typical DTN routing protocols. Message data is assumed as text contents such as life safety information or damage information after a large scale disaster, and 0.5–1.0 MB data were created at the Disaster-response Headquarter of Taro Town Hall in every 50–60 seconds and carried to the Green Peer Taro that is the largest evacuation shelter in the city. Then, the message delivery rate and the latency were calculated in each case.

For the simulation, the ONE (The Opportunistic Network Environment Simulator) [23], [24] was used. Also, for the simulation scenarios, some module modifications such as the experimental wireless interfaces, the GIS map, and the DTN routing were carried out.

The results of the Epidemic routing are shown in Fig. 4 and Fig. 5. Figure 4 is the result of message delivery for each wireless interface and CWN. The graph of IEEE802.11b demonstrates the sharp rise by 50 mobile nodes, and then the delivery probability is kept almost constant at around 80%. Also, IEEE802.11ah demonstrates the sharp rise by 50 mobile nodes, and then the probability is kept constant at around 60%. This is because IEEE802.11ah has only 128 kbps throughput and is not enough to carry the whole data by the Epidemic routing.

On the contrary, IEEE802.11a shows the poor results. This is because mobile nodes did not have enough time to duplicate the message data. Since mobile nodes ran fast from

Table 2 Simulation conditions and parameters.

Iterms	Desprition
Fixed wireless station	At headquarter and 6 evacuation shelters IEEE802.11a 5.6GHz 10mW IEEE802.11b 2.4GHz 10mW IEEE802.11ah 920MHz 10mW
Mobile node	Wireless vehicles IEEE802.11a 5.6GHz 10mW IEEE802.11b 2.4GGHz 10mW IEEE802.11ah 920MHz 10mW (1) 25 cars (2) 50 cars (3) 75 cars (4) 100 cars Shortest Path Model Speed 10 – 50 km/h
DTN protocol	(1) Epidemic routing (2) Spray and Wait (max. hop is 6)
Wireless conditions	IEEE802.11a (54Mbps, max.50m) IEEE802.11b (11Mbps, max100m) IEEE802.11ah(128kbps, max1,000m) Cognitive Wireless Network (all of three) Non-directional Antenna RTT (43,200sec)
Trasmitted data	Data are carried from Headquarter to Evaluation shelter (Green Peer) 0.5˜1.0 MB data are created in every 50˜60sec
Network conditions	5 sec. duration is needed before data sending for PWD identification and DHCP.
Node storage	2GB
Simulation Period	One day (43,200 sec.)

Fig. 3 GIS map of subjective simulation area.

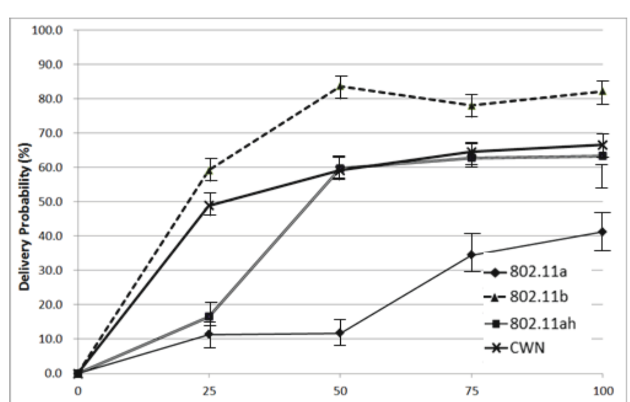

Fig. 4 Simulation result of delivery probability by epidemic routing.

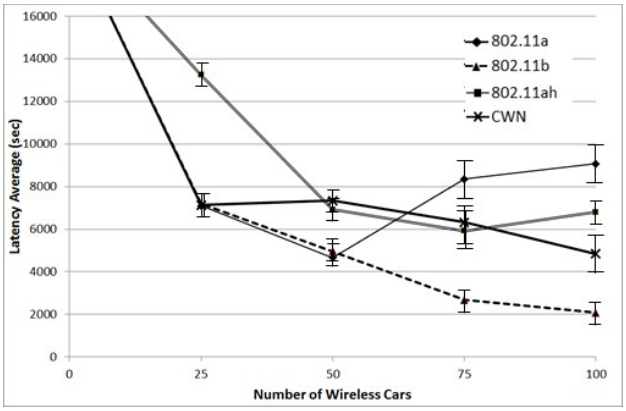

Fig. 5 Simulation result of delivery Latency by epidemic routing.

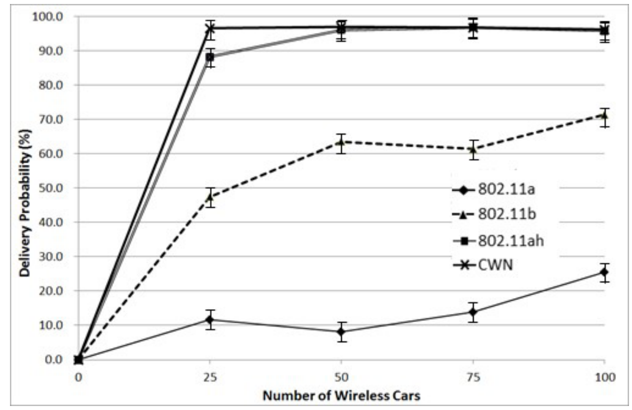

Fig. 6 Simulation result of delivery probability by spray and wait.

10 km/h to 50 km/h randomly and transmission range was extremely short as 50 m, transmittable mobile nodes have already passed by after 5 seconds duration of PWD identification and DHCP preparation even though transmittable nodes came closer.

However, the proposed CWN method did not work efficiently for Epidemic 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 less than the single IEEE802.11b. First of all, because of the better data transmission, more messages are possible to duplicate and these many messages disturb to copy for the destination node. In fact, the result 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 minimalized after the reach of the message. Secondly, the time duration of changing wireless interfaces affected the delivery probability. Since it took five seconds to change the wireless interfaces, the messages were not carried efficiently.

Figure 5 indicates the result of delivery latency for each wireless interface. IEEE802.11b rapidly decreases the latency by 75 mobile nodes, and then the latency is kept constant at around 2,000 seconds. However, as the same result as Fig. 4, the proposed CWN and IEEE802.11ah did not work well for the same reason.

Then, the results of the Spray and Wait Routing are shown in Figs. 6 and 7. Figure 6 indicates the proposed CWN demonstrates sharp rise by 25 mobile nodes, and then the delivery probability is kept constant at around 95%. This is better result than the Epidemic routing because the upper limit of copies makes the network resources efficiently.

Figure 7 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, the proposed methods under the Spray and Wait Routing work effectively, and about 25 wireless cars are expected to require disaster information delivery in challenged network environment at the occurrence of large scale of disaster in the town of Taro.

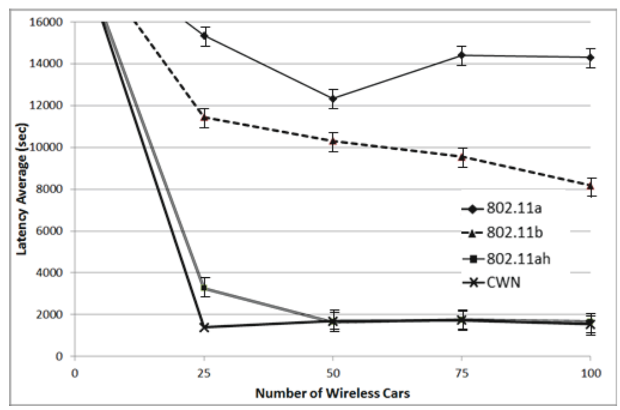

Fig. 7 Simulation result of delivery latency by spray and wait.

6. Conclusions and Future Study

In order to provide disaster-struck areas with temporary information infrastructure just after a larger-scale disaster, we introduced DTN for message delivery by Transport Vehicle Wireless node (TVW): cars moving between Disaster-response Headquarter and evacuation shelters are used to establish message passing. Cognitive Wireless Network (CWN) is introduced to improve the network performance by two different DTN routing methods, Epidemic and Spray and Wait routings. Through the computational simulation for the actual rural area city using GIS map, the effectiveness of the proposed method could be verified.

Now we are developing the DTN protocol to reduce the redundant message copies and the time of changing network interfaces in the CWN. We also implementing an experimental prototype of disaster information delivery system to apply for the actual area, in Taro of Miyako city and to evaluate actual performance of delivery rate and the latency with fewer mobile nodes.

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