Fast Deployment of Emergency Fog Service for Disaster Response

Jianwen Xu, Kaoru Ota, and Mianxiong Dong

Abstract

When natural disasters such as earthquakes happen, network architectures are highly vulnerable. Once the network connections cannot be guaranteed, even rescue operations are difficult to carry out. In this article, to help the people in affected areas retrieve network services, we come up with a solution based on fog computing to quickly deploy emergent distributed service. In case the original network infrastructures are damaged to varying degrees, we make use of the available equipment including routers and mobile devices as fog nodes to realize emergency networking and communication. In the simulation evaluation, we compare our method with existed one. The results show that our method can reduce time costs on fast deployment and improve work efficiency.

Introduction

September 6, 2018 at 3 a.m. Japan Standard Time, a 6.6 magnitude earthquake happened in southern Hokkaido, Japan. Strong vibrations swept across half of Hokkaido and caused large areas of power outages. Muroran, a coastal city 80 km away from the epicenter, suffered from network interruption more than 24 hours after reserve energy was running out. For a long time, residents had to leave home and move to the nearby base stations which were still working by reserved power.

However, in consideration of the risk from aftershocks as well as people are injured or with reduced mobility, we cannot fully rely on the available infrastructure in sparse distribution. Moreover, without network connections, rescuers also may face huge challenges in informing people who are out of services where to find rescue. As a result, in this case, the restoration of network services is very essential and with high priority in disaster response.

The existing solutions may not satisfy the demands of users without network connections. The first issue is that it is very difficult to access the cloud or other centralized services since the devices in the affected areas cannot connect to the backbone. The second one will be that the latency of Delay-Tolerant Networking (DTN)-based solutions is too high to satisfy the requirement of the disaster response. The third one is that the service coverage of specific disaster response services such as call centers, etc. is very restricted because of the limited service capacity. Facing the three issues in disaster response, we come up with the idea of designing a fast deployment strategy to provide emergency service based on fog computing.

Fog computing refers to the architecture raised by Cisco in 2012 [1]. Today fog computing is attracting more and more attention in many research fields. Compared to the cloud, in fog computing we rely on the resources at the edge of the network structure, and not only can obtain the reduction in latency, but also redundancy in case of failure [2]. Compared to the similar definition of edge computing, in fact, except the definition from different organizations, there are no essential differences between fog computing and edge computing. However, we still treat fog and edge differently in researching. That is, for edge computing, we usually refer to utilizing the end devices themselves to help each other in providing computing services. And for the case of fog, we put emphasis on introducing more available computing resources near the edge, which may include routers and other local area network (LAN) devices, and so on. And here we choose fog computing to express our purpose in restoring the connections and services by placing fog nodes instead of user devices themselves.

In this article, we apply fog computing as the solution in providing network services to users in the post-disaster scenario to save time cost on networking and service deployment. For the first issue, fog computing can be deployed at multiple positions in post-disaster scenarios. Even if some of the devices are out of service due to damage or power outage, users still can seek help from other available ones. For the second issue, fog computing can save the time cost on backhaul transmissions which not only reduce the response latency, but also ensure as much as possible that user requests are fulfilled. And for the third one, fog computing own the flexibility of service coverage as well as resource allocation which can make sure that specific disaster response such as call centers always work as usual.

In this article, we focus on the above situation immediately after the disasters when some of the base stations cannot work. To help users stuck in the disaster area, we need to integrate existing network resources and deploy emergency services to them all in the fastest way.

The contributions of our work are as follows.

- We design the system model of the emergency fog network and service platform.
- We propose a fast strategy for emergency networking and service deployment.

There are six sections in this article. The follow-

Digital Object Identifier: 10.1109/MNET.001.1900671

The authors are with the Muroran Institute of Technology. Mianxiong Dong is coresponding author.

ing section presents the related work on fog computing and fast deployment in disaster response. We then design the system model of our proposed emergency fog computing architecture and formulate the problems to solve. Following that we elaborate on the fast strategy for emergency networking and service deployment. Then we give the experimental settings and carry out the simulation. The final section summarizes and draws conclusions.

Related Work

Disaster management refers to all the measures taken before and after natural disasters. In disaster management, we can find the applications of Information and Communication Technology (ICT) in nearly every part from early warning to rescue work. Compared with carrier pigeon or messenger riding on a horse in ancient times, the appearance of the telegraph, telephone and Internet not only wins valuable rescue time but also makes the rescue itself no longer completely dependent on manpower. Robots or Unmanned Aerial Vehicles (UAVs) enabled by modern ICT can even handle many jobs in dangerous areas [3].

As an emerging technology and research hotspot, fog computing has been considered to have wide application prospects in multiple fields. For disaster management, there exist many works on using fog as solutions in providing distributed services and increasing the redundancy of the network architecture. Su *et al*. focused on content caching in fog to implement a mobile social network for disaster backup. With their system, users can protect their privacy while delivering messages in emergencies [4]. Wang *et al*. studied spatial data processing and made an effort to maximize the efficiency of data resolution in fog computing. They simulated the proposed algorithm with real-world disaster data and proved that their design could optimize processing efficiency [5]. Tang *et al*. applied fog computing as a component in building an integrated paradigm being mounted on UAVs [6]. Raja *et al*. developed a disaster monitoring system based on fog computing and Software-Defined Networking (SDN). In their work, fog plays the role of a bridge between constraint computational resources and delay-sensitive requirements from users in a disaster area [7]. Gao *et al*. proposed an access network selection method in solving the congestion problem in edge service placement. In their work, choosing the right access network also benefits the service quality [8]. Li *et al*. combined fog computing with related fields including information-centric networking (ICN), reinforcement learning to optimize performance. They took advantage of fog/edge computing in building network structures for the next-generation wireless systems [9, 10].

Fast deployment of network services, which refers to the procedure from packaged state to an operational state, is also receiving great concern in recent years. Ding *et al*. solved the problem of narrowing the gap between limited bandwidth and the requirement of high data rate [11]. Shafi *et al.* discussed deployment in 5G mobile communication. They considered that the challenge lies in how to upgrade the existing network infrastructure [12]. Chen *et al*. came up with the idea of proactive deployment for UAV assisted networks.

> Fog computing refers to the architecture raised by Cisco in 2012. Today fog computing is attracting more and more attention in many research fields. Compared to the cloud, in fog computing we rely on the resources at the edge of the network structure, and not only can obtain the reduction in latency, but also redundancy in case of failure.

In their design, UAVs can move to the optimal positions through the prediction of user requests [13].

Through the study of related work, we find that to solve the problem in fast deployment for disaster response, we need to consider as many constraints as possible in the post-disaster environment. That is to say, our goal is not only to surpass existing methods in quantitative metrics but also to find points that have not received attention in the past and give solutions.

Emergency Fog Service

In this section, we introduce the scenario and challenges of providing emergency fog services to affected areas after disasters happen.

Scenario

We first describe the details of the scenario in which the emergency services are being provided.

When natural disasters such as an earthquake happen, network infrastructure (base stations, relay stations, and so on) are susceptible to damage caused by shock waves or short circuit accidents. As a result, our cellular networks may experience some areas in which users cannot send or receive a signal. Moreover, depending on the severity of the disasters, sometimes the empty holes may turn into large areas losing signal coverage. Once such an extreme situation appears, the surge in users will place a huge burden on rescue work. For the case of network service retrieving in disaster response, the first built connection may face the competition for resources by users in affected areas. Especially for the equipment that can be used as network nodes during rescue, how many units are chosen for a known number of users will need to consider multiple factors. For example, in some rural areas, user distribution is sparse and sometimes we have to build relay routes for connecting all users.

In this article, we are going to cope with the situation when facing different levels of infrastructure paralysis in disaster response. For the situation that only a few base stations cannot work, our target is to help recover the out of service areas in a moment. For the situation when network architecture is extensively damaged, we need to rebuild a temporary network.

Challenges

To solve the problem of retrieving the network connections and services for users in affected areas after disasters, there exist several challenges.

The first one is that the damage to the original architecture is unknown. That is, in disaster response, we do not know which base stations are lost and users in which part of the affected areas are waiting for rescue. We have to understand the extent of the disaster while carrying out the rescue. Once secondary disasters appear, the known information is no longer up-to-date. At this

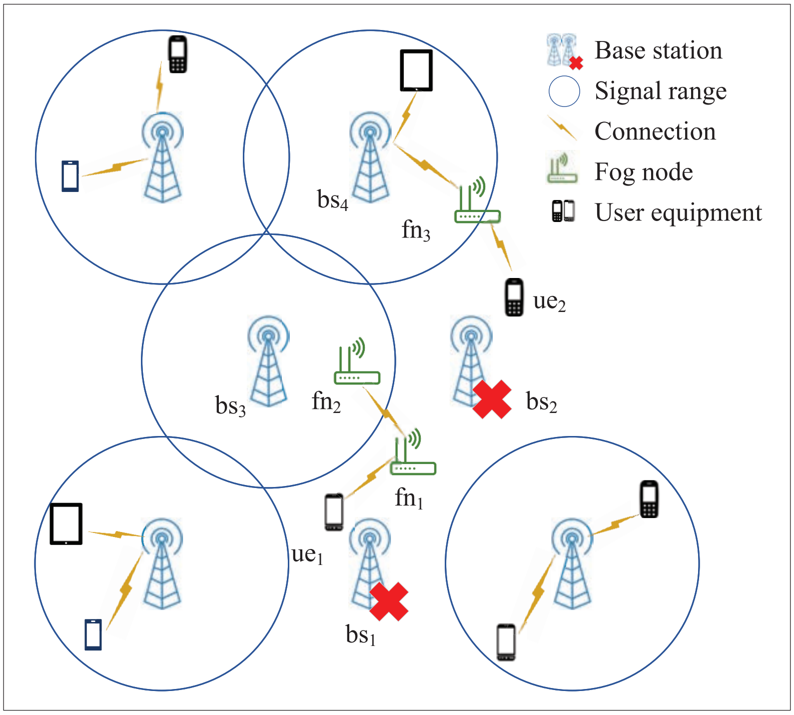

FIGURE 1. The network model of fast deployment in disaster scenario.

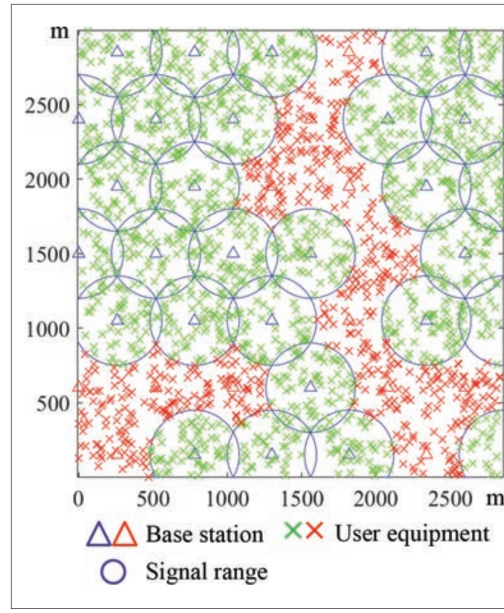

FIGURE 2. An example of affected area after disaster.

time, we also need to prepare for a possible situation.

The second one is the limitation of the available resources. Not only the devices can be used for temporarily providing emergency service, but also the power supply. We have to reduce the latency in satisfying user requests to save time and energy for as many users as possible. In the disaster scenario, since we do not know when everything returns to normal, the proper use of resources is always critical.

The third challenge is the efficiency and Quality of Service (QoS), although we cannot long for the same communication efficiency and QoS as usual in extreme environments. Achieving better performance for the proposed solution still remains a challenge in our research.

Problem Formulation

In this section, we design the system model of a fast-deployed emergency fog network and formulate the problems to solve.

Figure 1 gives the network model of fast deployment in disaster scenarios immediately after disasters, when some of the base stations providing network connections are no longer working. User equipment used to connect to these BSs are in a disconnected state. To help them reconnect to the network, our target is to reallocate the available network resources and fill the empty area of signal coverage. Here we suppose that when users are out of service, they may stay around to wait for rescue. Thus in the job of deployment, we are able to judge where to place fog nodes according to the previous information of user position.

Here we denote user equipment as $UE = \{ue_1, ue_2,\ldots, ue_{n_u}\}$, and base stations as $BS = \{bs_1, bs_2,\ldots, bs_{n_b}\}$. n_u, n_b are the numbers of ues in disconnected state and bs still working. In Fig. 1, there are seven base stations in which two (bs_1 and bs_2) are unusable. To share the network resources from other bs to ue_1 and ue_2, we draw support from access devices as fog nodes [14] $FN = \{fn_1, fn_2,\ldots, fn_{n_f}\}$. n_f is the number of f_n. For example, ue_1 and ue_2 are out of service at first because bs_1 and bs_2 are no longer working. To save and reconnect ue_1 and ue_2, we use three fog nodes fn_1, fn_2 and fn_3. For ue_1, fn_1 and fn_2 together construct a two-hop connection to bs_3, and for ue_2, fn_3 bridges a one-hop connection to bs_4.

When the number of affected bss is more than seven, this means we need a lot more fns to build an emergency fog network to cover the space caused by disasters. Our target is to deploy as few fns as possible to reduce the total time cost on the connections to BS.

For the total latency in transmission from UE to BS, we consider three parts, the la_{seri}, la_{proc}, and la_{prop}. la_{seri} refers to time cost on pushing the data in bits onto the transmission medium. la_{proc} is the processing latency; in our model, it relates to the processing speed of fog nodes in forwarding data packets. At last, la_{prop} is up to the physical distance and wave propagation speed. In the case of wireless, we use the speed of light c. For wired communication, it may vary according to what kind of cable is used.

$$
\begin{aligned}
la_{seri} &= \sum_{i}^{n_u} c_i z_i^{pkt} / br \cdot h_i \\
la_{proc} &= \sum_{i}^{n_u} \left(c_i \sum_{j}^{h_i - 1} z_i^{pkt} / v_j^{p} \right) \\
la_{prop} &= \sum_{i}^{n_u} \left(c_i \sum_{j}^{h_i} d_j^{h} / v_w \right)
\end{aligned} \tag{1}
$$

As a result, we have the calculations of three kinds of latency. First for la_{seri}, $c_i \in \{0, 1\}$ is a boolean variable. 1 stands for the result that ue_i find a path to connect to one of the BS, 0 stands for the result that ue_i is still in disconnected state. z_i^{pkt} is the packet size that ue_i is sending out. br

is the bitrate in transmission. h_i is the number of forwarding hops from ue_i to BS. Here la_{seri} already includes the latency of routing. Second for la_{prop}, v_j^p stands for the processing speed of the fog node in the path. $h_i - 1$ means when there exist h_i hops to forward a data packet from ue_i to a b_s, $h_i - 1$ *fn*s are serving as relay nodes. Third, to calculate la_{prop}, we need to consider the transmission distances in each time of forwarding. d_j^h is the physical distance in the transmission between ue_i and *fn*, or two *fn*s, or a *fn* and a *bs*. v_w is the wave propagation speed.

As a result, the main problem to solve in this article can be given by

$$\begin{aligned} &\textit{minimum } la_{u2b}(c_i, z_i^{pkt}, i = 1, 2, \ldots, n_u) \\ &\textit{subject to } c_i \in \{0, 1\} \text{ and } z_i^{pkt} > 0 \end{aligned} \tag{2}$$

Besides time cost, we also consider the coverage of emergency fog service ($\Sigma_i^{n_u} c_i$) and average forwarding hops between *UE* and *BS* ($(\Sigma_i^{n_u} h_i)/n_u$). The former metric can show the feasibility of our method. The latter one can display the efficiency of the emergency service.

A Fast Deployment Strategy of Emergency Fog Service for Disaster Response

In this section, we design a fast strategy to solve the problem of reducing total latency in fog service deployment for disaster response.

As shown in Fig. 2, within a square open area, blue triangles are base stations that can work while red ones are damaged (or power shortage) and cannot be used anymore. Blue circles as signal ranges together cover green crosses as user equipment can connect to these base stations. Our first task is to help the red crosses as user equipment to reconnect into the circles again by fog nodes. Here we suppose users all stay still or only move in a fixed range and wait for rescue. As a result, we can know the approximate locations of users from the last connections. At this time, first, we can seek help from the nearby end devices that can serve as fog nodes. That is, we make use of the nearby fog nodes to build an early-stage emergency fog network. However, we may not be able to figure out how many available fog nodes, and all we can do is to minimize the number of isolated user equipment, at least making sure that as many of them possible can access the limited fog service.

After this step, some of the lost user devices may get connected again to base stations while the other ones may form clusters. Even some users are still alone. As a result, in the next step, our task is to cover all the clusters and users by deploying new fog nodes in this area.

The algorithm design is as follows. We require the number of user equipments in a disconnected state, fog nodes to realize emergency networking, and a queue to record the forwarding from *UE* to *BS*. The first step is to start a polling loop for each *ue* out of coverage to choose a neighbor as a pair, then place a *fn* at the midpoint of this pair of users. At this time, we may traverse the other *ue* to check if any other ones can connect to this *fn*. After the placement of new *fn*, the next step we are going to test the routing from *ue* to any of the *bs* through placed *fn*. The output of this algorithm is the number of *ue* being reconnected and the total latency in emergency routing.

Parameter	Value
Simulation area	$2860\sqrt{3} \times 3000$ m^2
Number of *ue*, *fn*, and *bs*	1000/300/48
Signal range (radius) of *FN* and *BS*	100/300 m
Bitrate in transmission	100 Mb/s
Wave propagation speed	c (speed of light)
Processing speed of *FN*	6 Gb/s
Maximum transmission unit (802.11)	2304 Bytes

TABLE 1. Experimental settings

There are two parts in this strategy. First, the placement of fog nodes. We use new fog nodes to help rebuild the network connections between *UE* and *BS*. $n^{c=0}$ is the number of user equipment waiting for rescue in the disaster area. Q_{u2b} is a First In First Out (FIFO) queue to record the forwarding path from *UE* to *BS*. To output the number of needed fog nodes and total latency, we apply a method of finding *ue* pair according to their relative locations. j is used to count the number of *fn*. Then in the second part of emergency routing, we try to find the fn_{this} connected to any BS still working by means of the interconnection relationship among fog nodes. The recoverage percentage can also be obtained from the ratio of $n_u^{c=1}$ and $n_u^{c=0}$. The time complexity of this algorithm is $O(n_u^{c=0}(n_u^{c=0} - 1) + n_u^{c=0} \cdot 1/2 \cdot n_f) = O(n_u^{c=0}(n_u^{c=0} + n_f))$.

Performance Evaluation

In this section, we compare the performance of our proposed fast deployment strategy with the existing method. The experimental settings are as follows.

As shown in Table 1, in an open area, there are 5000 users sharing the network resources from 48 base stations. 300 fog nodes provide access service for the case that users are not in the range of some base stations. Signal ranges of fog nodes and base stations are 300 m and 100 m. Bitrate in transmission is 100 Mb/s. Wave propagation speed refers to the speed of light c. The processing speed or maximum transfer rate is 6 Gb/s. The maximum transmission unit (MTU) is 2305 Bytes. In case that different proportions of base stations cannot be used, we carry out a simulation to evaluate our fast deployment strategy and existing method in [15]. We repeat 10 times for each group of results.

As shown in Fig. 3, we calculate the time cost on realizing emergency communication in the network model from Fig. 1 stations in a disaster area. It focuses on the solution of building a network architecture from scratch. As a result, faced with the demand here, APPM may not be as good as combing the resources that still can be used. From Fig. 3, we can see that for the main problem of reducing latency from *UE* to *BS*, our strategy can save more time in delivering messages among the rebuilt network. Especially when the percentage of damaged base stations increases, the gap becomes larger. In case that half of the base stations fall, our fast strategy can save about 30 percent time in total.

Besides time cost, we also consider the results of service coverage after fast deployment. In the simulation, we make use of multiple fog nodes to fill the red part in Fig. 2. As shown in Fig. 4, our strategy is slightly lower than APPM in coverage percentage. Similarly, in the case that only 10 percent of the base stations are not working, both our strategy and APPM can rebuild the connections from 90 percent of the user equipment to base stations, and when half of the base stations fall, the coverage percentage decreases rapidly. That is, both our strategy and APPM still can hardly cope with the extreme situation of large area damage.

We also compare the results of average forwarding hops in the transmission. As shown in Fig. 5, more hops are needed in our strategy than APPM. This situation can be explained that the practice of APPM is done by more than twice the number of fog nodes used in our strategy. However, the advantage of more network nodes did not improve the overall performance of the network to a corresponding extent. In our point of view, considering the truth that any transmission path using fog nodes is no less than two hops (*UE* to *FN* and *FN* to *BS*), the average three hops are acceptable in disaster response.

In summary, from the performance evaluation of the simulation results, our proposed fast deployment strategy shows its feasibility in achieving emergency communication in the affected area immediately after disasters. Compared with the existing method, our strategy can use fewer nodes in providing fog services with less time cost.

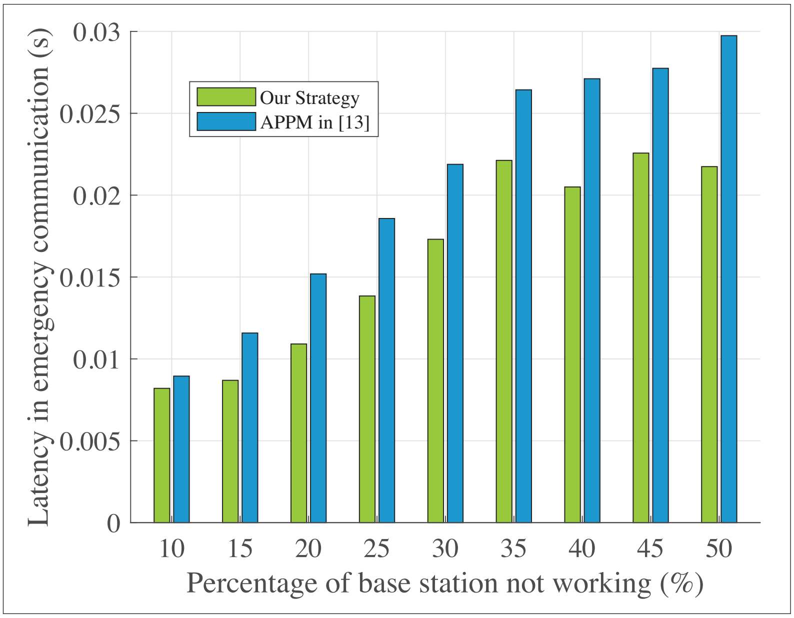

FIGURE 3. Total latency in emergency communication after fast deployment.

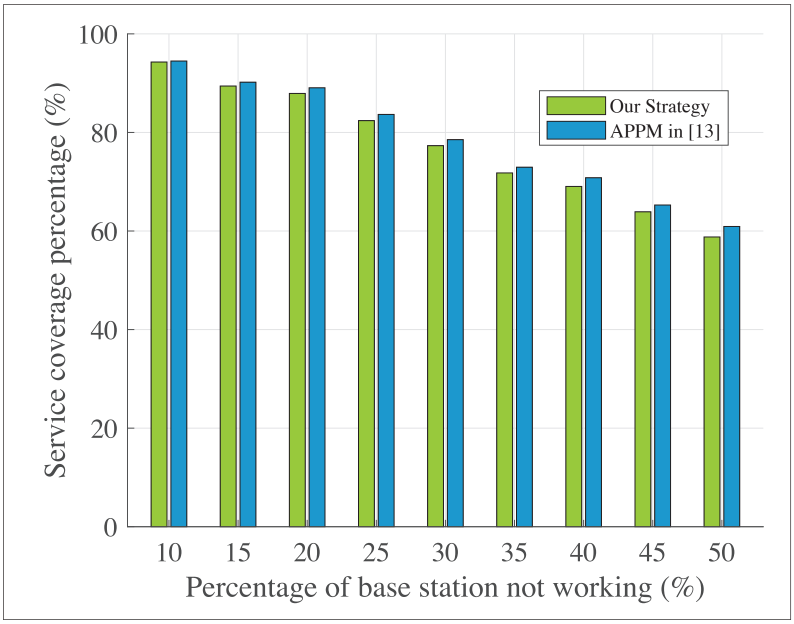

FIGURE 4. Service coverage in emergency communication after fast deployment.

Conclusions

In this article, we focus on solving the problem of fast deployment of fog service for disaster response. In the case that part of the base stations are no longer working because of damage or power shortage, our research target is to help user equipment in a disconnected state to reconnect back to the outside world. Our strategy is based on fog computing which can serve as solutions for centralized networking and service deployment in a disaster environment. We choose total latency from the user equipment to base stations, service coverage ratio and average forwarding hops in emergency communication as metrics. In the simulation, we compare our strategy with the existing one. The results show that our fast deployment strategy is feasible, can reduce the time cost on emergency communication and optimize the usage of fog nodes. Since our work is still in the simulation phase, we are going to consider more technical details in system design and implementation experiments.

There still exist some research issues in this field. For example, in real-world environments, base stations may not be set regularly as shown in Figs. 1 and 2, and this irregularity of distribution can bring unknown challenges to our proposed algorithm. Moreover, we cannot guarantee that the devices used are the same configuration performance. The diversity of equipment in experimental settings is also an issue worth exploring in the future.

Acknowledgment

This work is partially supported by JSPS KAKENHI Grant Numbers JP16K00117, JP19K20250, Leading Initiative for Excellent Young Researchers (LEADER), MEXT, Japan and KDDI Foundation.

References

[1] F. Bonomi *et al.*, "Fog Computing and Its Role in the Internet of Things," *Proc. First Edition of the MCC Workshop on Mobile Cloud Computing*, Aug. 2012, pp. 13–16.

[2] Y. Nikoloudakis *et al.*, "A Fog-Based Emergency System for Smart Enhanced Living Environments," *IEEE Cloud Computing*, vol. 3, no. 6, Nov. 2016, pp. 54–62.

[3] L. Li *et al.*, "Eyes in the Dark: Distributed Scene Understanding for Disaster Management," *IEEE Trans. Parallel and Distributed Systems*, vol. 28, no. 12, Dec. 2017, pp. 3458–71.

[4] Z. Su *et al.*, "A Secure Content Caching Scheme for Disaster Backup in Fog Computing Enabled Mobile Social Networks," *IEEE Trans. Industrial Informatics*, vol. 14, no. 10, Oct. 2018, pp. 4579–89.

[5] J. Wang *et al.*, "Maximum Data-resolution Efficiency for Fog-Computing Supported Spatial Big Data Processing in Disaster Scenarios," *IEEE Trans. Parallel and Distributed Systems*, vol. 30, no. 8, 1 Aug. 2019, pp. 1826–42.
[6] C. Tang *et al.*, "Integration of UAV and Fog-Enabled Vehicle: Application in Post-Disaster Relief," *Proc. 2019 IEEE 25th Int'l. Conf. Parallel and Distributed Systems (ICPADS)*, Tianjin, China, Dec. 2019, pp. 548–55.
[7] G. Raja *et al.*, "SAFER: Crowdsourcing Based Disaster Monitoring System Using Software Defined Fog Computing," *Mobile Networks and Applications*, vol. 24, no. 5, Oct. 2019, pp. 1414–24.
[8] B. Gao *et al.*, "Winning at the Starting Line: Joint Network Selection and Service Placement for Mobile Edge Computing," *Proc. IEEE INFOCOM 2019, IEEE Conf. Computer Commun.*, Paris, France, 2019, pp. 1459–67.
[9] H. Li *et al.*, "ECCN: Orchestration of Edge-Centric Computing and Content-Centric Networking in the 5G Radio Access Network," *IEEE Wireless Commun.*, vol. 25, no. 3, June 2018, pp. 88–93.
[10] H. Li *et al.*, "Deep Reinforcement Scheduling for Mobile Crowdsensing in Fog Computing," *ACM Trans. Internet Technology*, vol.19, Article 21, Apr. 2019.
[11] Z. Ding *et al.*, "Orchestrating Data as a Services-Based Computing and Communication Model for Information-Centric Internet of Things," *IEEE Access*, vol. 6, July 2018, pp. 38900–20.
[12] M. Shafi *et al.*, "5G: A Tutorial Overview of Standards, Trials, Challenges, Deployment, and Practice," *IEEE JSAC*, vol. 35, no. 6, June 2017, pp. 1201–21.
[13] M. Chen *et al.*, "Caching in the Sky: Proactive Deployment of Cache-Enabled Unmanned Aerial Vehicles for Optimized Quality-of-Experience," *IEEE JSAC*, vol. 35, no. 5, May 2017, pp. 1046–61.
[14] E. M. Tordera *et al.*, "What is a Fog Node? A Tutorial on Current Concepts towards a Common Definition," arXiv preprint arXiv:1611.09193, 2016.
[15] J. Xu *et al.*, "Fast Networking for Disaster Recovery," *IEEE Trans. Emerging Topics in Computing*, in press.

Biographies

Jianwen Xu received the B.Eng. degree in electronic and information engineering from Dalian University of Technology in 2014, the M.Eng. degree in information and communication engineering from Shanghai Jiao Tong University in 2017, and the Ph.D. degree in engineering from Muroran Institute of Technology in 2020. He is currently a postdoctoral researcher at Muroran Institute of Technology. He received the JSPS Postdoctoral Fellowship for Research in Japan for the 2020 fiscal year. He was selected as a Non-Japanese Researcher by the NEC C&C Foundation for the 2019 fiscal year. His main fields of research interest include edge computing, and Internet of things.

Kaoru Ota received her M.S. degree in computer science from Oklahoma State University in 2008, and her B.S. and Ph.D. degrees in computer science and engineering from the University of Aizu in 2006 and 2012, respectively. She is currently an associate professor with the Department of Sciences and Informatics, Muroran Institute of Technology. She currently serves as an editor for *IEEE Transactions on Vehicular Technology* (TVT), *IEEE Internet of Things Journal*, *IEEE Communications Letters*, and *IEEE Wireless Communications Letters*. She is a Clarivate Analytics 2019 Highly Cited Researcher (Web of Science).

Mianxiong Dong received B.S., M.S. and Ph.D. degrees in computer science and engineering from The University of Aizu, Japan. He is the Vice President and youngest ever professor at Muroran Institute of Technology, Japan. He is the recipient of the IEEE TCSC Early Career Award 2016, IEEE SCSTC Outstanding Young Researcher Award 2017, The 12th IEEE ComSoc Asia-Pacific Young Researcher Award 2017, Funai Research Award 2018 and NISTEP Researcher 2018 (one of only 11 people in Japan) in recognition of significant contributions in science and technology by MEXT, Japan. He is a Clarivate Analytics 2019 Highly Cited Researcher (Web of Science).

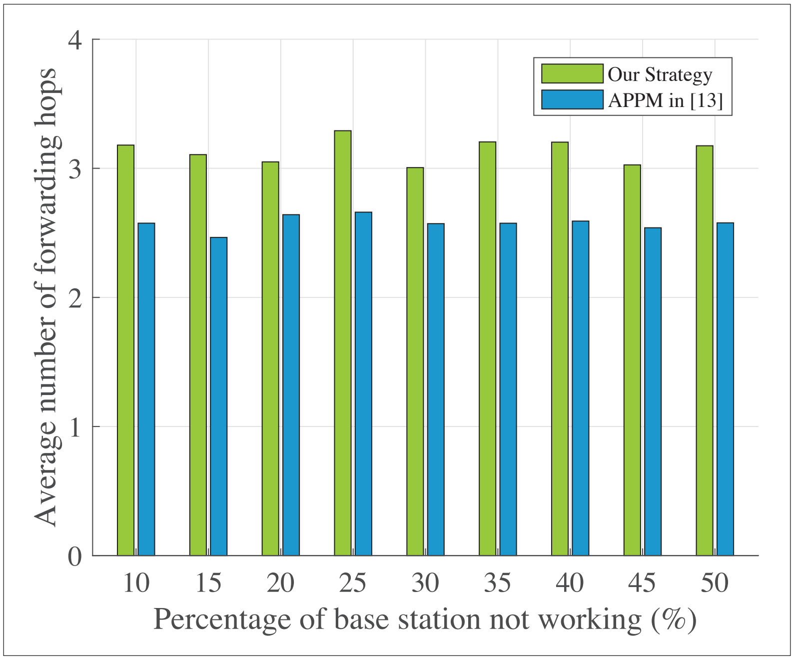

FIGURE 5. Average forwarding hops in emergency communication after fast deployment.