A temporary communication system using DTN for improving power consumption of mobile terminals

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Abstract—The power supply interruption and the destruction of communications infrastructure in the event of wide area disasters make it difficult to communicate urgent information such as disaster situation and safety information. DTN (Delay Tolerant Network), which is an infrastructure-less communication technique, is one of the solution methods. However DTN has a problem of power consumption in order to realize information communication in a wide area disaster. The evacuees are assumed to communicate with others by their own mobile terminals in the disaster-stricken areas. Since these terminals have limited electric power, it is preferable to use a communication method considering power usage efficiency. In this paper, we propose a disaster-time communication system using a message ferry method for exchanging and collecting disaster situation and safety information. Also, in order to improve the power usage efficiency of the network on the proposed system, we propose and evaluate a method to efficiently utilize electric power for communication by setting multistage threshold for power remaining.

Index Terms—DTN, Message ferrying, Disaster communication system, Communication Protocol, Energy consumption

I. INTRODUCTION

In recent years, an environment for easily connecting to the Internet even outdoors has been established with the widespread of mobile terminals such as smartphones and tablet terminals, the increase in base stations, and the spread of public wireless LANs. However, if a wide-area disaster occurs and these infrastructures become unusable due to power failure or physical damage, information communication by mobile terminals becomes impossible.

In the Great East Japan Earthquake of 2011, there were several areas where information communication was temporarily impossible due to long-term power outages and disconnection of the communication cables [1]. Collecting information on shelters in disaster-stricken areas, organizing the information, and providing the organized information to the shelters again are effective for the purpose of sharing information among evacuation shelters scattered in disaster-stricken areas. Google Japan’s effort “Shelter directory list sharing service [2]” is an example utilized by the Great East Japan Earthquake. In this service, user takes pictures of the list of evacuees created at the evacuation shelters, and sends a mail to the service staff of Google to aggregate the name of the evacuees and the evacuation shelters. This aggregated data can be checked on the Web. However, the use of communication is indispensable for this service. In this way, since information communication is difficult when the communication infrastructure becomes unusable, infrastructure-less information communication is required especially in the event of a disaster. There is a Delay Tolerant Network (DTN) as an information communication method that can withstand the poor environment such as communication disconnection between terminals due to delay and movement [3]. DTN enables information communication even under environments with large delays and large network fluctuations by store-carry forwarding technology that stores and transfers duplicate data in the buffer of the terminal that relays data. And DTN improves the message arrival rate to the destination by duplicating the message to multiple peripheral terminals without establishing an end-to-end communication path. However, when DTN is used in a disaster area in which power supply has been discontinued, it is conceivable that batteries of communication terminals of evacuees such as smartphones, tablet devices, laptop computers are consumed by message transmission and reception. Therefore, there is a problem of power consumption when conducting DTN type communication in disaster areas.

In this paper, we examine a communication system at a disaster to use a message ferrying method for the purpose of exchange and the collection of the disaster situation and the safety information. And we propose and evaluate a method to efficiently utilize electric power for communication by setting multistage threshold for remaining capacity of power.

II. RELATED WORK

A. Probabilistic Routing of DTN

In this section, we describe epidemic routing [8], two-hop forwarding [9], and spray and wait method [10] among probabilistic routing methods used for DTN.

1) Epidemic Routing: Epidemic routing is a representative probabilistic relay transfer method of DTN which transfers a message to contacted terminals capable of message transfer.
Since this method operates similarly in the data relay terminal, duplicate messages are generated as if it is contagious. This method shows very excellent performance in terms of the message arrival rate and delay time of the message, because this method creates large amounts of replication of data in the network. On the other hand, the method consumes a large amount of network resources such as buffer and battery of each terminal, because it increases the number of times of transmission and reception. In general, there is a trade-off relationship between network performance such as the message arrival rate and transfer delay and consumption of network resources.

2) Two-Hop Forwarding: Two-hop forwarding is a typical transfer method for suppressing the consumption of network resources which is the problem of Epidemic Routing. The transmitting terminal contacts a terminal that does not have a duplicate message and forwards the message when it is possible to transfer. A terminal holding a duplicate message can transfer only when it comes in contact with the destination terminal. From this, we can see that the message reaches the destination with a path of at most 2 hops. Since generation of duplicate messages is suppressed, consumption of network resources can be suppressed more than epidemic routing.

3) Spray and Wait Method: In spray and wait method, buffer consumption of each terminal is reduced by setting an upper limit on the number of replicated messages per message generated in the network and suppressing excessive generation of duplicate messages.

B. Message Ferrying Method

The message ferrying method [4] is a transfer method that performs effective data transfer by using terminals that moves systematically as ferry nodes. The ferry nodes circulate in the network and are responsible for forwarding the message received from theusual mobile terminals to the destination terminal. This message ferrying method can be effectively used in situations such as information sharing for rescue activities in the event of a disaster, sensing in a wide area. In the event of a disaster, it is possible for the aerial platforms and helicopters with large capacity buffers and batteries to serve as ferry nodes and to collect and transport messages between distant areas. In addition, it is possible to utilize the message obtained from the terminal possessed by the affected person for rescue activities.

B. Address Resolution

Since the location of the destination on the network is not clear, an address resolution mechanism is required when using DTN. In this system, address resolution using a server in the on-line area is assumed. First, the source mobile terminal in the off-line area specifies the telephone number or mail address of the destination terminal and transmits the message. At this time, location information of the source terminal is recorded in the message. The transmitted message is eventually collected by the ferry node and sent to the server when it enters to the on-line area. The server is checked whether or not a message from the destination terminal is registered in the database, and if there is the message, register that the source location of the message as the destination location (Fig.1). The ferry node carries the address resolved message in this way, and forwards the message to the mobile terminal close to the destination location. If the destination terminal of the message whose address is not resolved is within the communication range of the ferry node, message transmission is carried out. By recording a message on the server, it is also possible to refer from the on-line area as necessary, such as confirming the safety of the victim and information on the missing items at the evacuation shelter.

C. Moving Route of the Ferry Node

In the disaster communication system using the message ferrying method, the frequency of visits to the evacuation shelter, and the staying time of the shelter have a large effect on the performance of the system. However, it is very difficult to dynamically find out and optimize the moving route of evacuation shelters. In this environment, we assume that messages are exchanged between evacuation shelters using the message ferry method. Ferry nodes circulate between shelters in the off-line area and collects information in each cluster and carries it to the on-line area. When the ferry node enters the on-line area, it forwards the message to the server aggregating the message. Then, the message addressed by the server is carried to the evacuation shelter where the destination node of the off-line area exists.

III. PROPOSED METHOD

The objective of this research is to improve the power usage efficiency of mobile terminals in evacuation shelters in disaster time communication system using DTN. With this system, it is possible to improve the message arrival rate in disaster areas while suppressing battery consumption of mobile terminals. The power consumption in this system is assumed to be mainly due to sending and receiving of messages and sending of search beacons.

A. Operating Environment

In the situation where wide-area disasters occur and communication infrastructure does not function and power supply has stopped, the victims are assumed to evacuate to each evacuation shelters. In this environment, we assume that messages are exchanged between evacuation shelters using the message ferry method. Ferry nodes circulate between shelters in the off-line area and collects information in each cluster and carries it to the on-line area. When the ferry node enters the on-line area, it forwards the message to the server aggregating the message. Then, the message addressed by the server is carried to the evacuation shelter where the destination node of the off-line area exists.
the ferry nodes from factors such as the number and type of ferry nodes, the number of shelters, the number of people in the shelter, and the existence or absence of communication between ferry nodes. Therefore, in this paper, we use a simple route of the ferry nodes. A simple moving route is a route that traverses the off-line area so that each ferry node passes over at least one evacuation shelter. Also, we prepare as many ferry nodes as shelters. The ferry nodes shall pass through the off-line area at a constant speed and shall not stay at the evacuation shelter.

D. Determination of Relay Terminals using Battery Threshold

We propose a method to relay messages of mobile terminals with low battery level to terminal with more battery remaining. By concentrating the message on the terminal with the high battery level and preventing the terminal with the low battery level from receiving the message from the other terminal, battery of the terminal with low battery level is kept, and message arrival rate to the destination is improved. MultistageStdDev is our proposed communication method that exploits the battery remaining amount of the mobile terminal to send out searching beacons and to determine whether communication is possible or not. This method compares the remaining battery amount of its own with that of surrounding terminals and transmits the message only to terminals with battery remaining than itself. A multistage threshold is set for the remaining battery amount, and when the remaining amount drops to a certain threshold, transmission of searching beacons is stopped and the threshold is changed to a value lower by one level. It responds only when receiving a beacon from the surrounding terminals, thereby saving power. When the threshold value is changed, the message transfer probability is also changed to reduce the number of transfers, thereby reducing the power consumption of the mobile terminal with low battery level. The initial threshold is set to 1/2 of the battery amount of each mobile terminal. The transfer probability $P_{\text{new}}$ is defined as in Eq.1 where $P$ is the initial value of the transfer probability and $\alpha$ is the threshold change count.

$$P_{\text{new}} = P/(\alpha + 1) \quad (1)$$

IV. PERFORMANCE EVALUATION

A. Experimental Environment

We implemented and evaluated the proposed system on The Opportunistic Network Environment simulator (The ONE) [11] which is a network simulator specialized for DTN. The simulation assuming communication by Wi-Fi is performed. However, since the power consumption of mobile terminals in real environments depends on many factors other than communication, absolute evaluation only by simulation is difficult. Therefore, we mainly compare with the existing routing algorithm.

B. Evaluation Index and Experiment Parameter

The message arrival rate to the destination, the arrival delay of destination, and the average remaining battery power are used as evaluation index. The following scenario is assumed for the experiment. In the situation that wide-area disasters occurred and communication infrastructure is unusable, victims were gathered at multiple evacuation shelters. The victims try to contact a person who seems to be evacuating to other shelters with information such as safety information and the place where they are evacuated. The ferry node is responsible for collecting these messages from shelters and transporting them to the on-line area and other evacuation shelters. It is assumed that the buffer and battery amount of the ferry node are sufficient, and it takes little time to synchronize the message with the server.

In this experiment, we set 5 shelters and 5 ferry nodes. The simulation map is based on the vicinity of Goryokaku in Hakodate City, Hokkaido, and the location of the shelter is set based on the evacuation shelters map [12] that Hakodate City has released. Fig.2 shows the map, shelter location, off-line area, and routes of ferry nodes. The off-line area is a rectangle with 3800 m east to west and 3100 m north to south, and the moving speed of the ferry node is set to 20 km/h. The simulation time is 7200 seconds. In the experiment, the parameters are set by classifying the cluster of shelter into three types, large, medium and small as shown in TABLE I. The cluster size is set assuming that the victims will walk around the evacuation shelter. The shelter’s capacity is set to several dozen of people. An experimental scenario was used in which a total of 200 victims send and receive messages via a message ferry, assuming that there are 2 large size clusters, 2 middle size clusters, and 1 small size cluster.

<table>
<thead>
<tr>
<th>Cluster size</th>
<th>Cluster radius</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large</td>
<td>300</td>
<td>60</td>
</tr>
<tr>
<td>Medium</td>
<td>200</td>
<td>30</td>
</tr>
<tr>
<td>Small</td>
<td>150</td>
<td>20</td>
</tr>
</tbody>
</table>

TABLE II shows the parameter settings of mobile terminals in the cluster. The communication interface assumes Wi-Fi Direct for both the mobile terminals and the ferry nodes. For messages, we assume texts such as safety information and disaster information and small images. The message

Fig. 2. Arrangement of shelter and route of ferry node.
TABLE II
PARAMETERS OF MOBILE TERMINALS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moving speed of a terminal (m/sec)</td>
<td>0.5 - 1.0</td>
</tr>
<tr>
<td>Stopping time of a terminal (sec)</td>
<td>0 - 120</td>
</tr>
<tr>
<td>Transmission speed (Mbps)</td>
<td>250</td>
</tr>
<tr>
<td>Communication range (m)</td>
<td>100</td>
</tr>
</tbody>
</table>

generation frequency is assumed to be such that one message is generated between 3 seconds and 5 seconds in one of the terminals whose battery remaining capacity is not 0. The destination terminal is either a mobile terminal within the same emergency shelter or a mobile terminal of another emergency shelter. We measure the arrival rate and the delay time to the destination for the message generated up to 3600 seconds out of the simulation time of 7200 seconds. Since the generation frequency is 1 message from 3 seconds to 5 seconds, about 900 messages are generated in total. TABLE III shows the parameters related to messages. In this experiment, it is assumed that the buffer capacity of each mobile terminal is unlimited, and messages are removed only by TTL.

TABLE III
PARAMETERS ABOUT MESSAGE

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation frequency (sec/message)</td>
<td>3 - 5</td>
</tr>
<tr>
<td>Message size (KB)</td>
<td>50 - 150</td>
</tr>
<tr>
<td>TTL (sec)</td>
<td>3600</td>
</tr>
<tr>
<td>Last generation time (sec)</td>
<td>3600</td>
</tr>
</tbody>
</table>

In the experimental environment, power is consumed only by sending searching beacons and sending and receiving messages. In this experiment, relative evaluation with the existing routing protocols is done. For each power consumption, it is set with reference to the power profile value of smartphone AQUOS PHONE sv SH-10D developed by SHARP Corp. The initial value of the battery remaining amount of each terminal is randomly set between 4200 and 6000, and the frequency of searching beacon is set to transmit for 15 seconds every 15 seconds (TABLE IV).

TABLE IV
PARAMETERS ABOUT POWER CONSUMPTION

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial value of the power remaining amount</td>
<td>4200 - 6000</td>
</tr>
<tr>
<td>Power consumption of searching terminals (per 15sec)</td>
<td>22</td>
</tr>
<tr>
<td>Power consumption of sending / receiving (per 1 message)</td>
<td>12</td>
</tr>
<tr>
<td>Searching interval (sec)</td>
<td>15</td>
</tr>
<tr>
<td>Searching duration (sec)</td>
<td>15</td>
</tr>
</tbody>
</table>

The subjects of comparative evaluation are epidemic routing and two-hop forwarding. Two-hop forwarding is applied only to the communication method inside the emergency shelter, and when the ferry node collects the message, it is set to reset the number of possible copies. The ferry node forwards the message to the relay terminal of the emergency shelter where the destination terminal exists, and the received relay terminal transmits the message to the destination terminal based on two-hop forwarding. Therefore, in communication between evacuation centers, the maximum number of hops of the message is 3.

C. Experimental Result

Fig.3 shows the transition of the change in the average remaining battery amount with the simulation elapsed time. The average remaining battery amount is the average value of the remaining battery power of 200 mobile terminals totaling 5 evacuation shelters. It can be seen that MultistageStdDev has lower power consumption than epidemic routing.

Also, referring to the graph of 30 minutes after 90 minutes of the simulation time of 2 hours, MultistageStdDev is slightly larger than two-hop forwarding at the end of simulation (Fig.4).

The results of the arrival rate to the destination, the average delay time to the destination, and the average hop count are as shown in TABLE V. MultistageStdDev holds the same arrival rate as epidemic routing. As for transfer delay, epidemic routing is the least, and two-hop forwarding is the largest. The smaller the average hop count is, the greater the suppression of message duplication, and the greater the transfer delay. Two-hop forwarding makes it difficult to transfer to the destination.
when the source and the destination of the message are in different emergency shelters. Although the average hop count is larger than two-hop forwarding, the reason why the MultistageStdDev’s battery consumption was equivalent to two-hop forwarding is that the transmission of the searching beacons and that the control of the transfer probability using the battery remaining threshold value. It is effective to reduce battery consumption by changing the transmission probability of the searching beacons with the remaining battery power. As for the power consumption for each cluster size, the greater the number of mobile terminals, the greater the difference between epidemic routing and other methods (Fig.5, Fig.6) With the parameters in this paper, the population density decreases as the cluster size increases, but the population itself increases and the number of generated messages increases. Therefore, in epidemic routing, it is considered that the number of message transfers increases and the power consumption increases. The results are summarized in TABLE VI.

In the MultistageStdDev, since the arrival rate to the destination is as high as epidemic routing and the power consumption is somewhat better than the two-hop forwarding, it can be said that the improvement of the power utilization efficiency has been achieved.

V. CONCLUSION

In this paper, we propose a disaster time communication system using the message ferry method called MultistageStdDev. As a experimental result, it was shown that MultistageStdDev is the most efficient power operation compared with epidemic routing and two-hop forwarding which are representative communication methods of DTN.

The future task is to consider reduction of destination arrival delay which is the relationship between network resource consumption and trade-off. For this reason, examination of a moving route determination algorithm of a ferry node is an issue.

REFERENCES