Information Dissemination Using MANET for Disaster Evacuation Support

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SUMMARY To minimize the damage caused by landslides resulting from torrential rain, residents must quickly evacuate to a place of refuge. To make the decision to evacuate, residents must be able to collect and share disaster information. Firstly, this paper introduces the Grass-roots Information Distribution System and a fixed type monitoring system which our research group has been developing. The fixed type monitoring system is deployed at the location of apparent danger, whereas the Grass-roots Information Distribution System distributes disaster information acquired from the fixed type monitoring system through a mobile ad hoc network (MANET) to residents. The MANET is configured using mobile terminals of residents. Next, in this paper, an information dissemination scheme utilizing a MANET and cellular networks to communicate among mobile terminals is proposed and simulated in the area where our research group has been deploying the distribution system. The MANET topology and information distribution obtained from the simulation results for further field experiments are then discussed.

key words: mobile ad hoc networks, sensing techniques, information dissemination, disaster evacuation support

1. Introduction

Recently, changing weather patterns and an increase in torrential rain have led to an increase in landslides, including a landslide in Hiroshima city on August 20, 2014, which caused severe damage [1]. To minimize the damage caused by landslides, the most important things is that local residents must quickly evacuate before life-threatening situations occur. To make the decision to evacuate, residents must be able to collect and share disaster information. Monitoring landslide disasters in real time to collect and share disaster information have been in great demand [2], [3]. Our research group has been developing the Grass-roots Information Distribution System to share disaster information among residents in the local area [7]. In the Grass-root Information Distribution System, a fixed type monitoring system [6], [8], [9] is deployed at the spot where danger is apparent. The monitoring system takes camera images of the spot. The local residents can acquire the camera images by their mobile terminals through cellular connections, and then they are autonomously distributed through mobile ad hoc networks (MANETs) among local residents to their mobile terminals. The network systems based on wireless ad hoc network technology such as MANETs have been discussed and developed to exchange disaster information so far [4], [5]. These images can also be used to disseminate information at the places of refuge after landslides occur. The ad hoc short range connection between mobile terminals to configure MANETs uses Bluetooth technology. Currently, our research group has been developing the distribution system based on the Bluetooth technology of mobile phones. However, mobile phones are not readily available to some elderly persons. Thus, adopting other small devices and utilizing wireless technologies such as Wireless LAN and LPWA are also being considered.

In the distribution system, in addition to the disaster information provided by the fixed type monitoring system, another disaster information can also be shared by exchanging text messages and camera images among local residents. Since the use of a cellular connection generates a cost, the distribution system utilizes the MANET when a large amount of disaster information must be shared among local residents. However, the MANET has any connectivity problems and cannot distribute disaster information to many terminals because a mobile terminal does not always connect with many other terminals directly or in a multi-hop fashion. In the distribution system, disaster information should be distributed to many mobile terminals by avoiding using a cellular connection to lower a cost if at all possible. Therefore, this paper proposes an information dissemination scheme based on a two-layered wireless network to improve the MANET connectivity and lower the cost and then examines the effect of the proposed scheme through simulation experiments.

Our research group expects that the local residents can decide to evacuate before receiving the evacuation instruction from local government by the Grass-roots Information Distribution System because they can recognize the details of the disaster by the camera images of the spot where danger is apparent. In addition, they can learn the situations of the disaster which are changing with time even while moving to the place of refuge.

The rest of the paper is organized as follows. Section 2 presents the Grass-root Information Distribution System and the fixed type monitoring system which our research group has been developing. In Sect. 3, the information dissemination scheme used for the Grass-root Information Distribution System based on the two-layered wireless network is discussed in more detail. Simulation experiments in the
area where our research group has been deploying the distribution system are performed and the MANET topology and information distribution results are presented in Sect. 4. Finally, we conclude this paper with future works in Sect. 5.

2. Grass-Root Information Distribution System

2.1 Outline

An overview of the Grass-root Information Distribution System is shown in Fig. 1. This system consists of a fixed type monitoring system and mobile terminals (smart phones) owned by local residents. In order to reduce damages from natural disasters, the distribution system aims to capture disaster information for the residents in the local area, deliver it to the local MANET, and share it among the residents in the local area. In the distribution system, the MANET consists of mobile terminals such as smart phones owned by the residents. The residents can take disaster-related camera images with their smart phone camera, and then they will be autonomously distributed through the MANET and shared among the residents with grass-root approach. So the residents can easily recognize the details of the disaster. In addition, the fixed type monitoring system is operated in the dangerous place. Since the monitoring system is connected to the cellular network as well as the MANET, the residents can remotely monitor the dangerous place from a safe location without coming close to the dangerous place. The disaster information can be distributed to all over the area where the MANET terminals can connect to each other.

In the distributed system, the MANET is currently configured by Bluetooth technology, a short range radio standard that has durability against radio interferences. Bluetooth has some schemes such as Classic (Classic Bluetooth) and BLE (Bluetooth Low Energy). The Classic scheme aims to transfer data at high speed, while the BLE scheme can quickly establish a connection and has a lower power consumption. By use of both the Classic and BLE schemes, Kajikawa, Minami, et al. in our research group have proposed and developed a hybrid Bluetooth MANET capable of achieving high-speed data transfer [10], [11] and quick connection [12]. The Grass-roots Information Distribution System can be used in a variety of ways. If the local leaders of the residents acquire the camera images predicting disaster from the fixed type monitoring system, the leaders can then distribute the images over the MANET to alert local residents. Otherwise, residents can distribute any camera images obtained by either the fixed type monitoring system or their mobile terminals.

Our research group is also developing that a TV set used as a MANET terminal is for elderly residents, or others who cannot easily use a smart phone. The single-board computer, Raspberry Pi [13], is selected as a specialized terminal in the MANET that is able to connect to the TV set with an HDMI cable. Upon receiving disaster information, the specialized terminal powers on the TV and displays the information. This allows the distribution of information to elderly residents without needing any input from them. Using a specialized terminal in the MANET also provides better connectivity because the MANETs are configured and connected to each other by the TV sets and mobile terminals.

2.2 Fixed Type Monitoring System

The configuration of the fixed type monitoring system [8], [9] constructed in the distributed system is shown in Fig. 2. This system has solar panels and a battery for power supply to operate in locations where a commercial power supply cannot be provided and contains an infrared camera for 24 hour data collection. A Raspberry Pi is used for the control unit and a 3G wireless module is used to connect to the Internet. This system can upload camera images to the web server which is installed at our university. The residents can remotely monitor disaster locations by browsing the web pages, where real-time images and the battery level is displayed. The camera images can be also transferred to a MANET through the Internet.

Three fixed type monitoring systems around Hiroshima city (in Kouchi, Yagigaoka, and Toge) have been in operation since May 2015 by Nishi, et al. [9]. Landslides occurred in Kouchi in 1999 and in Yagigaoka and Toge in 2014. The first monitoring system was built at a location chosen by the local residents to monitor heavy rain days. Following demands from the residents, three more monitoring systems were added in Midorii, Nabaragawa, and Yamakuragawa.
in 2016; two more locations, Togegwa and Nenotanigawa, were then added in 2017.

The locations of the eight installed fixed type monitoring systems are provided on the web page and are shown in Fig. 3. Each location presents a danger of landslides and flooding. Residents can access each area’s images by placing their cursor on the circle indicating each area being monitored. The upper image shown in Fig. 3 was obtained at Kouchi, where a soil-saving dam was constructed after a landslide. Monitoring the images of the eight locations allows residents to monitor disaster danger.

An example presenting the image delivery system on the web page of Yagigaoka is shown in Fig. 4. In the Yagigaoka area, a metal net was constructed after the landslide disaster. And we started to monitor the accumulation of soil and sand using infrared camera. Real-time images are uploaded every five seconds and time series are shown for an hour with 10-minute intervals. The remaining battery is also shown to visualize the operational state of the monitoring system, as depicted in Fig. 4.

This monitoring system is a pull-based approach. Residents must access the web page to acquire the disaster information. However, in the distribution system, it is required for the disaster information to distribute from the monitoring system to residents through the MANET and cellular networks based on a push-based approach.

3. Information Dissemination Scheme

3.1 Outline

We propose an information dissemination scheme in the two-layered wireless network [15], [16] based on autonomous clustering [17]. The two-layered network consists of a MANET layer configured by short range ad hoc connections (e.g., wireless LAN/Bluetooth) of mobile terminals (shortly, nodes) and a P2P layer configured by cellular connections (e.g., 4G/LTE) of nodes as shown in Fig. 5. All nodes are assumed to have both cellular and short range ad hoc connections, and there is at least one P2P server to configure the two-layered wireless network. For the information dissemination from a source node to the other nodes, the source node can send a data message to neighboring nodes using short range ad hoc connections as well as to the other nodes using cellular connections. Although all nodes can connect to the P2P server as a super peer, a cluster head selected by autonomous clustering in the MANET layer becomes a super peer in the P2P layer and then configures the P2P network in the P2P layer.

In addition, in the proposed scheme, the source node sends data messages to the P2P server when it disseminates the data messages by using cellular connection in the P2P layer. Then, the P2P server does not disseminate the data messages to all super peers in the P2P network, but to some super peers selected by the P2P server. The nodes that receive data messages through either short range ad hoc or cellular connections disseminate them to neighboring nodes through short range ad hoc connections in the MANET layer. Finally, if a data message is not disseminated to a node by the preceding procedure, the data message is disseminated by Epidemic routing for the node.

3.2 Construction of Two-Layered Wireless Network

The network consists of the MANET layer and the P2P layer, as shown in Fig. 5. The MANET layer is configured by the autonomous clustering. The cluster heads in each
Autonomous clustering is used to divide the network into clusters and hierarchically manage nodes. Each cluster consists of one cluster head, one or more gateways and cluster members. The cluster head manages nodes in each cluster, and the node ID of the cluster head is assigned as the cluster ID. A gateway is neighbor to the nodes in the neighboring clusters. The packets are forwarded between clusters through gateways. The number of nodes in each cluster (cluster size) can be adjusted between the pre-defined upper bound \((U)\) and lower bound \((L)\). Initially, a node becomes a cluster head with some probability.

### 3.2.2 Cluster Configuration and Maintenance

The cluster head periodically broadcasts a control packet called MEP (MEMember Packet) within the cluster. Upon receiving the MEP, cluster members send MAP (Member Acknowledgment Packet) back to the cluster head. The cluster head can collect the information on cluster members and construct the cluster head-based tree in the cluster by these procedures. By the cluster head-based tree, all nodes in the cluster including a cluster head and cluster members can communicate with each other.

Each MEP includes the cluster ID and the node ID of the upstream node. The downstream nodes store the information received in the MEP and rebroadcast it. Thus, each node receives MEPs from its neighboring node, including the parent node and nodes of different clusters. Based on the received MEPs from the neighboring nodes, each node autonomously decides whether or not to change its state and cluster ID. For example, if the cluster ID included in one of the received MEPs is different from its own cluster ID, the node becomes a gateway.

Each node that received a MEP sends a control packet MAP back to the cluster head as a reply. The MAP includes the cluster ID of the neighboring cluster, the node ID of gateways, and the number of nodes in each neighboring cluster. The cluster head receives the MAPs from all of the cluster members and manages the cluster by recognizing the number of nodes and the state of each node in its cluster and the number of nodes in neighboring clusters.

If a cluster member does not receive a MEP from the cluster head for a certain period, it will become a cluster head with some probability. The cluster is then configured by the cluster configuration and merger procedures.

### 3.2.3 Cluster Division and Merger

As a cluster head must maintain a bounded number of nodes in the cluster between the upper \((U)\) and lower \((L)\), a cluster will merge with a neighboring cluster if the number of nodes is less than \(L\) or divide into two clusters if the number of nodes is greater than \(U\).

### 3.3 Information Dissemination

In the proposed information dissemination scheme, the source node does not send data messages to all the super peers in the P2P layer, but to some super peers that are selected by the P2P server. The proposed scheme consists of three procedures: network configuration, selection of super peers that disseminate messages from the P2P layer to the MANET layer by cellular connections, and information dissemination from source nodes in the P2P and MANET layers. During the network configuration, the clusters are configured by autonomous clustering in the MANET layer. The P2P network is then configured in the P2P layer. This procedure is continuous, allowing the P2P network to change according to the network topology. When the source node sends data messages, the information dissemination procedure from source nodes in the P2P and MANET layers is invoked. The P2P server selects the super peers to which it sends data messages, and then data messages are disseminated in both layers.

1. **Network configuration**
   a. Each node configures the clusters based on the autonomous clustering through short range ad hoc connections in the MANET layer.
   b. A cluster head acting as a super peer configures a P2P network through cellular connections in the P2P layer. 
   c. Each super peer periodically notifies the cluster member list and the neighboring clusters’ cluster head list that are obtained by the autonomous clustering to the P2P server.
   d. The P2P server calculates and manages the number of reachable nodes, which includes the number of nodes in a cluster and the total number of nodes in all neighboring clusters of the cluster, for each super peer. Here, a reachable node is defined as a node which can communicate with a cluster head (a super peer) only by ad hoc short range connections in the MANET layer.

2. **Selection of super peers which disseminate messages from the P2P layer to the MANET layer by cellular connections**
   a. When a source node disseminates data messages through cellular connections, it sends them to the P2P server.
   b. The P2P server selects super peers to which it
sends the data messages through cellular connections.

c. Each super peer in the P2P server makes the list of super peers to disseminate the data messages from the super peer by short range ad hoc connections based on the cluster member list and the neighboring clusters’ cluster head list, and then it calculates the sum of the cluster size of the super peers contained in the list. As a result, the number of nodes reachable only by short range ad hoc connections in each of super peers is calculated. Since the reachable nodes consists of some super peers, the super peer with the largest cluster size is selected from the super peers and then the reachable super peer list is made.

d. Based on the number of reachable nodes of each super peer which is contained in the reachable super peer list, the primary super peers are selected by the number of reachable nodes from the super peer through short range ad hoc connections from all super peers.

e. The primary super peers are managed in ascending order of the number of reachable nodes, the P2P server sends data messages to some primary super peers. Some primary super peers which have more than one reachable node are selected by the P2P server. If the number of reachable nodes is zero or one, the P2P server does not select the super peer because it has no neighboring nodes.

3. Information dissemination from source nodes in the P2P and MANET layers

a. The source node sends data messages to the P2P server in the P2P layer, and the P2P server then sends them to the primary super peers which are selected by the above procedure through cellular connections. The super peers receiving data messages through the P2P layer send them to the neighboring nodes in the MANET layer.

b. The nodes receiving data messages in the MANET layer send them to the neighboring nodes.

c. For any nodes that cannot receive these data messages, other nodes will disseminate the data messages by epidemic routing.

4. Simulation Experiments in Miiri District

We conducted the simulation experiments based on the road map in Miiri district of Hiroshima city to confirm the behavior of the network topology configured by MANET and to examine the resulting information dissemination.

4.1 Simulation Plan

We use map information “OpenStreetMap (OSM) [18]” and traffic simulator “SUMO (Simulation of Urban MObility) [19]” in our simulation to realize residents’ movement from their residences to the specified place of refuge in Miiri district. The data of the road information for Miiri district is extracted from OSM and then imported to SUMO. Figure 6 shows the map information of OSM and the road information of SUMO. Miiri district had a population of 8,352 (3,707 families), as of August, 2017. Thus, 2,000 people are assumed to start moving toward the place of refuge for 30 minutes. SUMO is used to generate the mobility scenario. In the scenario, a node is generated every 0.9 seconds from 0 to 1,800 seconds and appears from any one of 704 spots as a start point, and then it moves along the road from the start point toward the place of refuge (destination). Finally, 2,000 nodes appear in the field. The simulation experiments are conducted by using the mobility scenario through network simulator ns3 [20].

Five fixed type monitoring systems in Nabara, Nenotanigawa, Ymakura, Toge, and Togegawa (as depicted in Figs. 3 and 6) in Miiri district act as source nodes to confirm how data messages are disseminated from the monitoring systems to all nodes. Figure 6 shows the location of the five fixed type monitoring systems. Each monitoring system generates and disseminates a new data every 20 seconds to all nodes. Nodes receiving the data message hold it for 40 seconds, after that, discard it because old data messages are not appropriate for residents. When nodes received a new data message from the same source, the old data is discarded. After arriving at the place of refuge (destination area), it stops forwarding and receiving data messages.

Table 1 shows the simulation environment. IEEE802.11g is used as a MAC protocol and to vary the transmission range. The propagation delay time of up and down links of the cellular connection are set to 100 milliseconds. Each data message transmitted from the source node is 20 KByte, similar to the camera image provided to users from the fixed type monitoring system. Data messages are disseminated from five sources to all nodes by two schemes, which are Epidemic routing and the proposed scheme. Epidemic routing disseminates data messages only by short range ad hoc connections. Note that servers also
disseminate data messages to nodes in the vicinity of each server only by short range ad hoc connections. On the contrary, the proposed scheme disseminates them by cellular and short range ad hoc connections. In epidemic routing and the epidemic routing used in the proposed scheme, the interval of sending Hello to check the connectivity of the neighboring nodes is sent every 5 seconds.

### 4.2 Simulation Evaluation

At first, we show the number of nodes and the situation of node distribution in the mobility scenario of Miiri district. Figure 7 shows the number of nodes in the simulation field versus the simulation time. From 0 to 1,800 seconds, nodes are sequentially generated and randomly placed in the field, and then begin traveling from the start point to the destination. After a lapse of 1,000 seconds, nodes arrive at the destination in sequence. Then, after a lapse of 1,800 seconds, the number of nodes in the field gradually decreases because no more nodes are being generated. As shown in Fig. 7, the maximum number of nodes in the field is approximately 900 in the mobility scenario.

Figures 8 and 9 show the direct distance from the start point to the destination node versus the traveling time, respectively. In Fig. 8, the x axis denotes the node ID, which is sequentially given whenever each node is generated and appears in the field. In the mobility scenario, the distance of each node between the start point to the destination is mostly between 500 and 1500 meters. The traveling time of nodes generated near the destination is approximately 100 seconds. On the contrary, nodes generated far from the destination average a travel time of approximately 1,500 seconds.

Figure 10 shows the total number of data received at each node. ‘ER’ and ‘Proposal’ denote the epidemic routing and the proposed scheme, respectively. In this simula-
tion environment, with a transmission range of 50 and 100 meters, the data reception of ER is significantly low and thus the MANET does not offer a large advantage because each node discards each received data message after 40 seconds. Therefore, under low node density, the number of data receptions is low even in epidemic routing. In addition, some sources are deployed near the end of the district and the destination is located at the center of the district. As time proceeds, most nodes remain near the destination, making it difficult to forward a data message from some sources only by using short range ad hoc connections.

We demonstrate the network topology configured by MAENT in the simulation environment. We show the number of neighboring nodes of each node and the number of nodes encountered by each node during the traveling from the start point to the destination in Figs. 11 and 12, respectively, to confirm the network topology generated by the road information and mobility scenario in Miri district. Each node confirms the neighboring nodes and newly encountered nodes every 5 seconds during the traveling from the start point to the destination. In Fig. 11, the y axis denotes the cumulative number of the number of neighboring nodes counted by each node every 5 seconds. At a transmission range of 50 meters, there are generally less than 10 nodes, while at a transmission range of 150 meters, there are a maximum of approximately 50 nodes. As time goes on, the nodes approach the area around the place of refuge, and thus the node density increases. In addition, the node density in each area frequently changes for disseminating data messages to all nodes using short range ad hoc connections is required to utilize the MANET system more. Figure 12 shows the number of nodes encountered by each node during the traveling from the start point to the destination and each node checks the neighboring nodes every 5 seconds. In this experiment, the maximum number of nodes in the field at any point during the trial is approximately 900 nodes. At a transmission range of 50 meters, most nodes encounter only between 2% and 5% of the nodes. In contrast, nodes encounter approximately 13% of the nodes in the field at a transmission range of 150 meters. The above node density is required to disseminate data messages only using short range ad hoc connections.

Figure 13 shows the ratio of data messages received by each node during the traveling from the start point to the destination. Figure 13 shows the result of Fig. 10 in more detail. If a node receives all messages from its generation in the field until arriving at the destination, the ratio of data messages received is 1.0. As shown in Fig. 9, the traveling time varies with each node. At a transmission range of 50 and 100 meters, the ratio of data messages received in ER is very low. Even in case of Proposal, some nodes have a low ratio of data messages received at a transmission range of 50 meters. There is a possibility that the proposed scheme cannot provide enough information to some users due to its low density and the small number of nodes although it adopts epidemic routing. However, at a transmission range of 150 meters, the ratio of data messages received in ER is approximately 0.5. Overall, the proposed scheme achieves a high
data reception ratio regardless of transmission range because of its use of the cellular connections.

Finally, Fig. 14 shows the number of selected super peers versus simulation time in the proposed scheme. In the proposed scheme approximately 5% of nodes in the field have access to the cellular network and disseminate data messages from the sources to all nodes. We could confirm only the selected super peers have access to the cellular network and disseminate data messages to the other nodes with lower cellular connections.

5. Conclusion

This paper has presented the Grass-root Information Distribution System which our research group has been developing to share disaster information among local residents for disaster evacuation support. In the distribution system, eight fixed type monitoring systems have already been deployed and are now providing camera images to the local residents. The distribution system also includes a disaster information distribution to local residents. So, we have proposed the information dissemination scheme using the MANET to lower the cost and conducted simulation experiments in Miiri district of Hiroshima city where our research group has been deploying the distribution system. In future works, our research group has a plan to conduct field experiments of the Grass-root Information Distribution System in Miiri district.

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References


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