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Design and implementation of a Witness Unit for opportunistic routing in tsunami alert scenarios

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ABSTRACT

Some earthquakes generate tsunamis in the ocean or coastal regions. An early alert is essential for the coastal population to prevent loss of human life. The propagation of the alert is made through a range of communication means: radio, television, sirens, landlines and cell phones, social media including Twitter, and, if electrical power and communications utilities are blacked-out, through an alternative opportunistic network. In this article, a special device, named Witness Unit (WU), designed to work with a satellite network is presented as an alternative communications means in a temporarily degraded disaster environment. A greedy heuristic algorithm for the placement and deployment of the WUs is introduced and its interaction with emergency managers and citizens is discussed.

1. Introduction

Tsunamis are one of the many consequences that earthquakes in the ocean or coastal regions may cause. If an earthquake generates a tsunami, the population in seaside towns and cities should be evacuated to prevent human injury and life loss. An early alert of the situation is very important as the probability of survival is strongly linked to the chance of people reaching a safe place or shelter. However, if the earthquake affects the city's infrastructure, producing power utility and communication failures, the coordination of the evacuation procedure with little to no communication becomes one of the most challenging issues to be solved. An early detection and alert system for near-field tsunamis has several components, as presented in other articles in this special issue. This article focuses on the implementation of an alternative communication network that can dynamically provide the necessary information for the population to reach shelter in case an earthquake causes a tsunami and the collapse of traditional communication networks.

The proposed information retrieval and dissemination method is based on a dynamic and interactive design, operating at several levels of authority and information exchange. The Emergency Operations Center (EOC) is responsible for alerting the population to tsunami risk and coordinating the evacuation procedure. Officials at the EOC transmit the tsunami alert through multiple independent methods like TV, radio, sirens, social media, and street signs. Community leaders, such as Imams at mosques or principals at schools, are used to guide groups of local residents or students in their immediate care to safety. People tend to trust familiar leaders more than formal announcements, and the goal is to harness existing forms of social organization to mobilize collective action rapidly. The local leaders seek to guide their followers to a safe place or shelter, based on information they receive from reliable sources. Such information is provided by the EOC through any functioning means of communication or through our proposed alternative opportunistic network (OppNet), explained in more detail below. The leaders may also contribute to the state-of-affairs by providing updated information to the decision support system. For example, local leaders may indicate that a route is blocked and cannot be used any more or update the status of congestion on certain routes. There is a very short time between the seismic alert and the arrival of the tsunami, so the decision support system operates within hard, real-time constraints (Stankovic, 1988). The proposed system is based on GIS layered maps so local information is stored in the leaders' smartphones, reducing the data traffic in the opportunistic network (Ai et al., issue).

In the last decade, the use of social networks has changed completely the way in which people interact. There are several examples of people using, for example, Twitter to self-organize rescue procedures after natural disasters like floods (Meier, 2015). These

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uncoordinated efforts were helpful in some situations and show the potential of these tools. The use of information and communication technologies (ICTs) during emergencies should improve the resilience of the overall system, that is, the ability of organizations to adapt to unexpected situations that may turn into catastrophe (Wybo and Lonka, 2002). In the case of our proposed system, the ICT support is focused on assisting community leaders in the decision process, in particular in the search of secure routes to shelters. This has been identified in previous events as one of the main tsunami safety issues. The introduction of an alternative network to ensure communication flow between people and emergency managers is of major importance in scenarios in which traditional communication means and power utility are unavailable. The use of this network requires special training for the community leaders and the general population to take advantage of the technology during the critical interval of time between the tsunami alert and the actual wave arrival.

The deployment of an alternative opportunistic network is one means of communication that may augment the range of methods needed for issuing early warning for an imminent tsunami. Its deployment also provides support for the after-event search and rescue process. Once the earthquake has subsided and the tsunami has washed over the coastline, there are only a few hours to rescue survivors. This period is called the golden relief time and lasts approximately 72 h (Ochoa and Santos, 2015). After a devastating tsunami event, there is likely very little functional infrastructure, so deploying an alternative network to guide search and rescue efforts is very important.

This article makes three contributions. First, we present the design and a scenario for the implementation of a Witness Unit (WU) to be used as a communication gateway between the community leaders and the EOC. These WUs are built with off the shelf (COTS) components; they are cheap, easily assembled, and provide the necessary functionality to route messages between personnel at the EOC and the community leaders. Second, we devise a heuristic algorithm to bypass the NP-Hard coverage deployment problem of the WUs throughout the city. Finally, we propose an information dissemination policy to inform people of the best[1] route to a shelter from their existing location. This communication process is interactive and dynamic.

The paper is organized as follows. Section 2 describes the main elements used to build the WU and its functionality. Section 3 outlines the implementation steps for deploying WUs, providing technical information. Section 4 describes a heuristic deployment algorithm for the WU network throughout the city. Section 5 presents the opportunistic dissemination policy. In Section 6 the information flow among the different agents (EOC, leader, community) is presented. In Section 7, the WU functionalities are discussed, extending the application of this technology to other areas. In Section 8 previous work in the area is reviewed, and conclusions are drawn in Section 9.

2. Materials and methods for a WU network

The basic elements needed to build a WU are explained and a functional description of each part is introduced without proposing any commercial solutions. Assembly and software implementation details are provided in Section 3.

In situations where communication is needed but traditional Internet or cell infrastructures fail to provide it effectively, the best alternative may be opportunistic networks, which are characterized by intermittent connectivity, a heterogeneous mix of nodes, node churn, and widely varying network conditions. The purpose of WUs is not to provide an alternative network for everyday communications. Instead, the use of these units should be triggered only during emergency situations in which traditional networks are down or have collapsed. After an earthquake or any large disaster, electricity is typically either disrupted or shut down to prevent fires. If the earthquake also affects telephone lines and telecommunications infrastructure, most daily means of communication are blacked out and what little communication resources remain working are usually overloaded and become unusable. It is in this degraded technical context that the use of an OppNet becomes a feasible alternative. The OppNet can be defined as a peer-to-peer application in which nodes implement a basic store-and-forward transfer protocol. However, given that OppNets are not reliable, we add a WU, with embedded system design characteristics, to provide connectivity from nodes to the leader's smartphones (the main device used in many situations, and a device that will probably replace the currently ubiquitous walkie-talkie) in disaster situations.

Our proposed WUs are built based on three main components: a small on-board computer, a satellite modem, and a Wi-Fi access point device. The leaders will have in their smartphones an application that can connect to the WU access point via Wi-Fi to receive and send information. The leader will receive relevant information on how to reach the nearest shelter following the quickest route; this is possible because the WUs are static and the leaders have geo-localization (i.e., GPS capabilities and the supporting software). At the same time, the application on the leader's smartphone will upload real-time information it can sense, such as streets blocked by fallen trees or debris, broken bridges, etc. (Ai et al., issue). This information is used by the EOC to update the situation and provide safe routes to leaders. Fig. 1 shows the architecture of the WU and its interaction with leaders.

2.1. Access to Witness Units

The most accepted protocol today for wireless communications is based on the IEEE 802.11 standard (IEEE, 2010). In addition to having a Wi-Fi radio, even cheap smartphones are sold with a GPS device, and the leaders will certainly have smartphones. The WU will provide an ad-hoc Wi-Fi interface access point (AP) that is easily identified by the Service Set Identifier name (SSID), called WUAP-*address*, where address indicates the location of the WU. The AP will be accessible through a simple association process provided in the application executing in the leader's smartphone. WU access is restricted to certified leaders as its purpose is to provide information before, during, and after disasters (e.g., earthquake and tsunami alerts) and not to provide Internet access on a regular basis. As the smartphone of each leader is geo-located by its GPS and the locations of the WUs are known, the application will easily find the relevant WU in each area, and quickly associate with it.

2.2. On-board computer

The WU is not a simple AP. It should have the capability of executing the basic opportunistic transfer protocol of store-and-forward (Cao and Sun, 2013). The WU will receive the alerts from the EOC and will also receive updates from the leaders, such as new information on blocked or congested roads. This information would be updated in the EOC through the satellite connection, but it will also be kept at the WU because it may be useful for other leaders getting in contact with that WU. There are many on-board computers available in the market with enough capabilities for a WU as mentioned in Section 3. As these units do not use hard disks or monitors for displaying information and do not require a

[1] Note that "best" is typically decided based on speed of evacuation time but can also take into account the ability of people to climb stairs, use bicycles, etc. These factors are outside the scope of this paper.

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