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Exploring the Applicability of Participatory Sensing in Emergency Scenarios

(Extended Abstract)

Diego Costantini, Andreas Reinhardt, Parag S. Mogre, Ralf Steinmetz
Multimedia Communications Lab, Technische Universität Darmstadt
Rundeturmstr. 10, 64283 Darmstadt, Germany
Email: *{dcosta, areinhardt, pmogre, rst}@kom.tu-darmstadt.de*

***Abstract*—In emergency scenarios, rescuers need specific information about the affected areas. Such information are normally collected by sensors, but sometimes they could not be available because, as a consequence of a disaster, the pre-deployed infrastructure might be damaged, and rescue teams could not easily deploy new sensors in unfavorable conditions. In such situations, it is possible to exploit the victim's devices, already located within the affected area, and powerful enough to provide the needed sensing information (environmental, like smoke and temperature, and personal, like users' biometrics). Furthermore, this paradigm (so called Participatory Sensing), by providing a highly pervasive computing, can drastically save deploying costs for extra sensors. This paper presents the main research challenges expected for participatory and opportunistic sensing in emergency scenarios, and gives insights into possible solutions to tackle them.**

I. Introduction

The ongoing embedding of smartphones with sensors has led to some interesting service, like BikeNet [1], Ear-phone [2], and more. These services are based on the idea that users generate content through their mobile handsets. Such novel means of data acquisition are termed Participatory Sensing [3] or People-centric Sensing [4], and allow many yet unknown services to be realized. In contrast to traditional sensor networks, system architecture in participatory sensing has no control over users' mobility and actions. In fact, the assumptions on scalability, mobility, availability, etc., are in this case completely different [4]. Such issues have recently been faced by researchers, but in this paper we focus on application of participatory sensing to emergency scenarios, an interesting application domain which has not yet received significant attention. In this domain, requirements and constraints are more restrictive than in classic participatory sensing. We believe that using participatory sensing/actuators for emergency scenarios will enable the extension of the existing emergency response infrastructure (e.g., public warning) and also permit faster detection of emergencies with better granularity of sensing in certain scenarios. Additionally, the use of user equipment for sensing brings with it certain benefits:

- Sensors (users' handheld mobile devices) are usually carried by the users without any overhead, and hence provide an ideal platform to gather vital information about the users (who are the primary concern in emergency scenarios) and, at the same time, provide a platform to inform the users about actions to be taken or avoided in an emergency scenario.
- Deployment and maintenance costs for the sensor network are reduced drastically and are borne by the users (willingly, and without much overhead) to a great extent.
- The range of the network can potentially be extended with each new mobile handset being purchased and brought into service by the users, and given the recent numbers forecasting 970 million of smartphone users by the end of 2013 against the 100 million of 2009 [5], the amount of sensors in such a system is expected to grow very rapidly, giving the potential to sense at a granularity (both temporal and spatial) which is not possible using traditional sensor networks.

However, to realize the full potential of the above, certain important research challenges need to be addressed. In Section II we highlight some basic difference between participatory sensing in normal and emergency scenarios and we provide a concrete reference scenario to better understand the implications of our assumptions. Our contributions in Section III are: (1) an outline of the most critical and interesting research challenges detected for the reference emergency scenario, and (2) some insight into possible solutions to tackle them; Section IV discusses the related work in participatory sensing and in emergency scenarios, and finally Section V concludes the paper.

II. Participatory Sensing in Emergency Scenarios

Assumptions and constraints in an emergency scenario can be very different to traditional participatory sensing. We are going to quickly show a few examples of such differences, and to propose a concrete class of events (earthquakes, explosions, gas leaks) to give the reader a specific reference situation for the research challenges that will be described.

A. Major Differences with Traditional Participatory Sensing

The most prominent problems usually associated to participatory sensing are scalability, privacy, and battery consumption [6], [4], [7]. Scalability (in terms of amount of data and network traffic) is a critical issue due to the huge number of devices participating, because applications can potentially receive data from participating devices all over the world; privacy defines the amount of information provided by the users, and balancing such amount to provide a useful set of information while preserving the privacy of the users is no easy task; battery consumption is an even bigger problem, because users can directly notice fast battery exhaustion and most likely block any sensing application. In emergency scenarios, though, scalability normally has a reduced impact due to the locality characteristic of the scenario. However, it cannot be completely ignored, because there could be emergency situations where a high number of people (and their devices) are gathered (i.e., during an event in a stadium). Also privacy can be seen from a different point of view, since the scope of the application making use of it is limited to a specific set of information, and the goal of such application is the immediate benefit of the participating users. Battery consumption, instead, is much more critical in emergency scenarios. What normally is just an annoyance for the users, which have to recharge the devices more frequently (often it happens daily), becomes now of paramount importance, because the battery should last as long as possible, without the chance to recharge it, until the rescuers can help the victim.

B. Reference Scenario

When a disaster situation occurs, many people suffer injuries and/or tend to panic, sometimes also hindering the work of rescue teams. These people, and especially their technological devices, can however provide much help and information about their surroundings. For example, following an earthquake or an explosion, rescue teams will have to explore and search for victims in buildings that are on fire or collapsed. Some of the victims might be unable to communicate their position, but the environment can provide useful data through sensors to locate them or describe the status of particular areas. In particular, envisioning the continuous growth of handheld devices market, we expect everybody to have a sensor-equipped device able to help the rescue teams with sensed information (such as camera feed, microphone, smoke, temperature, . . .) or alarms (i.e., loud noise and blinking light to help detect the device and, hopefully, the trapped or injured owners). These devices will be an addition to the sensors already present in the environment, which may not be working anymore due to the disaster. These are the conditions we assume while addressing the following research challenges.

III. Research Challenges

To provide a system able to take advantage of personal devices within the scenario just defined, multiple research challenges must be addressed, many of them covering different research areas. We will present here those we consider most interesting and critical (see Fig. 1).

A. Devices Participation

The first important issue to solve regards the devices participation. Several problems must be faced to make sure that the users, and thus, their devices, are properly participating. Motivation and incentives for users is quite a big issue for traditional participatory sensing, because users are normally

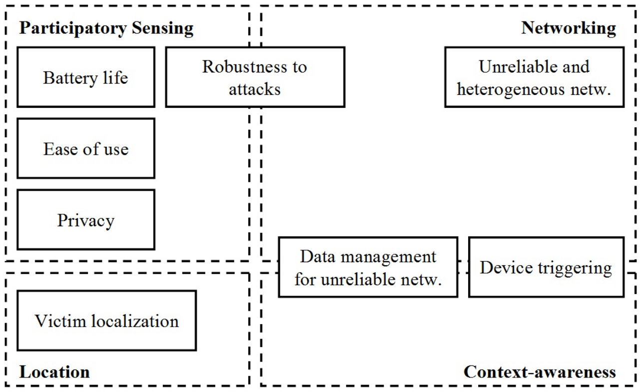

Figure 1: Logical View of the Research Challenges

not voluntarily willing to share and spend their resources for the benefit of the community. In this case, though, being a tool to potentially save their lives, should be a good enough incentive. However, users often do not foresee a disaster, and they judge how the system impacts them every day. That is why the sensing application, to be accepted by the users, has to take into consideration the following problems, regardless of any technical reason.

1) Battery Life: Battery life is already a concern for smartphone users [8], and adding more (visible) consumption will not make any sensing application welcome on their devices. Therefore, it must be consumption-aware. But besides users' attitude, saving battery is a requirement also for the reference scenario. In fact, if we consider an earthquake or an explosion, some building could collapse, and victims might be trapped under the debris and extracted after a long time, making paramount to have the devices able to participate as long as possible. Hence, highly efficient and robust algorithms and protocols are needed.

2) Ease of Use: Further, special emphasis is needed on ease of use. Users should not note the overhead of the sensing application, as this is not the primary aim of the users neither of the handheld devices. Therefore, the application should be seamless and lightweight. Ideally, it could be seen as a safety feature offered by the device manufacturer, on which users have no power (or even awareness) at all, as it currently happens with the emergency call system of mobile phones. Giving rights on the application to the users could bring, especially with a full featured set of sensors, to misconfigurations or rejections, which go against the purpose of the sensing application itself.

3) Privacy: Since users provide sensitive sensor data, it should be clear what is disclosed, when, and to whom [9]. For the purpose of an emergency application, only the information relevant to the current emergency should be transmitted, for the duration of the emergency, and only to other devices actively or passively participating to the system.

4) Robustness to Attacks: The system should be robust to attacks of all kinds: from compromised user devices providing bogus or misleading data, to unnecessary emergency response costs due to false/malicious alarms, or misdirection of people in real emergency scenarios. For this purpose, the system should rely on multiple sources of data and treat them before acknowledging an alarm, in particular, detecting and filtering outliers, and giving trusted devices (i.e., belonging to some trusted authority) a heavier weight for decisions.

5) Device Triggering: One main mechanism related to the previous problem is the activation of the devices. Three options are envisioned in case of disaster: (1) users manually turn their devices into emergency mode if they are able to, (2) authorities remotely trigger them, or (3) devices are able to recognize a disaster pattern and to automatically turn into emergency mode (e.g., measuring high temperature and a sudden acceleration could represent an explosion). The manual trigger is trivial, but the other two present research challenges. For example, the remote triggering requires a secure authentication mechanism to avoid malicious actions. It also requires that the triggering signal is limited to the area of the emergency, to avoid undesired propagation. The automatic emergency inference, instead, relies only on the device sensors, and extensive tests to study events patterns are required to be able to reliably infer a particular event.

B. Unreliable and Heterogeneous Networking

Once the devices are properly participating within the system, the focus must be shifted to the networking problems in hostile post-disaster conditions [10], [11]. In fact, any pre-deployed network infrastructure is not guaranteed to be fully connected at all times because of malfunctions due to the disaster, and much more mobility than in traditional networks is expected (if not by the victims V, the rescue team R is supposed to move within the area of interest - see Fig. 2), thus they can be treated as Delay Tolerant Networks (DTNs).

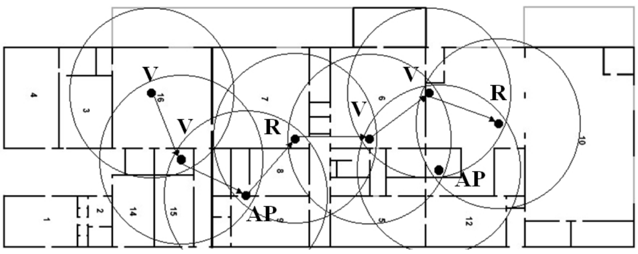

Figure 2: Heterogeneous static/mobile scenario.
R: rescuers - **V**: victims - **AP**: access points

Because of these reasons, routing solutions in DTNs over multiple wireless technologies should be investigated to cope with such assumptions. For example, bridging routing through different wireless technologies (i.e., WiFi and Bluetooth) can help solving partitioning problems, while peer-to-peer protocols can be used to address scalability issues, although scalability is expected to be a much smaller concern with respect to traditional participatory sensing, as already explained in Section II.

C. Data Management for Unreliable Networks

Assuming the unreliability of the network, data management mechanisms must be able to correctly map, spatially and temporally, sensor information collected during disconnections. They must also provide data replication and distribution. This way, nodes churn and mobility will have a smaller impact on sensor data availability and correctness. Peer-to-peer protocols could be good candidates for such tasks, and, if carefully designed, they can also mitigate the problem of scalability in crowded areas. Another important mechanism to consider in order to reduce scalability issues, is aggregation/mediation [12], [13]. Nodes can reduce the amount of data transmitted and stored (trade-off between processing power, battery consumption, and memory requirements), but they must preserve an appropriate level of informative content, thus taking into consideration Quality of Information (QoI [14]).

D. Victim Localization

Finally, victims should be located with good accuracy. Although there are countless location mechanisms proposed in literature, roughly divided between fingerprinting and triangulation/trilateration methods, they mostly have requirements/assumptions that cannot be always taken for granted. The former method assigns a position based on a set of parameters (called fingerprint), i.e., the visible WiFi access points or GSM cells, and requires the system to be trained with an initial set of fingerprints. Unfortunately, they result to be unusable when the infrastructure changes due to a disaster. The latter, instead, measures angles/distances from known points to determine the position, but again, in case of infrastructure changes and failures, it might not be possible to do it. Some examples are [15], [16], [17] for fingerprinting and [18], [19] for triangulation/trilateration. In a disaster scenario, the worst case should be assumed, and the location mechanism should work in such adverse conditions. Basically, assuming that the networking infrastructure could be absent, no area map available, and no external help (i.e., GPS or special purpose antennas) can reach the disaster area, the only "beacons" available are the victims' and rescue team's devices. Of course, every additional technological help should be exploited to improve the accuracy and reliability of the designed mechanism(s). They should try to provide an exact or relative position of the devices within the disaster area, and possibly build a map in real time as well. Locations and nodes could also be tagged with metadata representing useful information (e.g., temperature and picture taken by the target device) for the rescuers.

IV. Related Work

In literature, a number of applications relying on participatory sensing can be found. For example, NoiseTube [20] and Ear-Phone [2] use mobile phones as noise sensors, sharing geo-tagged noise pollution levels measured by the users; the BikeNet [1] application measures cyclists' movements (speed, distance, position, ...) and physical values (heart rate, galvanic skin response, or other values measurable through body sensors), and stores/shares them with other participant users; Nericell [21] uses smartphones' sensors to monitor road and traffic conditions, and reports them to a server for aggregation. Other examples are available, but, to the authors' knowledge, none of them applied participatory and opportunistic sensing paradigm to emergency scenarios. For these scenarios, researchers normally rely on pre-deployed equipment or devices deployed after-the-fact by rescue teams, like, for example, Dilmaghani in [22], which plans to deploy wireless mesh nodes within the disaster area. A couple of works considering users' devices located within emergency areas are: SHIELD [23], which focuses on alarm propagation to trusted nearby entities, mostly in relation to localized crimes, but does not offer any automatic help to rescue teams; and WIPER [24], which provides a crisis detection mechanism by monitoring cellphones call data, searches for anomaly patterns, and proposes responses to emergency situations. Our work is different from previous ones in literature because it plans to exploit the participatory paradigm in emergency scenarios by making use of casual victims' devices happening to be in the area of the emergency even when they are not able to interact with their devices, i.e., if they are unconscious. Furthermore, it will not limit itself to the initial alarm propagation, but also to help rescue teams during the critical phases of first response and later retrieval of victims.

V. Conclusion and Future Directions

In this paper, we presented the most critical research challenges expected while applying participatory and opportunistic sensing to emergency scenarios. Having different constraints and assumptions in such scenarios, the same challenges result to be different than in traditional participatory sensing. Tackling such challenges would provide the chance to cover with sensors those areas subject to disasters which rescue teams cannot reach because pre-deployed infrastructures broke and it is not possible to deploy new sensors. In the future, we are going to work on the aforementioned open issues, starting from the devices participation and moving to networking. An additional interesting topic to investigate in relation to emergency scenarios is body sensor networks, which, especially during critical post-disaster conditions, could provide to the authorities very important data regarding victim's health.

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