Smartphone Based Emergency Communication

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1 Definition of Basic Terms

We first review the definitions of basic terms appeared in this chapter.

- *Emergency Communications* are communication paradigms that are exploited to support one-way and two-way communication of emergency information between two peers, or within a group of peers.
- *Emergency Communication Networks (ECNs)* are networks organized to convey information over multiple types of communication devices, intended to serve disaster-relief missions during emergency situations such as natural disasters.
- *Disruption/Delay Tolerance Network (DTN)* is a type of computer network architecture that aims to solve the technical issues in heterogeneous networks where the continuous network connectivity is not always available [1]. The examples of DTN networks are those operating in mobile terrestrial or space environments.
- *Edge/Fog Computing* is a computing paradigm that brings intelligence and processing capabilities closer to where the data originates from sensors, actuators, relays, etc. Therefore, it does not need to send the data to a remote cloud or other centralized systems for processing. Taking advantage of Edge Computing, the distance and time consumed in sending data to centralized sources can be eliminated, such that the data transportation and service performance are able to much improved.

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R. Akerkar (ed.), *Big Data in Emergency Management: Exploitation Techniques for Social and Mobile Data*, https://doi.org/10.1007/978-3-030-48099-8_7

2 Introduction to Smartphone Based ECNs

Large-scale disasters such as devastating earthquake, flood, wild fire and tsunami bring severe damages to telecommunication infrastructures, and incur massive blackouts to the affected areas. It usually takes months to recover the damaged infrastructures. Thus, aiming to satisfy the sharply growing communication demands and reduce loss of lives and properties, the ECNs [2] need to be immediately established to response to post-disaster missions. ECNs are designed to provide reliable communications under emergency [3]. For example, the ECN Center can collect messages from disaster areas and notify the rescue team members the required actions for disaster-relief.

2.1 Background of Smartphone Based Networks

Nowadays, smartphones are pervasive in our daily life. In each of them, various sensors such as GPS, cameras, compass, gyroscopes, microphones and light sensors are embedded inside. Thus, when a group of smartphones connect to the Internet through cellular or WiFi networks, or when they connect together under a certain topology using the built-in bluetooth technology, a sensor network is actually constructed and can be exploited to organize ECNs for disaster-relief tasks.

Smartphone based ECNs have attracted enormous attention in recent years. In this chapter, we first review the state-of-the-art smartphone related disaster-relief efforts. We then reveal the open issues and future research directions.

2.2 Overview of ECN Architecture

Through Fig. 1a, we have an overview of the typical smartphone based ECNs. When disasters attack, the affected areas will be usually divided into multiple communities. Due to the damage of the telecommunication infrastructures, these distributed communities potentially disconnect from the Internet and form isolated “islands”. As illustrated in Fig. 1a, to build network connection, the approaches exploiting vehicular mobile stations [4–8] and DTN techniques [9–13] have been widely studied. In the communities where vehicular mobile station can go through, people could use the social media apps such as Twitter, Instagram, etc., to communicate with their family members and friends with the Internet connection provided by the mobile stations. In the communities where the mobile stations cannot reach, community residents could share content with their smartphones based on Unmanned Aerial Vehicle (UAV) and Device-to-Device (D2D) technologies. Meanwhile, smartphones can also help to collect data from the Internet of Things

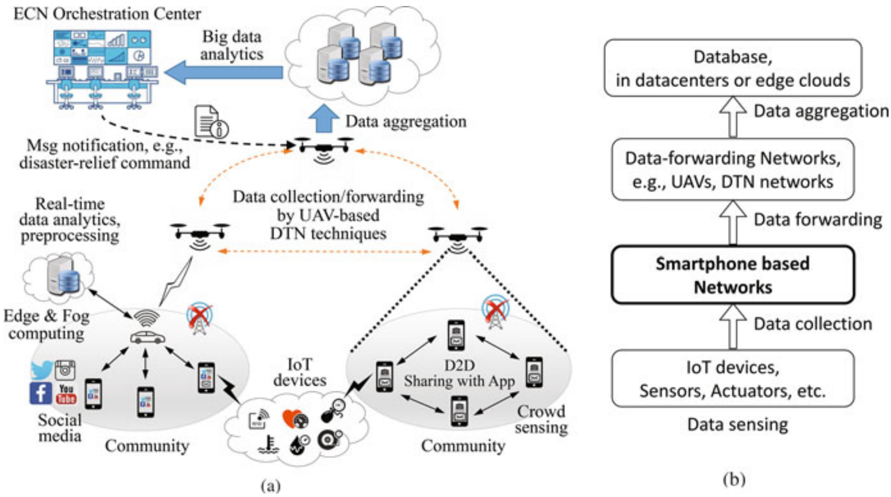

Fig. 1 The overview of smartphone based ECN architecture and the corresponding data-transmission stages. (**a**) Smartphone based ECN architecture. (**b**) Data-transmission stages

(IoT) devices deployed in disaster areas. Then, all the collected data originated from disaster scenes can be gathered by the mobile stations and finally aggregated to the database that locates in remote cloud for big data analytics. By invoking the big data technologies, critical useful information can be mined. For example, the occurring probability of disasters can be predicted using historical records. These useful information is delivered to the ECN Center, which will help make the disaster-relief decisions, e.g., evacuation guidance and rescue commands. In particular, in the edge networks where edge servers are deployed, the real-time data analytics and data preprocessing can be accomplished by exploiting the edge computing technologies [14].

To precisely draw the relationship between ECN components, we use Fig. 1b to illustrate the stages of data-transmission from *sensing* stage to *aggregation* stage. We can observe that the *smartphone based networks* play an important role that bridges the bottom device-layer and the data-forwarding networks. Especially under the ECN scenarios where the UAVs and other DTN network components are constrained by energy limitation, weather conditions and various disaster aftermath, smartphone based networks are much easier to establish comparing with other DTN networks, thanks to the pervasive mobility of smartphone holders, i.e., human. Therefore, smartphone based networks provide the powerful *data collection* functionality for ECN.

2.3 *Key Concepts for Emergency Management*

2.3.1 Situation Awareness (SA)

Situation Awareness (SA) is a procedure to perceive the environmental events and elements in either time or space dimension, aiming to know the comprehensive understanding of their meaning, and the projection of their future status [15].

The SA information plays a significant role during disaster-relief, because the ECN Center makes rescue planes for rescue teams relying on the onsite situations such as road damages, resident distribution, resource requirement, medical demands, and so on. Thus, it is critical to timely sense the situation awareness information for ECN management. Based on the pervasive sensor-equipped smartphones, the *opportunistic sensing* technology [16] has been considered as the promising paradigm for scalable context monitoring, such as the large-scale crowd-behavioral sensing and environmental monitoring. Especially, the *crowd-mobility* study, such as prediction of crowd mobility in public areas [13], is obviously very useful for guiding evacuation when disaster occurs, to avoid the casualties caused by chaos and panics in the crowd.

2.3.2 DTNs

As we have mentioned, communities in the disaster area may be separated to multiple isolated ECNs, incurring that the end-to-end connection cannot be established. The approaches to construct an ECN by exploiting mobile stations and aerial vehicles [4–8] are options under DTN theories.

2.3.3 Big Data Analytics

A large volume of data can be collected from various sources such as the IoT devices deployed in disaster scenes, smartphone based networks, and social media networks. Then, with the collected data, *big data analytics* is essential to understand the situations in each disaster site, because useful information can be extracted from the collected raw data for situation awareness. For example, a number of recent studies [13, 17–20] have retrieved meaningful information by specifically focusing on analyzing the social media data such as Twitter or Facebook datasets, to response to disasters and manage the emergency networks.

2.3.4 Edge/Fog Computing

As reported in a white paper of Cisco [21], there will be 50 billion things to connect to the Internet by 2020. Such a large number of IoT devices will produce tremendous volume of data that needs to be processed and analyzed. Similarly, as shown in Fig. 1a, in the post-disaster scenes, the IoT devices deployed in the disaster areas and the smartphones themselves can yield a large volume of raw data. To retrieve the real-time useful information for rescue teams, the collected data requires distributed onsite processing. However, the conventional cloud based data processing paradigm needs to direct the data streams to the servers located in the remote cloud for processing or computing. This traditional paradigm results in unacceptable performance under disaster scenarios. *Edge computing* [14] and *fog computing* [22] are proposed to mitigate the workload in conventional datacenter servers by processing local data on the computing nodes located at the edge of networks. Thus, it is necessary to adopt the techniques of edge computing and fog computing to reduce the situation-awareness delay and improve the quality of service in the smartphone based ECNs.

3 Data Source

Generally, any text messages, GPS traces, images and videos reflecting the situations of disasters are greatly helpful for disaster-relief. In this section, we introduce several representative datasets used in ECNs, such as the data for capturing crowd mobility, for estimating the distribution of victims, and for better situation awareness. The brief features of the typical datasets are shown in Table 1.

3.1 Mobility Related Datasets

The mobility pattern analysis towards human or vehicles benefits the evacuation when disaster occurs. For example, to know the road conditions such as blocked, damaged or normal, and the mobility of the crowd determines the rescue plans directly. The typical datasets related to crowd mobility can be found as follows.

The floating car data is sensed and collected from the cars under driving by the mobile devices such as smartphones holding inside cars. For example, to predict the traffics in highway of Rome, Fabritiis et al. [23] successfully estimated the mobility patterns by analyzing the floating car data that was collected from a large number of cars. Then, Ganti et al. [24] studied the movement patterns of the taxi passengers by analyzing the floating car data from taxis.

Table 1 Typical datasets for smartphone based ECNs

Datasets	References	Significance for disaster-relief
Floating car data	[23, 24]	To estimate traffic mobility patterns in disasters
GPS trace data	[25, 26]	To estimate human mobility patterns in disasters
Social media data	[13, 17–20, 27]	To retrieve situation-awareness at disaster scenes

GPS traces of mobile-phone users have been exploited to estimate people who are traveling in urban areas. For instance, in [25], the GPS traces obtained from mobile phones during some social events such as sport games and sudden entry/departure in transport stations, were used to study the correlations between crowd mobility and special events. Horanont et al. [26] analyzed the discerning behavior change during the evacuation after the 2011 Great East Japan Earthquake using the large-scale GPS trace samples.

3.2 Social Media Related Datasets

People who are close to the disaster scenes may post the real-time texts, images, and even videos to the social media such as Twitter, Facebook, Instagram or YouTube. Therefore, social media data captures the first-hand dynamic information at disaster scenes, and it has significant value to disaster-relief. Some examples of using social media data are presented as follows.

The analytics on Twitter dataset has been used in the response to Great East Japan Earthquake [17]. Also, the Twitter dataset has been used to estimate the density of victims via analyzing the distribution of Twitter messages in the post-disaster areas [18]. However, the accuracy of this approach is not convincing, because not everyone has a Twitter account, and not everyone will pose a Twitter when disaster occurs.

Musaev et al. [19] first proposed a rapid ensemble classification system to monitor natural disasters by exploiting the social media texts, such as Twitter data. In this study, the proposed approach specifically addressed an unique challenge caused by multiple meanings of the search word. Furthermore, Musaev et al. [20] developed an online disaster detector that collects keyword related events and particularly supports multiple-language, based on the Twitter social media data.

Higashino et al. [13] presented a smartphone based crowd and event detection architecture, in which the data source from Twitter social media has been used. At first step, the correlation between popular words in the Twitter dataset is analyzed to extract the event keywords. Then, the crowd information is shared among smartphone apps and uploaded to could servers for matching keywords with the event database. In this manner, the presence of crowd in real world could be detected, and the reason behind the crowd event can be also estimated. This is very useful to public safety, because some dangerous events, such as fires and terrorist attacks, could be timely identified to raise an alarm.

In addition, Giridhar et al. [27] developed an adaptive localization algorithm that localizes urban events using the set of pictures retrieved from the Instagram images containing the specified tag keyword.

4 Methodologies and Key Techniques

In this section, we review the state-of-the-art existing methodologies and key techniques in the smartphone based ECNs (Table 2).

4.1 Construct ECNs by Ad-hoc Networks and DTNs

To quickly response to disasters, recent studies [9–13] explored the techniques of ad-hoc networks, opportunistic networks and DTNs to construct ECNs in the affected disaster areas for the survivability and evacuation of victims. For example, Based on the DTN communication techniques, Trono et al. [12] developed a smartphone application called DTN MapEx, which generate and share maps of disaster areas by exploiting multiple nodes in the system. This application can minimize the individual computational workload, since the map generation tasks are shared within all mobile sensing nodes in DTNs. Higashino et al. [13] have launched a research project for disaster mitigation, leveraging the DTN-enabled distributed micro-modules. In their approach, a smartphone-based crowd-event detection architecture has been designed.

4.2 Data Collection and Aggregation in ECNs

4.2.1 Mobile Base Stations

To better understand the situational awareness of disasters, data collection and aggregation are the main tasks in ECNs. A handful number of studies [4–8] realize such missions by applying the vehicle-based or aerial-based mobile base stations. For example, Gomez et al. [4] presented the outcomes of the ABSOLUTE project

Table 2 Key techniques and methodologies of smartphone based ECNs

Contribution	References	Key techniques and methodologies
Construct ECNs	[9–13]	Proposed approaches to communicate in ECNs by ad-hoc networks, Opportunistic networks and DTNs
Data collection and aggregation	[4–8]	Proposed mobile base-station, like UAV, based mechanisms
	[28–31]	Proposed Device-to-Device (D2D) communication based mechanisms
	[32–36]	Proposed crowd-sensing based mechanisms
	[37, 38]	Proposed satellite based technologies for network discovery and connection

[28], in which a low-latency IP mobile network with large coverage has been prototyped by combining aerial, terrestrial and satellites communication networks. In particular, the aerial base stations have been implemented as the main components to provide resilient communications for the mobile devices in disaster scenarios. A low cost balloon based Network [6] has been proposed for the post-earthquake rescue. Li et al. [5, 7] proposed to build a disaster management network based on mobile stations implemented by drones and vehicles, in which sensors and network connection interfaces are equipped. Via this framework, a lot of disaster management tasks can be achieved, such as sensing damage conditions, information collection and message delivery in disaster areas. Then, Narang et al. [8] proposed to build a cyber-physical buses-and-drone based mobile edge infrastructure for the emergency communications in case of large scale disaster, in which the cellular infrastructures have been destroyed.

4.2.2 D2D Communications

Many recent works in the literature have explored D2D communications to extend the network coverage, especially in the context of disasters. For example, Wu et al. [29] exploited smartphones as the medium to collect and disseminate messages in a natural disaster network while the traditional cellular base station is inaccessible. A modified epidemic routing protocol is also proposed to enable smartphones working collaboratively in D2D manner in disaster environments. In the ABSOLUTE project [28], the short-distance D2D communications are applied for rescue teams and emergency agencies when the conventional network infrastructure have been damaged in disasters. Orsino et al. [30] studied the social-aware data collection and information diffusion using D2D communication techniques. The proposed approach can be applied to the emergency networks for public safety. Based on D2D communications in ad-hoc network, Meurisch et al. [31] recently proposed an emergency communication system called NICER911, aiming to provide reliable communication and emergency services in infrastructure-less disaster areas.

4.2.3 Crowd Sensing

To enhance situation-awareness in disaster scenes, the existing studies [32–36] have developed impressive smartphone based crowd sensing techniques. For example, Higuchi et al. [32] proposed a low power cooperative localization algorithm that captures the stop-and-go behavior of indoor pedestrians. Based on the cooperative operations among multiple smartphones, Noh et al. [33] developed an infrastructure-free localization identification technology with high-speed positioning effect. Kojima et al. [34] proposed a new application that estimates the reason behind the scheduled human crowd events using the mobile crowd sensing techniques. To improve the rescue efficiency in terms of bandwidth utilization and energy consumption, Zuo et al. [35] explored the image sharing mechanism that acquires significant onsite situation-awareness information of disasters, e.g., earthquake and Typhoon. In this mechanism, the shared images are collected via the smartphone based crowd-sensing techniques. Based on the fact that a camera can help rescue team well identify the situation-awareness information, e.g., victims trapped in a disaster, Dao et al. [36] implemented a network of cameras with smartphones, which energy-efficiently coordinates among the built-in cameras to transmit the objects detected with high accuracy.

4.2.4 Satellite Based Technologies

Pal et al. [37] proposed a novel WiFi tethering strategy based on smartphones to construct a disaster-relief network architecture, named E-Darwin2. The satellite and its modem in the proposed architecture play the roles of a network gateway and an intermediary cell tower for discovery and connection device. Huang et al. [38] studied an energy-efficient online data upload scheme for geo-distributed IoT networks. Because the low-earth-orbital satellites have global coverage, it is easy to aggregate the data collected by smartphones when satellite modems are configured as gateways in the isolated disaster communities.

5 Real-World Applications and Case Study

In this section, we first review the real-word applications related to the smartphone based ECNs. Then, a case study is presented in the context of disaster management.

5.1 Dedicated Smartphone Apps For Disaster-Relief

Peng et al. [39] developed a bluetooth based smartphone app named "E-Explorer", which can deliver rescue information for the survivors trapped in post-earthquake sites. Then, Han et al. [40] extended the aforementioned iOS based application E-Explorer to other platforms, to better support the emergency communication and fast investigation of damages on the post-earthquake circumstance. Recently, to efficiently response disasters such as large-scale earthquake and tsunami, Miyazaki et al. [41] developed a resilient information management system, which can be executed on Android and iOS platforms and bring convenient information management and data exchange functionalities between rescue teams and victims in disasters. Chiou et al. [42] proposed a mobile emergency system (MES) that can be used in houses, hospitals, and other nursing facilities offering continuous care services for elders and disabilities. The proposed emergency rescue alert system is implemented on Android smartphones, and is able to provide the security and privacy-preserving functionalities, including authentication, location confidentiality, data integrity and anonymity. Kau et al. [43] implemented a smartphone app that can detect the user fall-accidents, perform location positioning, and communicate with the rescue center for assistance.

To detect faces efficiently in a wireless on-demand emergency network, Lampe et al. [44] proposed a smartphone based app, which performs face detection in local mobile devices by exploiting a two-stage combination of existing algorithms.

5.2 Case Study: Resilient Information Management (RIM) System

We now present our previous project named RIM system [41] as a case study for serving ECN. In the proposed RIM system, the smartphone- and UAV-based integrated network aims to provide more delay-efficient and reliable solutions in many harsh disaster environments where conventional cellular communication infrastructures have been almost unavailable or severely damaged. At these crucial scenarios, although the ad-hoc mobile social networks built through mobile devices such as smartphones are the most promising communication approach, the delivery delay could be very large, leading to unacceptable performance for disaster-relief tasks.

As shown in Fig. 2, to reduce the delivery delay, we propose to use the UAVs that are equipped with wireless communication capability. They are controlled to travel along the designed routes, collect the information such as damage conditions, injuries and medical demands, from certain specified sites, and deliver the gathered data to information center. Through this way, the delivery latency of the emergency information can be reduced greatly compared with the systems that rely on the ad-hoc communication paradigm.

Under this smartphone and UAV based architecture, we have designed an integrated information management and sharing mechanism benefiting both rescue teams and victims [41]. Also, an online algorithm that addresses the disaster management tasks with different weights have been proposed by dynamically scheduling mobile stations [5]. Besides, some problems under the RIM system will be studied in the future work, e.g., the energy-efficient schedule of drone-route during the data collection and aggregation missions.

6 Challenges and Open Issues

6.1 Key Challenges of Smartphone Based ECNs

Some notable challenges in smartphone based ECNs can be summarized as follows.

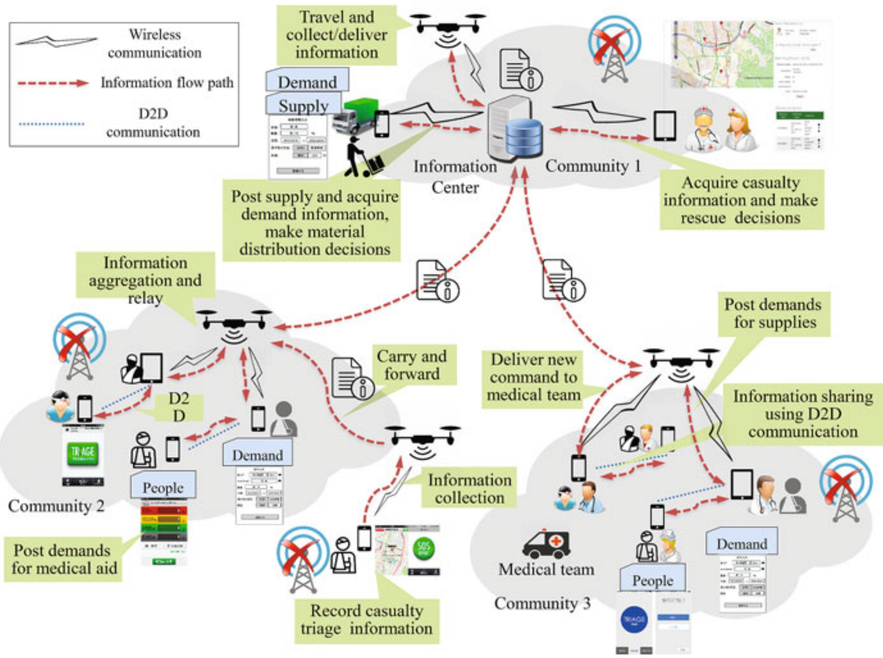

Fig. 2 Case study: the smartphone and drone based resilient information management (RIM) system

- The constrained battery budget of the sensing devices in disasters, e.g., sensors, cameras, smartphones and drones.
- Long delay to grasp the situation of the entire regions in real time. Massive power/network outages make the grasping delay even longer.
- Safe evacuation for the crowd when disaster occurs in the indoor environments.

Disaster possibly destroy the power supply infrastructures and cause massive outage. Thus, maintaining the alive status of the big number of sensing devices with limited power budget becomes an intractable challenge.

Service delay is always the key metric concerned by the literature on DTNs. Although the state-of-the-art techniques and technologies such as UAV based mobile base stations and D2D communications, have been exploited in ECNs, the inter-community delivery delay still cannot be reduced to online service level for disaster communications.

During disaster scenarios in urban districts, for example, big fire occurs in a tall building, or explosive incidents hit the public crowd areas, people are every easy to get into panics and cause casualties. Thus, to provide the efficient evacuation guidance to the crowd is of great significance. This can be realized by studying the mobility of the crowd during disasters. The existing related studies on estimating crowd mobility [32–34] still cannot fulfill the rigorous requirement of safe evacuation for everyone. It can be seen that safe evacuation for the crowd still remains as an intractable challenge in the field of disaster-relief.

6.2 Open Issues and Future Directions

6.2.1 Reliable and Efficient Disaster-Relief Architecture

First, it is an open problem to build a high reliability disaster-relief architecture that can handle the disaster data-sensing and aggregation efficiently in terms of energy and delivery delay. The trade-off between detection accuracy and energy consumption should be emphasized.

6.2.2 Recognition for Indoor Environments

The GPS signal is only available in the outdoor environments, resulting in that GPS based technology is not applicable to the indoor localization and tracking. Therefore, the smartphone based approaches that can actually track human mobility and recognize human behaviors in the indoor environments are in urgent need to satisfy the requirement of disaster-relief applications. For example, Berbakov et al. [45] proposed an indoor positioning system that exploits the built-in inertial sensors of a smartphone to realize the situation awareness in emergency contexts. This work motivates us that various other smartphone sensors are able to be applied to implement the indoor recognition applications.

6.2.3 Fast Data Aggregation

To understand the disaster situations from the collected data, machine learning based classification is a popular approach to recognizing different contexts. On the other hand, to build a machine learning model for classifications, sufficient volume of training data is needed. This implies that to quickly aggregate the required amount of training data samples is a critical problem. Furthermore, since large-volume of sensing data needs to transmit to aggregation gateways, it is crucial to schedule the efficient data delivery such that the data-loss ratio is minimized in DTN based ECNs.

6.2.4 Deployment of Computing Resources

With the collected data that needs to be processed to quickly retrieve the meaningful information for evacuation and rescue, several groups of edge servers might work in a decentralized manner at real-time. Consequently, the deployment of the data processing/computing resources while coordinating with data-collecting devices becomes another open problem.

6.2.5 Privacy

Privacy is an important issue that should not be ignored in the smartphone based ECNs. To achieve situational awareness, data needs to be collected from both public and private sensor networks, and smartphone based applications. This results in privacy issues. Because the existing social medias are used with the annotation functionality, through which some private information of users such as personal home address, daily office routines and social activities could be easily inferred from the multimedia data including images, audio records and videos posted on their social media networks. In order to preserve the privacy of users, social medias usually allow them to tune the privacy level when they are sharing something online. This leads to a trade-off between the privacy-preserving level and situational awareness performance in ECNs: strict privacy control limits the useful information that is aware from disaster scenes.

6.2.6 Emotion Sensing

We notice that the *emotion sensing* [46] is an emerging topic in the smartphone based data analytics. Especially, under disaster scenarios, to know the emotions of victims is great helpful to their emotional care, so as to help them overcome difficulties and recover from disasters. Although some recent studies [47, 48] have conducted the sentiment analysis based on Twitter datasets, it is still a challenge to estimate the psychological status of people with high accuracy in the context of disasters. This poses an interesting open problem for the smartphone based ECN management.

6.2.7 Smart Cities with Integrated Disaster-Relief Infrastructures

Finally, establishing the smart cities with resilient disaster recovery capability is a promising direction for the future sustainable development of human. To achieve this goal, the integrated disaster-relief infrastructure equipped with multiple heterogeneous technologies including satellite communication networks, aerial-vehicle based networks and ground smart-device networks, should be exploited and developed. On the other hand, the efficient distributed algorithms that can work in the decentralized and autonomous environments are also needed to coordinate with the integrated infrastructure.

6.2.8 Bridging IoT Networks and UAV Systems

As illustrated in Figs. 1a and 2, in the isolated disaster communities, smartphone based networks can be treated as the bridge between IoT Networks and the UAV based data collection systems. Although UAVs have flexible flying trajectories, which make them easily aggregate the distributed disaster data to the central database. However, because of the on-board energy limitation, UAVs are impossible to travel every corner to collect data generated from the widely distributed IoT devices. Thus, smartphones can be exploited to bridge the data-transmission between IoT devices and UAVs. With the three primary components of ECN, i.e., smartphone networks, IoT networks, and UAV systems, the time- and energy-efficient collaborative data collection, forwarding and aggregation strategies are expected to design as open issues.

7 Conclusion

In this article, we have reviewed the basics and the state-of-the-art research efforts on smartphone based ECNs. Some key techniques and technologies are summarized. A real-world project, RIM system, is also exhibited as a case study of the smartphone based ECN. Some open problems and future research directions are discussed finally.

Exercises and Mini Projects
At the end of this chapter, we supplement several exercises, programming problems, or mini projects for student readers.

(1) Design an ECN architecture/system that enforces smartphones to collaborate with IoT devices, sensors or actuators for *data collection* stage.
(2) Design an ECN architecture/system that integrates smartphones and UAV based system for *data forwarding* stage.
(3) Develop smartphone applications using open APIs of social media such as Twitter, Facebook, Instagram, etc., to accelerate *data collection* or *data forwarding*.

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