Smart Disaster Response Through Localized Short-Term Cooperation

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Abstract. As the information and communication technology (ICT) has advanced, research on smart cities that take advantage of ICT has been extensively conducted to improve resource management and enhance citizen's quality of life. Disaster management is a critical component in smart cities to secure citizen's safety. From experiences with recent disasters such as tsunamis, earthquakes, and hurricanes, we can easily find evidence that shows an urgent need for intelligent disaster management systems. In a disaster situation, a disaster response system must address not only long-term needs that require continuous disaster recovery, but also short-term needs that require ephemeral cooperation between people and smart devices nearby. However, existing disaster-responsive applications have been based on pre-established long-term relationships and focused on communication among human users. To address the limitation of disaster management, in this paper, the smart disaster response system (DRS) is proposed. The Smart DRS allows connectivity among users and sensing devices with short-term relationships based on geographical location within. The approach allows effective sharing of disaster information and immediate cooperation within communities in a manner that reconciles with requirements of security and privacy.

Keywords: Smart city · Disaster response system · Temporary social network · Overlay network · Localized cooperation

1 Introduction

As evidenced by experience from recent natural disasters such as the Tsunami and earthquake in Japan, and Hurricanes in the USA (Sandy and Katrina) and Haiti (Fay, Gustav, Hannah, and Ike), it is essential to develop smart disaster response systems in order to secure citizen's safety in smart cities. In a disaster situation, long-term needs coexist with short-term needs that must be addressed in a timely fashion. For examples, people in disaster areas need to continuously receive updated disaster data that are related to local areas (such as flooded areas nearby or the collapse of the nearest freeway) to exactly know the situation of the surrounding areas and quickly escape from disaster areas, as well as related to the overall situation, such as the path of a Hurricane. One of

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the short-term needs arise in search and rescue situations, where it is critical to dynamically establish communication between citizens in distress and nearby emergency response personnel.

The ubiquity of smart mobile devices and the advent of online social networks (OSNs) have enabled a paradigm shift in how users interact with each other, allowing unprecedented ease in discovering and communicating with their peers at anytime and anywhere. To respond to disasters using such emerging technologies, some mobile applications have been developed, such as the Shelter Finder App of the Red Cross [1], the Outbreaks Near Me App of the HealthMap [2], the Disaster Alert App of the Pacific Disaster Center [3], the SOS+App [4], and the HelpBridge App of Microsoft [5]. However, current mobile applications focus on sharing or alerting of general emergency events, and do not fully exploit the potential benefits of tapping into mobile devices and OSNs in enhancing the ability of users to organize disaster-responsive communities and cooperate with each other during emergencies. For example, in a search and rescue scenario, a distressed person with a mobile device can potentially use sensor information (GPS coordinates, images and audio) in combination with user-input messages to a disaster community of nearby users as valuable information to assist in their rescue. To this end, the following challenges must be addressed.

1. It is desirable that users are able to establish short-term social relationships to peers that may not be in their circle of friends, such as other users who are nearby within a geographical area. Typical OSNs, however, connect users to friends who are selected by users themselves based on relationships built over a long period of time. In disaster situations, in which short-term relationships with strangers are necessary, users may not be able to effectively discover and communicate with others who may be in the best position to provide help, such as nearby emergency response teams. Existing OSNs are thus fundamentally hindered by these constraints.
2. Existing centralized OSNs may become unavailable during a disaster due to outages in the network. For instance, users may not be able to connect to the central services of Twitter [6] or Facebook [7] in a disaster situation. Furthermore, considerations on performance, capability, and privacy are additional limitations of traditional OSNs, as they require all information to be processed by (and shared with) a provider.
3. Real-time processing and sharing of local disaster data captured by environmental sensors and people in the surrounding areas is essential for effective evacuation and rescue. Furthermore, disaster data must be retained for disaster recovery in the future. However, centralized data management may not be working in a disaster situation.

To meet the challenges above, I propose a smart disaster response system (Smart DRS) that operates on the basis of on-demand collaboration between eligible objects, including smart devices and users nearby, over ad-hoc social networks. The rest of the paper is organized as follows. In Sect. 2, I describe our vision for innovative disaster response and identify the contributions of the Smart DRS. In Sect. 3, I explain an overall architecture and operational flow and then describe an example use case. In Sect. 4, I present evaluation plans and, in Sect. 5, provide a comparison with existing approaches for location-based disaster response. In Sect. 6, I summarize our contributions and future research directions.

2 Disaster Response in Smart Cities

2.1 Requirements for Innovative Disaster Response

To guarantee the safety of citizen, a disaster response system needs to support the following features.

1. **Creation and maintenance of localized disaster community** – As stated earlier, in disaster situations, localized communities can play a key role by enabling people closely located each other to receive sensing information from nearby sensors, share local information, and provide/obtain help to/from nearby people. OSNs have great potential to facilitate wide and rapid dissemination of disaster information and recruitment of nearby people because of its huge user set and, in fact, many location-based social networks (LBSNs) have been proposed. However, existing LBSNs have not much considered relationships between human users and devices such as sensors and mission-oriented cooperation.
2. **On-demand creation and management of ad-hoc localized social networks** – As users are increasingly interacting with peers through OSN services and applications, OSN services that mediate user communication raise major concerns in performance, fault-tolerance, and privacy. Therefore, it is required to dynamically establish and maintain connections between peers without interference of a centralized server.
3. **Localized disaster data management** – For more prompt process and analysis of localized disaster information, distributed management of disaster data management is required. Furthermore, disaster data can be retained even if infrastructures and central data servers are destroyed.

2.2 Disaster Response with the Smart DRS

The Smart DRS allows users to effectively cope with a disaster by discovering essential sensors and users who can give vital information and help and communicating with them using their mobile devices. It dynamically creates ad-hoc social overlay networks that encompass mobile devices of users and sensors to enable real-time information sharing and knowledge creation on top of in a peer-to-peer (P2P) so that it is not constrained by the availability, capability and privacy considerations of central services. The followings are the contributions of the Smart DRS.

1. **Short-term static and dynamic localized disaster community** – The Smart DRS extends the organization and cooperation mechanism of Whistle [8] that creates a large-scale user pool with structured user contexts while minimizing user interference, searches the most suitable user in real-time, and organizes emergency communities with eligible and available users. Unlike Whistle, in the Smart DRS, environmental sensors can be also a community's members. Basically, the communities are divided into two types, the static community and the dynamic community. A static community is a location-based community that is automatically created by a corresponding a local manager when a disaster occurs, while a dynamic community is a goal-oriented community that is created upon a distressed person's request by

one or more local managers. To organize more effective communities, the Smart DRS searches suitable objects in real-time and search criteria can be varied depending on a community's goal. Once a community is created, members start to communicate and cooperate with each other. Currently, the Smart DRS is supposed to provide four types of cooperation services: (1) Posting (Passive information sharing), (2) Alerting (Active information sharing such as notifying users in disaster area), (3) Donate (Passive cooperation such as donation of water, food, or shelter), and (4) Rescue (Active dynamic cooperation between users and smart devices).

2. **Ad-hoc localized social overlay networks** – The Smart DRS requires instant peer-to-peer (P2P) communication among social peers nearby. To this end, the Smart DRS leverage SocialVPN [9] to incorporate bootstrapping through social connections. SocialVPN is a network overlay technique that embed social links in its topology by providing virtual private IP networking, in order to support mobile peers, unstructured P2P routing, and network resilience. At the networking layer, the overlay can be visualized as a communication system where every participating device (e.g. mobile, desktop, or cloud instances) has virtual private links to each of their social peers that are determined based on their proximity. Such an overlay provides a foundation to address privacy, fault-tolerance and performance concerns. This is because it allows users to leverage OSN services to discover and establish peer relationships, while bypassing the centralized service to communicate with social peers. Direct peer-to-peer communication is important when privacy is desired, when the exposed OSN interfaces are performance-limiting and/or limit scalability (e.g. OSN imposes limits on size or rate of requests), or when the OSN service is unavailable.
3. **Hybrid-decentralized management of disaster data** – A localized disaster communities can take an important role of sharing and retaining of disaster data. In the Smart DRS, each disaster community is able to provide vital information about disaster to community members and store disaster data in a community manager node or member nodes. While localized communities deal with localized data sharing and processing, a centralized disaster management system gathers all disaster data from local communities and conducts a comprehensive analysis on them.

The Smart DRS consists of three response layers as shown in Fig. 1: the physical layer, the localized response layer, and the generic response layer. The physical layer represents our real world, and contains immobile objects (such as local managers and fixed sensors) and mobile objects (such as human and vehicles). Each object is an end node of a disaster-responsive social network and has short-term connections with previously-unknown users and sensors in order to effectively respond to disasters. Ordinarily, each user performs normal social networking tasks – for example, posting a message and making friends through existing OSNs. When a disaster occurs, users, who turn on the proposed disaster response application, are automatically involved in the nearest local community based on their current locations, and are able to communicate with their nearby friends. Furthermore, if necessary, a rescue community consisting of necessary objects can be dynamically created for active cooperation. The major objective of the localized response layer is to manage local communities and local disaster data. In the generic response layer, a centralized disaster management system collects and analyses all disaster data and announces generic disaster situations.

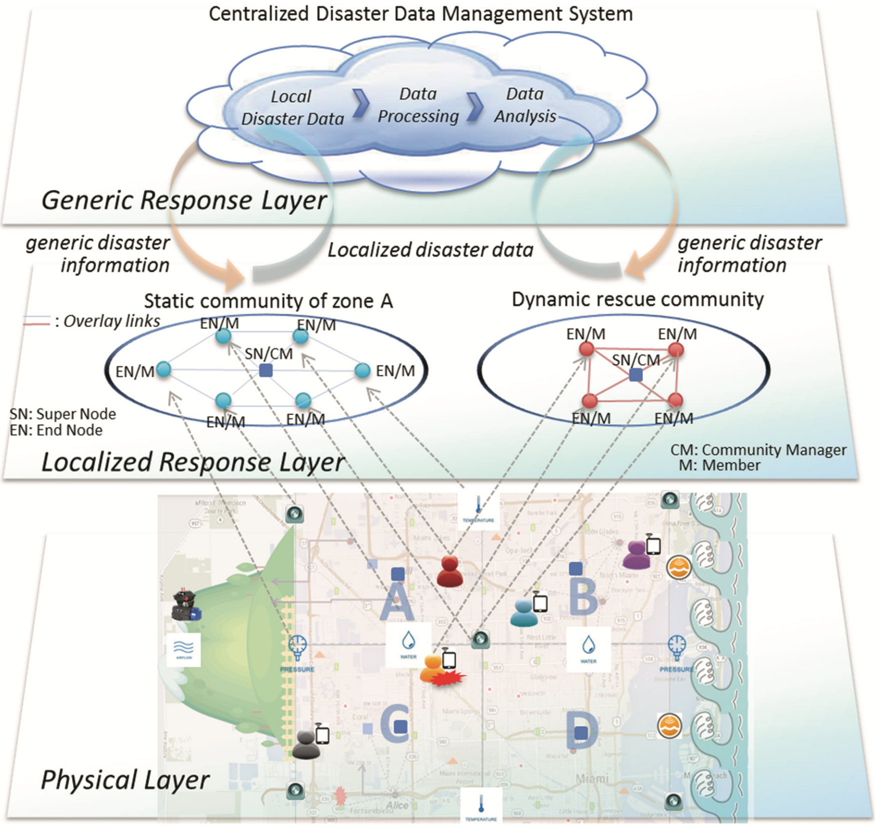

Fig. 1. Disaster Management with the Smart DRS

Unlike existing disaster response applications using pre-established relationships only and focusing on comprehensive analysis on disaster data in a centralized fashion, the Smart DRS allows people to communicate and cooperate with necessary peers regardless of long-term relationships within geospatial proximity and a common goal. With the Smart DRS, distressed people can give and receive vital information as a data provider and consumer, and furthermore actively contribute to the rescue of people in danger. From the perspective of disaster data handling, the Smart DRS employs local managers that govern local communities, initially process local disaster data, and deliver data to the central server. This approach allows providing and storing disaster data associated with certain geospatial area for effective post-disaster management and disaster modeling, even if the connection to the central DRS is damaged.

3 Smart Disaster Response System

3.1 Architecture

The Smart DRS consists of a number of local managers and object applications that are connected through disaster-responsive social networks as shown in Fig. 2.

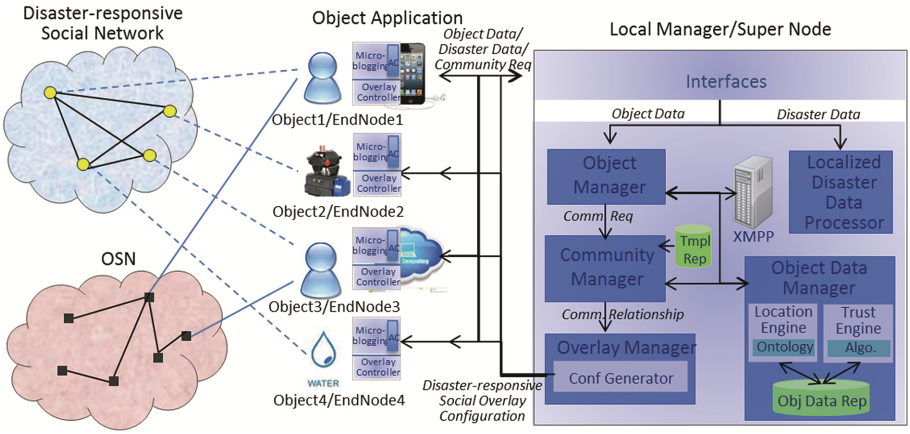

Fig. 2. Overall architecture of Smart DRS

A local manager is a trusted party that complies with laws and regulations relevant to privacy protection and it consists of five components below.

- **Object Manager:** The main task of this component is to handle objects' entrance and leaving by interacting with a local manager's own XMPP server which acts as an OSN server. The Object Manager receives an object's XMPP account when the object enters a zone assigned to a local manager, and shares that account information with the Community Manager and the Object Data Manager.
- **Object Data Manager**: This component manages object-related data, including dynamic location information and trust values of objects. If requested, it searches eligible objects based on objects' conditions in real time.
- **Community Manager**: This component aims to organize a localize disaster –responsive community with most suitable users. When receiving a request, it delivers required information specified in a corresponding template to the Context Manager. If the Object Data Manager returns a set of candidates, it checks availabilities of candidates and creates a member list with only available users.
- **Overlay Manager**: The goal of this component is to dynamically create overlay network configuration files for each member so that members can automatically establish social connections among them. To do so, it gets members' XMPP OSN accounts from the Community Manager, generates virtual IP addresses for members, and then distributes the generated configurations to member's applications.

– **Localized Disaster Data Processor**: The module manages disaster data produced by objects, generates information about local disaster situation, and analyzes disaster risks in near real-time. For better scalability, the Localized Data Processor will leverage existing technologies in big data management and cloud computing to accommodate a sudden burst of data flooding from massive population in the future.

An object application is composed of two components: the Overlay Controller, and the Microblogging-based Disaster Communicator.

– **Overlay Controller**: This controller takes responsibility of creating, maintaining, and removing social overlay links. According to a configuration file that the Overlay Manager sent, it establishes ad-hoc overlay connections between members, maintains network condition, and removes connections when cooperation is terminated.
– **Disaster Communicator**: This communicator displays members and enables them to cooperate with each other through a rich set of communication and sharing methods, such as text messaging, text/audio/video conferencing, and file transfer. Each communicator has an Access Controller that prevents indiscriminate sharing of private information and resources based on privacy policies of users and devices. To facilitate immediate yet secure cooperation in disaster situations, the Access Controller should be able to answer to three questions: what should be protected during cooperation for each type of objects; what can be criteria to authorize an access (for examples, an object's status/attribute, access purpose/action, or role); and how we can enforce security policies in a decentralized manner. As an initial step, the Smart DRS leverages the community-centric property-based access control model (CPBAC) [10], a cooperation-aware access control model for OSN users. Since the CPBAC model considers human users only, a more comprehensive model that can be applied to cooperation between sensors and users should be applied in near future.

3.2 Operational Flow

In a disaster situation, the Smart DRS is operated according to the following operational flow.

1. **Object registration** – An object including a user should register in the Smart DRS before taking or giving cooperative help in disaster situation. A user can sign up with his/her existing OSN account (for example, Facebook or Twitter) and enter additional contexts in the central server. With a user's OSN username received from the Object Manager, the Object Data Manager fetches various user data from an OSN using APIs that the OSN provides. Once the Object Data Manager retrieves all related data from the OSN, the Object Manager creates a sticky object data set, encrypts the sticky data set with its private key, and sends it to the object.
2. **Object joining in a static disaster community** – When a mobile object (such as human users and vehicles) enters the zone of a local manager, it automatically sends a joining request with its sticky data set to a local manager. Information about available local managers may be pre-configured in the application, or discovered by querying nearby devices. The nearest local manager receives the request, decrypts

the object's sticky data set with the public key of the central server, and maintains those data until the object leaves the zone.

3. **On-demand creation of a dynamic rescue community across multiple zones** – When receiving a request for disaster rescue from a user, a Community Manager retrieves a community template selected by the requester from the Template Repository and asks the Context Manager to find out candidates who meet eligibility conditions. In candidate search, the primary criterion is users' locations. If there is no eligible users and the local manager broadcasts the request to neighbor managers. After receiving the candidate lists from neighbors, the Community Manager selects best candidates and sends an invitation to each candidate with information about a rescue community. With only available candidates, it finalizes a list of members, while the Overlay Manager creates configuration files for each member.
4. **Secure and unrestricted cooperation among members** – As soon as a member object receives a configuration file and a member list, it establishes ephemeral social overlay connections between members and runs microblogging communicator. All conversations and resources shared through the communicator are protected from unauthorized accesses of non-members by the Access Controller.
5. **Localized disaster data processing** – The localized disaster data processor extracts disaster situations such as local torrential rainfalls in its zone based on user-generated data and sensing data. Note that the third, fourth, and fifth operations can be operated in parallel.
6. **Community dissolution** – When an object is out of the zone, the Object Manager removes the data related to the object. This may be accomplished by obtaining GPS coordinates from the device. In case of a dynamic community, if a community's goal is achieved, a leader of a community notifies members of the end of cooperation, and in turn each object application removes all overlay connections with a community's members.

3.3 Use Case Scenario

For better understanding, we describe an example use cases of the Smart DRS in case of dynamic cooperation for search and rescue. Let's assume that Bob breaks his leg while escaping a disaster area. He sends a request for emergency rescue with his location to its local manager node. Let's assume that Bob gets injured in the zone C (See the Fig. 1). The local manager of the zone C broadcasts Bob's location and necessary capability/object types into neighbor manager nodes in the zone A, B, and D. After receiving response from neighbors, the manager of the zone C federates responses and dynamically creates a rescue community with eligible objects. Finally, two people who are close to him assist in search and rescue. They all then can escape successfully. Compared to existing passive cooperation through OSNs, the Smart DRS can promote active rescue by creating a dynamic community. To protect Bob's privacy, his rescue request and medical/location information are shared with only a few selected members.

4 Evaluation Plan

To test the performance and reliability of the proposed Smart DRS, I plan to evaluate it in two steps: (1) The individual evaluation that tests each component of the Smart DRS and (2) the integrated evaluation that tests the performance of an integrated DRS based on several example scenarios.

For the individual evaluation, I plan to create the set of synthetic data related to users and devices by randomly selecting values among values actually used for each attribute types of objects. To do this, well-known ontologies (for example, GeoNames [11] ontology for location data) and the occupation profiles of the United States department of Labor will be used. Using the synthetic data set, I will evaluate the accuracy and speed of the candidate search algorithm and the effectiveness of the community management model. To test the organization management model and the cooperation model, I plan to simulate objects' cooperation based on few scenarios including members' failures, and evaluate the goal achievement rate. To measure the performance of the access control, I will check the privacy violations rate of shared data and resources. After completing individual evaluations, I plan to develop a prototype by integrating individual components, and test the overall performance of the prototype from the perspectives of localized disaster data processing and on-demand creation of static and dynamic disaster communities.

5 Related Work

Location-based Social Networks (LBSNs) aim to enable social users to share location-embedded information with friends and also make new friends who are recommended based on similarities in locations in the physical world as well as their location-tagged media content [12]. At present, there is a variety of LBSNs; for example, NeerbyFeed [13], Facebook Places [14], and Sonar [15]. According to the study of TNS in 2012 [16], mobiles users are increasingly using location-based services. Around a quarter uses it to find restaurants and entertainment venues (26%) and one in five is using it to find their friends nearby (22%).

Unlike existing LBSNs that are mainly focusing on sharing of geo-tagged information and recommending nearby friends, the Smart DRS focuses on dynamic organization of local communities and cooperation management within communities. Existing LBSNs process location-embedded data in a centralized manner to find interesting places, events, and people, while the Smart DRS processes location-tagged disaster data in decentralized manner to grasp local disaster situations. Above all, existing LBSNs basically consider human users only. In contrast, the Smart DRS aims to create localized ad-hoc social networks that include computing devices, such as sensors and vehicles, as well as users. Furthermore, existing LBSNs is insufficient for disaster response due to lack of real-time organization and cooperation management mechanisms.

6 Conclusions

To address an urgent need for short-term ad-hoc connectivity between nearby people and sensors in disaster situations, I propose a smart disaster response system that enables distressed people to connect with each other regardless of pre-established relationships, share vital information related to surrounding areas, and rescue distressed people without serious privacy loss. For complete disaster response service, the following work should be conducted in the future.

- Distributed data processing under the constraints of computing resources
- Disaster-specific situation model
- Organization, cooperation, trust, and access control model considering sensors as well as human users
- Resilient peer-to-peer overlay routing in situations where the SocialVPN XMPP service is unavailable, or when Internet connectivity of a subset of devices is restricted and only ad-hoc connections to nearby Internet-connected devices (e.g. over Bluetooth) are available.

References

1. Red Cross Shelter Finder App. http://www.redcross.org/mobile-apps/shelter-finder-app
2. Outbreaks Near Me App. http://healthmap.org/mobile
3. Disaster Alert App. http://www.pdc.org/solutions/tools/disaster-alert-app
4. SOS+App. https://plerts.com/mobile-apps/sos-plus-emergency-alert/
5. HelpBridge App. http://www.microsoft.com/about/corporatecitizenship/en-us/nonprofits/Helpbridge.aspx
6. Twitter. https://twitter.com
7. Facebook. https://www.facebook.com
8. Jung, Y., Figueiredo, R., Fortes, J.: Location-based timely cooperation over social private network. In: 10th International Conference on Collaborative Computing: Networking, Applications and Worksharing (CollaborateCom), 25 October, pp. 388–396 (2014)
9. Juste, P.S., Wolinsky, D., Boykin, P.O., Covington, M.J., Figueiredo, R.J.: SocialVPN: enabling wide-area collaboration with integrated social and overlay networks. Comput. Netw. **54**(12), 1926–1938 (2012)
10. Jung, Y., Joshi, J.B.: CPBAC: property-based access control model for secure cooperation in online social networks. Computer and Security **41**, 19–39 (2014)
11. GeoNames Ontology, http://www.geonames.org/ontology/ontology_ v3.1.rdf
12. Zheng, Y., Zhou, X.: Location-based social networks. In: Zheng, Y., Zhou, X. (eds.) Computing with Spatial Trajectories. Springer, New York (2011). ISBN 978-1-4614-1629-6
13. NeerbyFeed. http://www.nearbyfeed.com
14. Facebook Places. https://www.facebook.com/places
15. Sonar. https://play.google.com/store/apps/details?id=me.sonar.android&hl=en
16. TNS, "Two thirds of world's mobile users signal they want to be found", April 2012. http://www.tnsglobal.com/press-release/two-thirds-world´s-mobile-users-signal-they-want-be-found