RescueMe: Smartphone-Based Self Rescue System for Disaster Rescue

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***Abstract*—Recent ubiquitous earthquakes have been leading to mass destruction of electrical power and cellular infrastructures, and deprive the innocent lives across the world. Due to the wide-area earthquake disaster, unavailable power and communication infrastructure, limited man-power and resource, traditional rescue operations and equipment are inefficient and time-consuming, leading to the golden hours missed. With the increasing proliferation of powerful wireless devices, like smartphones, they can be assumed to be abundantly available among the disaster victims and can act as valuable resource to coordinate disaster rescue operations. In this paper, we propose a smartphone-based self rescue system, also referred to as *RescueMe*, to assist the operations of disaster rescue and relief. The basic idea of RescueMe is that a set of smartphones carried by survivors trapped or buried under the collapsed infrastructure forms into a one-hop network and sends out distress signal in an energy-efficient manner to nearby rescue crews to assist rescue operations. We evaluate the proposed approach through extensive simulation experiment and compare its performance with the existing scheme *TeamPhone*. The simulation results show that the proposed approach can significantly reduce the schedule vacancy of broadcasting distress signal and improve the discovery probability with very little sacrifice of network lifetime, and indicate a potentially viable approach to expedite disaster rescue and relief operations.**

***Index Terms*—Natural Disaster, Disaster Rescue and Relief, Scheduling, Distress Signal, Smartphone**

I. Introduction

Unexpected natural disasters such as tornadoes, earthquakes, hurricanes, and tsunamis have been rising dramatically in recent years. In particular, earthquakes tremendously kill innocent lives and damage the environment around the globe, and the epicenter of an earthquake can occur anywhere and now no place would be safe from ubiquitous earthquakes. For example, a 5.6-magnitude earthquake struck Oklahoma and impacted six neighboring states in the U.S. on September 04, 2016 [1]. The Ecuador earthquake (April 16, 2016) left a 272 death toll and more than 2,500 injured [2]. An earthquake often happens in a flash but has the potential to massively destruct the infrastructures, buildings, and homes in a short period of time. After the disaster, it was impossible for disaster victims to utilize their communication devices, such as smartphone, tablet, or laptop, to notify their families and friends of their safety and confirm the safety of their loved ones since the communication infrastructures were physically damaged or lacked the energy necessary to operate. [3]. More importantly, since many people could be trapped beneath the rubble and brick, the victims may have a large chance to survive if they are located and rescued within ”Golden 72 Hours”. If a severely injured person does not receive care or medical treatment quickly, the probability of survival rapidly decreases. Thus, in order to minimize casualties and save innocent lives across the world, it is essential to plan and conduct expedited disaster rescue operations.

However, when an earthquake occurs, the rescue teams or planners of disaster rescue and relief mainly suffer from the following issues. First, since the current disaster situation of sudden earthquake may not be available, it is difficult to make a plan or decision on the priority of rescue operations in terms of the focused rescue areas, the distribution of rescue teams, or the allocation of equipment. Second, the impact areas are admittedly wide, ranging from a few miles to several U.S. states, but the number of rescue teams and man-power are very limited in reality. Third, due to the collapse of power and communication infrastructure, the impacted areas become a blackspot where WiFi and 4G-LTE services are not available and the affected area is cut off from the outside. Last but not least, most rescue teams still heavily rely on the traditional operations and equipment, such as detection dogs, video cameras, or sound sensors. In summary, the traditional rescue operations and equipment are inefficient and time-consuming, leading to the golden hour missed.

On the other hand, smartphones have become an essential electronic device what people always carry for communication and social connection, or place them where they can be easily and immediately accessed. It has been predicted that the number of smartphone users in the United States is estimated to reach 148.68 million in 2019, and the number of smartphone users worldwide forecasts to exceed 2 billion by that time [4]. Thus, with the increasing proliferation of smartphones, they can be assumed to be abundantly available among the disaster victims and act as valuable resources to coordinate rescue operations. For example, after the Haiti earthquake in 2010, there were approximately 2.8 million active mobile subscribers out of 10 million inhabitants contributing data for tracking the movement of population in the affected region [5].

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In light of these, this paper is to develop a novel disaster self rescue system incorporating with increasingly popular smartphone in the disaster area. Our major contribution is summarized in the following:

- We propose a smartphone-based self rescue system, also referred to as *RescueMe*, to assist the operations of disaster rescue and relief. The basic idea of RescueMe is that a set of smartphones carried by survivors trapped or buried under the collapsed infrastructure forms into a one-hop network and sends out distress signal in an energy-efficient manner to nearby rescue crews to assist rescue operations.
- We develop a customized simulator framework and implement the proposed scheme for experiment study. For performance comparison, we revisit an existing approach TeamPhone [6], and modify it to work in the developed simulation framework.

We compare and analyze the performance of RescueMe and TeamPhone in terms of network lifetime and schedule vacancy of broadcasting distress signal through extensive simulation experiments. The simulation results show that the proposed approach can significantly reduce the schedule vacancy of broadcasting distress signal and improve the discovery probability with very little sacrifice of network lifetime, and indicate a potentially viable approach to expedite disaster rescue and relief operations.

The rest of paper is organized as follows. The prior approaches are summarized and analyzed in Section II. The proposed smartphone-based self rescue system is presented in Section III. Section IV presents extensive simulation results and analyses. Finally, we conclude the paper in Section V.

II. Related Work

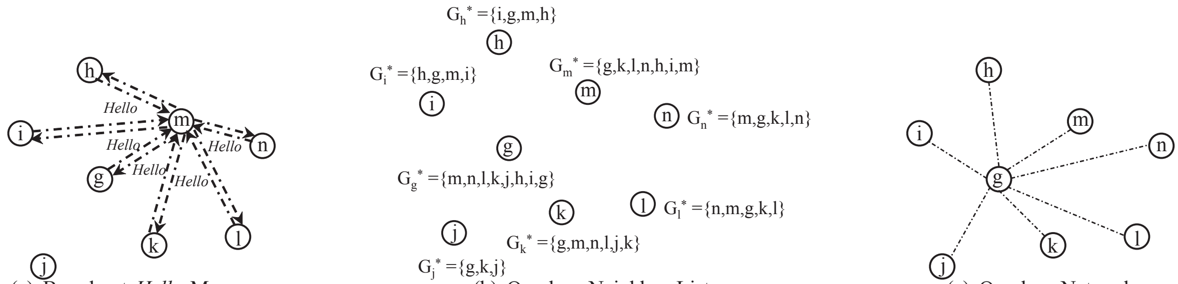
Using smartphones for constructing disaster recovery network and assisting the operations of disaster rescue and relief has been extensively explored in the last decade.

The [7] develops a mechanism to enable the devices to discover their neighbors autonomously and transmit data of disaster-affected area by different network to WiFi access points using a smartphone-based WiFi tethering technique. In the [8], a novel architecture called energy aware disaster recovery network using WiFi tethering is proposed to create the desired network infrastructure using wireless device. The basic idea is to make use of WiFi tethering technology ubiquitously available on wireless devices, like smartphones and tablets, to set up an ad hoc network for data collection in disaster scenarios. The [9] proposes a smartphone-based post-disaster management mechanism in the disaster affected areas using the concepts of WiFi tethering, where smartphones in the affected areas may turn themselves into temporary WiFi hotspots to provide Internet connectivity and important communication abilities to nearby WiFi-enabled user devices. In the [3], the concept of multihop device-to-device communication network systems integrating with different wireless technologies is proposed to deliver messages using only users mobile devices, send out emergency messages from disconnected areas, and share information among people gathered in evacuation centers. In the [10], a robot snakes with hyper-redundant body and unique gaits is proposed to offer a promising solution to search and rescue applications in the disaster. An unmanned aerial vehicles-aided disaster rescue system is proposed to locate possible victims in [11], where unmanned aerial vehicles [12] fly around the disaster area and sniff out wireless signals from any mobile devices to support the search team to narrow down the search area within meters.

The [13] presents a smartphone-assisted victim localization method in which smartphones belonging to trapped victims and other people in disaster affected areas can self-detect the occurrence of a disaster incident by monitoring the radio environment and can self-switch to a disaster mode to transmit emergency help messages with their location coordinates to other smartphones nearby. To locate other neighboring smartphones also operating in the disaster mode, each smartphone runs a rendezvous process. In the [14], an application, also referred to as SOSCast, is proposed to propagate SOS messages from trapped survivors through a direct communication between smartphones. By collecting SOS messages that include significant information such as their name, state, and location, rescuers can estimate the locations of the survivors. Without relying on any infrastructure, the [15] presents a new algorithm that allows the smartphones of the rescuers and victims to seamlessly collaborate in order to estimate the locations of the victims by using both the received signal strength indicator of the WiFi signals and the GPS information of the rescuers' smartphones. The [16] proposes a smartphone and IoT devices-assisted emergency and recovery method in a post-disaster environment, where smartphones can utilize the IoT devices in the disaster affected areas to successfully relay the emergency messages to other smartphones.

In [6], by bridging the gap among different kinds of wireless networks, a system called TeamPhone is proposed to provide smartphones the capabilities of communications in disaster recovery. TeamPhone consists of two components: a messaging system and a self-rescue system. The messaging system integrates cellular networking, ad-hoc networking and opportunistic networking seamlessly, and enables communications among rescue workers. The self-rescue system energy-efficiently groups the smartphones of trapped survivor and sends out emergency messages so as to assist rescue operations. However, the self-rescue system does not consider that each smartphone of trapped survivor may carry different amount of residual energy, and the smartphone with less residual energy may turn off quickly because of frequently broadcasting emergency messages. Thus, the schedule of sending out emergency messages should be dynamically adjusted accordingly when the network topology changes because of the death of certain smartphone.

In summary, various kinds of smartphone-based wireless communication technologies and hybrid networks have been widely investigated for disaster rescue and relief. However, to the best of authors' knowledge, the proposed research focusing on dynamically adjusting the schedule of sending out distress



(a) Broadcast *Hello* Messages (b) One-hop Neighbor List (c) One-hop Network

Fig. 1. A set of nodes broadcast *Hello* messages to build one-hop neighbor list G^* and one-hop network.

signal according to the change of network topology is new.

III. The Proposed Smartphone-Based Self Rescue System

In this section, we first present an overview of the proposed smartphone-based self rescue system, also referred to as *RescueMe*, and then discuss the RescueMe and its corresponding techniques in details.

A. Overview of the RescueMe

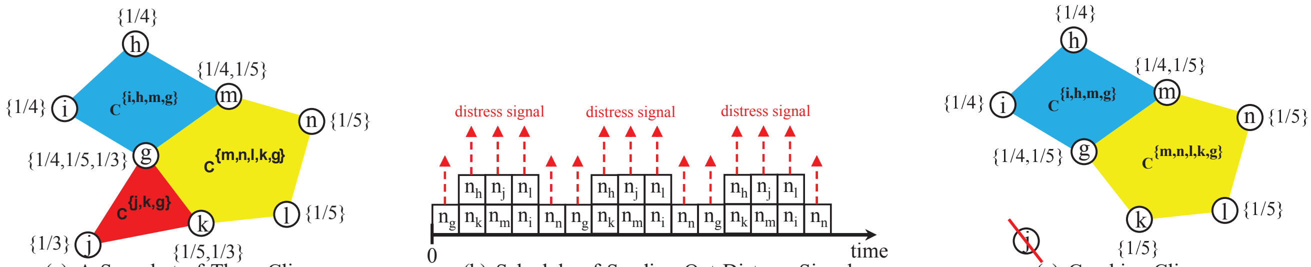
With the proliferation of powerful smartphones, they can be assumed to be abundantly available among the trapped survivors in the affected region and act as valuable resources. Most smartphones are equipped with both WiFi and Bluetooth transceivers. WiFi technology allows a smartphone to connect to a wireless local area network (WLAN) based on the IEEE 802.11 standard. WiFi running in the 2.4 GHz radio band covers a larger range than 5.0 GHz. Unlike WiFi consuming high battery power, Bluetooth wireless technology (BWT) is primarily designed for a short range communication with low-power consumption. With the support of WiFi or BWT, survivors even trapped under the rubble can periodically send out a distress signal using their smartphone. If each smartphone continuously stays awake and sends out distress signal, this will increase discoverability and reachability of trapped survivors. However, continuously broadcasting distress signal can quickly drain battery, and rescue operations may even last for days after disasters occur. Thus, how to collaborate smartphones of survivors trapped under the collapsed infrastructure to send out distress signal in an energy-efficient manner is a challenge problem.

In this paper, we propose a smartphone-based self rescue system, also referred to as *RescueMe*, to assist the operations of disaster rescue and relief in the disaster area. The basic idea of RescueMe is that a set of smartphones (later nodes) carried by survivors trapped or buried under the collapsed infrastructure forms into a one-hop network and sends out distress signal in an energy-efficient manner to nearby rescue crews to assist rescue operations. After detecting seismic signal, the nodes can automatically enter into the self-rescue mode. Or after disaster occurs, the trapped survivors can click a rescue app to enable the nodes to enter into the self-rescue mode. In the self-rescue mode, each node broadcasts an one-time *Hello* message, overhears bypassing *Hello* messages, and constructs an one-hop network. The one-hop network consists of cliques, in which the direct connection exists between every two nodes, and each node can communicate with every other node. In order to extend the battery lifetime through reducing energy consumption, the nodes in the one-hop network wake up alternatively in a coordinated way and send out distress signal to discover nearby rescue crew. In addition, each node may be equipped with different amount of battery energy when the disaster happens, and the node with less amount of energy will turn off quickly. Thus, the wake-up schedule of broadcasting distress signal should be dynamically adjusted in response to the change of one-hop network topology. In the following, we investigate three major issues to implement the RescueMe: (i) how to construct the one-hop network; (ii) how to determine the wake-up schedule of broadcasting distress signal; and (iii) how to dynamically adjust the wake-up schedule according to the change of network topology.

B. RescueMe: Smartphone-Based Self Rescue System

First, each node broadcasts an one-time *Hello* message piggybacked with its node id, overhears *Hello* messages broadcasted by other nodes, and then build the one-hop neighbor list G^* [17], [18]. For example, as shown in Subfig. 1(a), n_m broadcasts a *Hello* message, and overhears the *Hello* messages broadcasted by its adjacent nodes (e.g., n_h, n_i, n_g, n_k, n_l, and n_n). As a result, n_m can build its one-hop neighbor list, G^*_m = $\{h,i,g,k,l,n\}$, as shown in Subfig. 1(b). By using the same technique, other nodes also can build their one-hop neighbor list. In this paper, each node also considers itself as an one-hop neighbor node and adds its id in the one-hop neighbor list. Thus, $G^*_m = \{h,i,g,k,l,n,m\}$. Each node then exchanges its one-hop neighbor list G^* with adjacent nodes, and identifies the *center node* who has the largest number of neighbor nodes and the G^* of all other nodes is a subset of the center node's one-hop neighbor list. Then the center node builds a one-hop network, where every other node can directly communicate with the center node, vice versa. For example, as shown in Subfig. 1(c), an one-hop network is built by the center node n_g.

Second, the center node examines the received G^* of all other nodes in the one-hop network, and groups the nodes that have the same subset of G^* into a clique, where a direct connection exits between every two nodes and each node can cover all other nodes in a clique. For example, in Subfig.



(a) A Snapshot of Three Cliques (b) Schedule of Sending Out Distress Signal (c) Combine Cliques

Fig. 2. A snapshot of three cliques in one-hop network, schedule of sending out distress signal, and combine existing cliques.

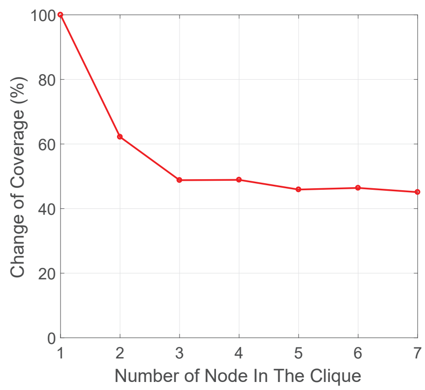


Fig. 3. The change of coverage ratio against the number of nodes in the clique.

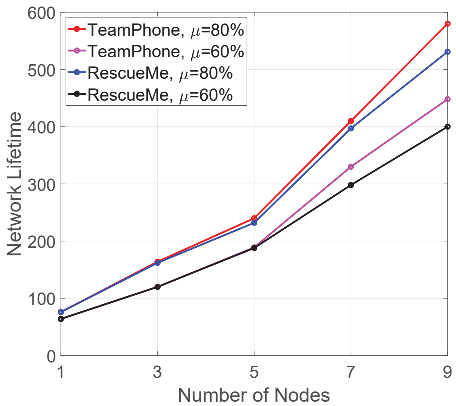
1(b), n_g, n_i, n_h, and n_m contain the same subset of one-hop neighbor list, G^*_{sub} = {*i*,*h*,*m*,*g*}. Thus, the center node n_g groups n_i, n_h, and n_m along with itself into a clique, $C^{\{i,h,m,g\}}$, as shown in Subfig. 2(a). In the one-hop network shown in Subfig. 2(a), there are another two cliques, which are $C^{\{m,n,l,k,g\}}$ and $C^{\{j,k,g\}}$, respectively. In a clique, nodes are close to each other, thus, the area covered by one node can be a larger proportion of the area covered by all nodes in the clique. Here, Fig. 3 shows the change of coverage ratio between the coverage of one node and the total coverage of all nodes in a clique against the number of nodes in a clique.

Third, since the center node belongs to multiple cliques in the one-hop network, it will determine the schedule of broadcasting distress signal for all nodes across all the cliques. In order to reduce the energy consumption, the node that is located in the multiple cliques will choose the lowest fraction of the clique that it belongs to as its broadcasting frequency, denoted as ψ. For example in Subfig. 2(a), the center node n_g belongs to three cliques, $C^{\{i,h,m,g\}}$, $C^{\{m,n,l,k,g\}}$, and $C^{\{j,k,g\}}$, and the clique fraction of n_g is $\frac{1}{4}$ (since there are four nodes in $C^{\{i,h,m,g\}}$), $\frac{1}{5}$ and $\frac{1}{3}$ in the $C^{\{i,h,m,g\}}$, $C^{\{m,n,l,k,g\}}$, and $C^{\{j,k,g\}}$, respectively. Thus, the center node n_g choose $\frac{1}{5}$ as its broadcasting frequency, $\psi_g = \frac{1}{5}$. In addition, the center node also calculates the sum of fractions of the cliques for each node, and determines the schedule of broadcasting distress signal accordingly. In this paper, the node with the larger sum of fractions of the cliques will broadcast distress signal earlier. For example, node n_m and n_h has the fractions of the cliques $\{\frac{1}{4}, \frac{1}{5}\}$ and $\{\frac{1}{4}\}$, respectively, the sum of fractions of the cliques is $\frac{9}{20}$ and $\frac{1}{4}$. Thus, n_m will broadcast distress signal earlier than n_h. The center node determines the broadcasting schedule for all the nodes based on the following two criteria: (i) the broadcasting frequency for each node must be ψ; (ii) there is no more than one node broadcasting distress signal at any time in the clique. After determining the schedule, the center node broadcasts the *Schedule* packet, pkt^{sched}, piggybacked with the broadcasting schedule to all other nodes in the one-hop network. When the node successfully receives the pkt^{sched} packet, it replies an *Ack* packet, pkt^{Ack}, back to the center node after a randomly backoff period [19]. Here, Subfig. 2(b) shows the schedule of sending out distress signal of each node in the one-hop network of Subfig. 2(a), where the schedule begins at time 0.

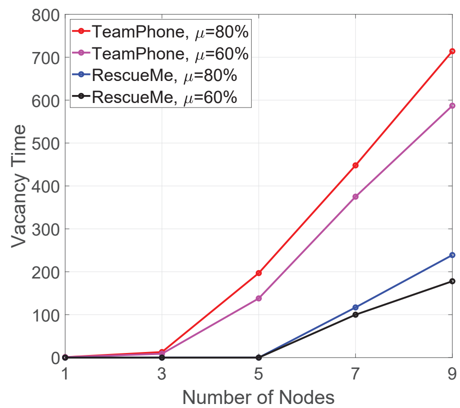
Fourth, since each node may carry different amount of residual energy, and the node with less residual energy may turn off quickly because of frequently broadcasting distress signal, thus, the schedule of broadcasting distress signal should be dynamically adjusted in response to the change of network topology. If the node is about to run out of the battery energy, it will notify the center node by sending a *TurnOff* packet, pkt^{off}. As a result, the center node removes the leaving node from existing cliques, and rebroadcasts the pkt^{off} packet to all other nodes in the one-hop network. After receiving the pkt^{off} packet, each node also removes the leaving node from its one-hop neighbor node list. Then, the center node examines the updated cliques, combines the cliques if one is the subset of another, determines a new broadcasting schedule, and broadcasts the new schedule to all other nodes. For example, as shown in Subfig. 2(c), node n_j leaves the network and the center node n_g combines $C^{\{j,k,g\}}$ and $C^{\{m,n,l,k,g\}}$ into $C^{\{m,n,l,k,g\}}$. If the center node has to leave the network, it will broadcast a *Dismiss* packet, pkt^{dis}, to all other nodes. After receiving the pkt^{dis} packet, all other nodes will restart RescueMe scheme from the beginning, and the same aforementioned operations will be applied.

IV. Performance Evaluation

We develop a customized simulation framework using Java to conduct our experiments. The number of nodes in the network is from 1 to 9, and the time interval of broadcasting distress signal is 5 seconds. In this paper, we measure the performance in terms of network lifetime and schedule vacancy by changing key simulation parameters, including the

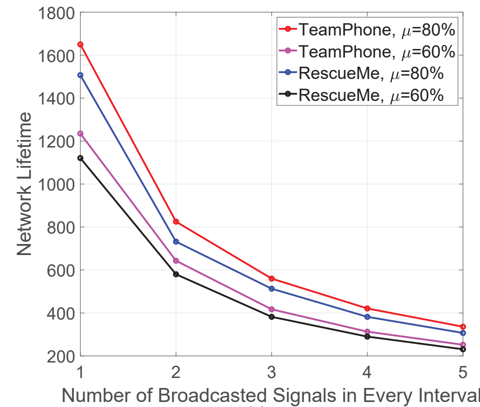


(a)

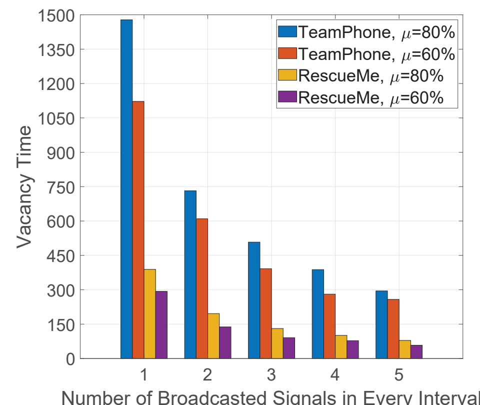


(b)

Fig. 4. The performance of network lifetime and schedule vacancy against the number of nodes.



(a)



(b)

Fig. 5. The performance of network lifetime and schedule vacancy against the number of broadcasted distress signals in each interval.

number of nodes, the number of broadcasted distress signal in each time interval, and the number of cliques. For performance comparison, we compare the proposed scheme RescueMe with TeamPhone.

First, we measure the network lifetime and schedule vacancy time by varying the number of nodes in Fig. 4. In Subfig. 4(a), the overall network lifetime of RescueMe and TeamPhone increase as the number of nodes increases. This is because more nodes exist in the network, and the time interval of broadcasting distress signal for each node increases, resulting in a longer network lifetime. As the initial battery power of each node is increasing, the longer network lifetime will be observed. This is because the more power the node has, the longer time the node lasts, which results in a higher network lifetime. However, the RescueMe shows a slightly lower network lifetime than that of TeamPhone because TeamPhone uses the same schedule of broadcasting distress signal even if the node leaves the network. In Subfig. 4(b), the overall schedule vacancy time of RescueMe and TeamPhone increase as the number of nodes increases. This is because the schedule of broadcasting distress signal of TeamPhone does not change when the nodes leave the network because of running out of battery. As a result, the schedule vacancy time increases significantly. The RescueMe shows a lower schedule vacancy time than that of TeamPhone. In the RescueMe, when the node is out of battery, the structure of network will be changed and other nodes will fill in the empty interval of broadcasting distress signal, resulting in a lower schedule vacancy time.

Second, we measure the network lifetime and schedule vacancy by varying the number of broadcasted distress signals in each interval in Fig. 5. Overall, the network lifetime decreases as the number of broadcasted distress signals increases in Subfig. 5(a). With the number of broadcasted distress signals in each interval increases, the energy consumption in each interval increases. However, the RescueMe shows a slightly lower network lifetime than that of TeamPhone because the TeamPhone does not reschedule the interval of broadcasting distress signal whenever the node leaves the network. As shown in Subfig. 5(b), the overall vacancy time of the RescueMe and TeamPhone decreases as the number of broadcasted distress signals increases in every interval. The RescueMe shows a lower increment of schedule vacancy time than that of the TeamPhone. This is because if the node is out of power, the RescueMe reschedules the rest of nodes in the network, which results in a lower vacancy time. Although the number of broadcasted distress signal in every interval decreases and the network lifetime increases, the RescueMe still shows much smaller schedule vacancy time than that of TeamPhone.

Third, Fig. 6 shows the network lifetime and schedule va-

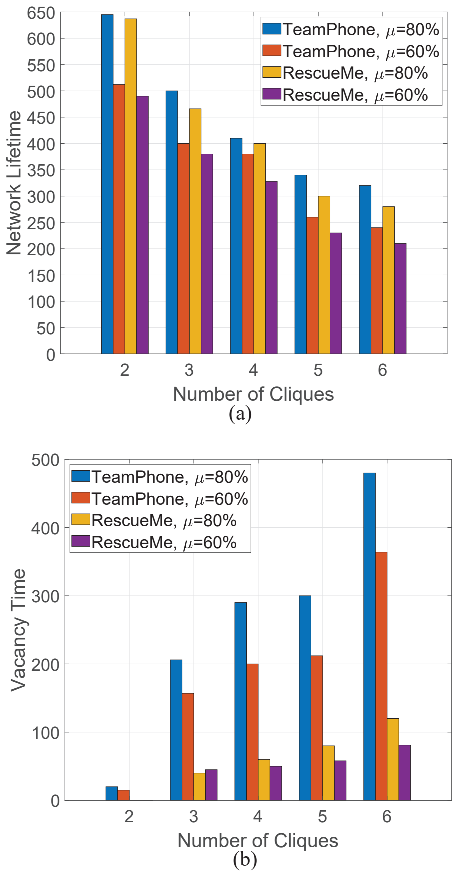


Fig. 6. The performance of network lifetime and schedule vacancy time against the number of cliques.

cancy of the RescueMe and TeamPhone with varying number of cliques in the network. As shown in Subfig. 6(a), the overall network lifetime decreases as the number of cliques increases. This is because when the number of cliques increases but the total number of nodes in the network is not changed, more nodes broadcast distress signals in every interval. As a result, the energy consumption of each interval increases, and the network lifetime decreases accordingly. The TeamPhone shows a higher network lifetime than that of RescueMe, this is because the TeamPhone does not reschedule the rest of nodes for broadcasting distress signals when certain nodes are out of power, which results in the higher schedule vacancy time. In Subfig. 6(b), as the number of cliques increases, the overall schedule vacancy time increases. However, the RescueMe achieves a better performance than TeamPhone. This is because the RescueMe reschedules the network to fill in the empty time interval, which results in the lower vacancy time.

V. Conclusion

In this paper, we proposed a smartphone-based self rescue system to assist the operations of disaster rescue and relief. The basic idea of RescueMe is that a set of smartphones carried by survivors trapped or buried under the collapsed infrastructure forms into a one-hop network and sends out distress signal in an energy-efficient manner to nearby rescue crews to assist rescue operations. We evaluated the proposed approach through extensive simulation experiments and compared its performance with the existing scheme TeamPhone. The simulation results showed that the proposed approach can significantly reduce the schedule vacancy of broadcasting distress signal and improve the discovery probability with very little sacrifice of network lifetime, and indicate a potentially viable approach to expedite disaster rescue operations.

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