Information Fusion 22 (2015) 71–84

Contents lists available at SciVerse ScienceDirect

Information Fusion

journal homepage: www.elsevier.com/locate/inffus

Human-centric wireless sensor networks to improve information availability during urban search and rescue activities

Sergio F. Ochoa [a,*], Rodrigo Santos [b]

[a] Department of Computer Science, Universidad de Chile, 2120 Blanco Encalada Av., CP 837-0459 Santiago, Chile
[b] Department of Electrical Engineering, Electrical Engineering Research Institute, Universidad Nacional del Sur, CONICET, 1253 Alem Av., CP 8000 Bahia Blanca, Buenos Aires, Argentina

ARTICLE INFO

Article history:
Available online 11 June 2013

Keywords:
Human-centric wireless sensor networks
Information availability
Human-based sensors
Opportunistic networks
Information fusion

ABSTRACT

When a natural disaster hits an urban area, the first 72 h after are the most critical. After that period the probability of finding survivors falls dramatically, therefore the search and rescue activities in that area must be conducted as quickly and effectively as possible. These activities are often improvised by first responders, stemming from the lack of communication and information support needed for making decisions in the field. Unfortunately, improvisations reduce the effectiveness and efficiency of the activities, in turn, affecting the number of people that can be rescued. To address this challenge, this article introduces the concept of a human-centric wireless sensor network, as an infrastructure that supports the capture and delivery of shared information in the field. These networks help increase the information availability, and therefore, the efficiency and effectiveness of the emergency response process. The use of these networks, which is complimentary to the currently used VHF/UHF radio systems, was evaluated using a simulated scenario and also through the feedback provided by an expert in urban search and rescue. The obtained results are highly encouraging.

1. Introduction

Every year natural disasters, such as earthquakes, hurricanes, volcanic eruptions and tsunamis, hit urban areas. During the first 72 h after the event, usually known as the "golden relief time", the response process is focused on searching and rescuing people [1]. The probability to find survivors after that time is increasingly low [2]. Coburn et al. [3] report the evolution of the survival rate over time, by analyzing the results of four earthquakes (Fig. 1). The analysis indicates the survival rate does not evolve in the same way in every extreme event; however, it is clear that the first 72 h after the occurrence are the most critical ones to search and rescue efforts. Similarly, after studying the survival rate in earthquakes, Fiedrich et al. [4] proposed a model to estimate such a rate (Fig. 2). The prediction model also indicates that the first 72 h are the most critical for rescuing survivors. Therefore the SAR activities must be quick and effective, because the number of survivors is directly related to such efficiency.

Several types of first responders participate in this process, for instance firemen, medical personnel, police officers and military units, who are grouped in teams and deployed to the affected area. In particular, firefighters and military units are usually trained to guide these teams. They typically use VHF/UHF radio systems to support the communication in the field and thus try to coordinate their activities.

These communication systems have shown to be easy to deploy and also reliable in supporting rescuer interactions when the regular communication infrastructure of the affected area is not available. Particularly, UHF radio systems can work as a multi-hop network, which extends their communication threshold and improves their capability to connect teams in the field. In spite of this, the use of these radio systems often leaves teams isolated because of the limitations imposed by their communication links [5–8]; for example the number of communication channels are typically not enough to support the communication in the field, the messages delivered by a radio device are frequently overwritten by messages delivered by more powerful devices, and often the messages are not understandable because they were mixed with others that were transmitted at the same time. If a SAR team has to wait an extensive time period to access a communication channel during the golden relief time, it is highly probable that the commander decide to improvise their actions/decisions because in such a period every minute counts. Several researches indicate that the response process during the golden relief time is improvised, due lack of communication and information support for making decisions in the field [6,9–11].

Trying to deal with this issue, some communication requirements [12] and architectures have been proposed [5,13]. Moreover,

* Corresponding author. Tel.: +56 2 9784879; fax: +56 2 6895531.
E-mail addresses: sochoa@dcc.uchile.cl (S.F. Ochoa), ierms@criba.edu.ar (R. Santos).

1566-2535/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.inffus.2013.05.009

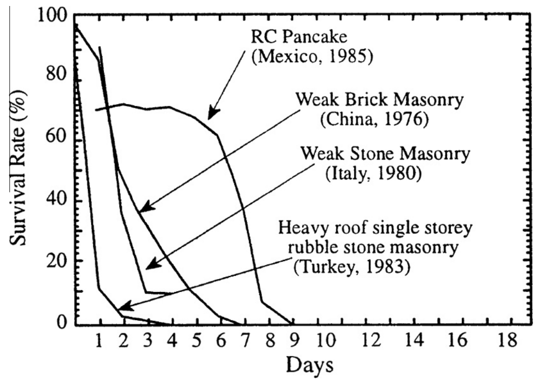

Fig. 1. Real survival rate [3].

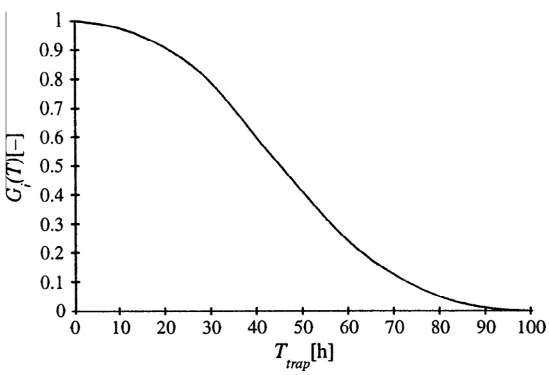

Fig. 2. Estimated survival rate [4].

communication standards have been defined to address the stated problems, for example TETRA (Terrestrial Trunked Radio) [14] and TETRAPOL [15], and also several IT platforms that adhere to these standards have been implemented. These technologies are useful in practice, however their acquisition involves a cost that is not affordable (at least in the short-term) for firefighting organizations of many countries. Particularly, this is the case of Latin American countries where firefighters are almost exclusively volunteers, and they receive minimal economical support from their governments.

The authors hypothesize that *human-centric wireless sensor networks (HWSN) can contribute to the improvement of the information availability during SAR activities*, and thus increase the efficiency and effectiveness of the process. The HWSN combines regular and human-based sensing devices that interact among them to reach a pre-established common goal, e.g. increase the information availability in a physical area. Therefore, these networks can be considered as collaborative and multi-sensor. Because these networks involve regular technology, their cost would be more affordable for volunteer firefighting organizations than modern radio systems (e.g. those based on the TETRA or TETRAPOL standards). The HWSN, which are complimentary to VHF/UHF radio systems, involve a minimal effort to be deployed in the field. Therefore, they could be used to support the teams from the beginning of the SAR activities.

These networks could also be used to increase the information availability in work scenarios where there is little or no communication support, and where mobile workers act as information fusion agents. Examples of these work scenarios include underground mining jobs or massive health campaigns in isolated areas.

The definition of a HWSN is based on the formalization of an opportunistic network done by the authors in a previous work [16]. This article extends such a definition by describing the elements that are part of a HWSN, the way in which they interact and the strategy used by the nodes to share information through the network. The article also presents a simulated search and rescue scenario that allows us to compare the performance of the SAR process using both the regular supporting tools and the proposed HWSN.

The next section explains the basic structure of a SAR process. Section 3 presents the related work. Section 4 describes the structure and components of a HWSN. Section 5 formalizes the information delivery in a disaster area, using two well-known routing protocols on a HWSN. Section 6 presents a simulated search and rescue process and elaborates on the obtained results. Section 7 presents the conclusions and future work.

2. The urban search and rescue process

The international SAR protocol for urban areas establishes that this process must be conducted by teams [17]. Each team has a leader that makes the local decisions, assigns activities to the team members and coordinates the team actions with the incident commander (i.e. the main decision maker in the field) that is usually located in a command post. Most first response efforts are coordinated by firefighter companies since they are trained to guide such activities, they are usually located in the affected area (or close to it), and the emergency response is part of their mission. The SAR process conducted by these companies involves four major activities:

1. The commander in charge of a company establishes a *search area*. Such an area is typically a 2×2 or 3×3 square of blocks, which helps to minimize the communication problems in the field.
2. Immediately after that, the commander establishes the *command post* in a safe place inside or within the border of the search area. Everyone participating in the SAR process must know where the command post is located due this is the main coordination point for a company.
3. The commander organizes the first responders in two types of teams: scout and rescuers. A *scout team* involves three or four people and they are in charge of searching a sub-area for trapped survivors. The *rescue teams* complete the task by rescuing people identified by the scouts.
4. The teams perform the search and rescue of victims in a parallel way. The scout teams provide information to the command post about the search result in the sub-area, and the rescue teams retrieve such information from the command post to directly access the buildings with trapped victims.

Fig. 3 shows a search area being explored by a first response company composed of 43 members grouped in seven teams: 4 scout teams, 2 rescue teams and the command post. Every team has one or more coordinators that make local decisions and keep the command post informed. For operational reasons, the number of scout teams is usually more important than the rescue teams. Once the scouts have completed the work in a search area, they can be grouped to form new rescue teams, and thus to help other teams in such activities. When the company has finished the task, it moves to another search area. Then, the commander can keep or redefine the original composition of these teams.

The coordination of activities inside these teams (and also inter-teams) is typically supported two or three VHF/UHF radio channels [7]. It means that just two or three people can be speaking by radio at the same time, which is not sufficient for monitoring high risk activities. The number of available radio channels can be even low-