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Evolutionary deployment and local search-based movements of 0th, responders in disaster scenarios

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HIGHLIGHTS

- We propose to use drones or unmanned aerial vehicles as 0 th responders in disaster scenarios.
- Finding the best positions of the 0 th responders is divided into two phases.
- The initial deployment is based on an evolutionary algorithm using collected information.
- The adaptation of the real conditions phase is based on a local search algorithm using real time information.
- The obtained simulation results demonstrate the validity of the proposed approach.

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ABSTRACT

The establishment of communications in disaster scenarios is of paramount importance, especially because preexisting communication infrastructure is likely to be destroyed or malfunctioning. Consequently, there is a need for an alternative and self-organizing communication infrastructure that can be rapidly deployed in disaster situations. In this paper, we propose to use drones or unmanned aerial vehicles as 0th responders to form a network that provides communication services to victims. Finding the best positions of the 0th responders is a non-trivial problem and is, therefore, divided into two phases. The first phase is the initial deployment, where the 0th responders are placed using partial information on the disaster scenario. In the second phase, which we call the adaptation to real conditions, the drones move according to a local search algorithm to find positions that provide better coverage to the victims. We conduct extensive simulations to validate our proposed approach for rural disaster scenarios under different conditions. We show that our proposed initial deployment based on genetic algorithm provides coverage for up to 94% (maximum) and 86% (mean) of victims if complete knowledge of the disaster scenario is known and 10 drones are used. When the adaptation to the real condition phase is used, this percentage is increased to 95% (maximum). If no knowledge of the scenario and 10 UAVs are used 80% (maximum) and 59% (mean) of victims are found and successfully covered. The proposed approach outperforms in 6.4% the random deployment method, and in 2.4% the best grid deployment approach. Finally, we show that by using different numbers of drones for the two phases of the proposed approach, the percentage of victims is increased up to 51% for low values of knowledge of the scenario.

1. Introduction

Every year, millions of people are affected by natural and man-made disasters involving large expanses of land. Such disasters include earthquakes, tsunamis, volcano eruptions, hurricanes, tornados, floods, and terrorist attacks. Governments all around the world spend huge amounts of resources not only on preparation for such events but also on reconstruction in their aftermath. These traumatic events can severely damage both public and private infrastructure and can dramatically compromise people's welfare. Studies suggest that the first 72 h post-disaster are extremely important [1,2]. This period is called the "golden relief time" [1]. After the golden relief time, the probability of finding survivors is very low. Consequently, coordination of 1st responders and victims is of paramount importance. Communication, both in general and among 1st responders in particular, is vitally important to efficiently coordinate rescue efforts during this critical window.

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A thorough survey of interviews with German 1st responders indicates that the first few minutes of an emergency are the most important [3]. Furthermore, while a basic communication infrastructure has to be established, rescuers should not spend their valuable time in this effort.

Nowadays, people commonly communicate with each other using their cell phones, i.e., smartphones with Internet access provided either by their telecommunication operator or by connecting to Wireless Fidelity (Wi-Fi) access points (APs). Chat applications like Whatsapp and Google Talk, or social networks like Facebook and Twitter, have changed the way that people communicate. It should be noted, however, that the use of the above-mentioned Internet-based applications could be compromised by damage to the communication infrastructure, leaving many people isolated and unable to communicate. Moreover, even traditional communication services, like voice calls and text messages, will not be possible in the event of major damage. Device-to-device communications, like the ones established by using Wi-Fi direct, are limited due to the slow market penetration of such technology so far. Furthermore, wired Internet connectivity could be compromised by the catastrophic events in the disaster [4]. Many nodes can be down due to the damages caused by the disaster event.

Therefore, alternative communication infrastructures should be deployed in a rapid and self-configuring manner to allow interpersonal communication and access to the Internet. In this paper, we study intelligent deployment and tactical movement of mobile APs that act as 0th responders, arriving at the disaster area as soon as possible in order to provide communication services. In our work, these APs are drones or Unmanned Aerial Vehicles (UAVs) equipped with Wi-Fi transceivers that can move throughout the disaster area. The most optimal deployment of the 0th responders will depend on several factors. First, such deployment depends on the available information regarding the disaster scenario. In other words, there exists a need to collect certain information before the deployment of the 0th responders. Such information can be collected via satellite images, from people living in the vicinity of the disaster area or from other mechanisms. If the requisite information is available, we can design an initial deployment of the 0th responders to cover the most important target points or areas. After that and once the drones have arrived at the disaster area, their positions should adapt to the conditions of the disaster, using local information collected directly from the disaster area. After the full deployment of the 0th responders, the ultimate objective is to find possible victims that have not been found during the aforementioned deployment. For the first deployment problem, we propose an evolutionary algorithm, i.e., a genetic algorithm (GA). Next, we propose a local search algorithm to adapt to the real conditions. The adaptation to real conditions requires a local search algorithm for several reasons. First, the problem is complex enough that brute force or other simple algorithms cannot solve it successfully. Second, the desire for a fast response necessitates algorithms that provide a good solution in a short period of time (such as local search algorithms).

One important feature of the proposed deployment and subsequent tactical movements is that drones should form a connected mesh ad hoc network. A connected network means that there are no isolated drones and that every drone is reachable from every single other drone. This connectivity requirement exists because one of our main objectives is to provide Internet services to victims. To make this possible, the mesh network should use another long range communication technology (i.e., satellite communications). The idea is that one of the drones will be equipped with a satellite transceiver with Internet connection and it will share the Internet connection with the rest of the drones forming the network. Thus, in an unconnected mesh network, some drones would not be able to provide Internet services to victims in their locations. Fig. 1 illustrates an example network deployment and communications that are possible with a set of drones in a disaster scenario. Fig. 1 also shows how the drones form a mesh network (blue dotted lines) and how the drones provide communication services to the victims (red dotted lines).

It is important to highlight that this study differs from the direct application of the ad hoc paradigm in disaster scenarios [5]. We aim to deploy an alternative and dynamic communication infrastructure to which the victims can easily connect with their cellular phones in the same way that they connect to Wi-Fi spots at home or in public spaces. To reiterate this important feature: victims and 1st responders will access the network using common portable devices such as smartphones, tablets, etc. Thus, unlike the specialized mobile radios normally used by 1st responders, our proposed network is easy to access and provides widespread usability. Consider, for example, the TETRA (Terrestrial Trunked Radio) technology that is widely used in Europe [6]. TETRA terminals allow 1st responders to establish wireless communications; however, they lack interoperability with other ubiquitous free band wireless technologies like Wi-Fi and Bluetooth. There are no commercial smartphones with TETRA technology, therefore, it is impossible the exchange of information among 1st responders and possible victims.

The main contributions of this study are:

- An intelligent deployment of a dynamic mesh network in disaster scenarios that adapts to the real conditions, provides communication services, and searches for possible victims.
- A detailed evaluation of the proposed approach in disaster scenarios. We conduct extensive simulations to validate our approach under different conditions in a rural disaster scenario.

The paper continues as follows. Section 2 includes some relevant related work on two similar topics, such as the deployment problem and the mobility models for disaster scenarios. Section 3 presents the proposed approach and outlines the evolutionary and the local search algorithms used in our work. Section 4 presents and analyzes our simulation results. Finally, Section 5 concludes this paper.

2. Related work

We divide the related work into two subsections. Section 2.1 reviews related works that address the deployment problem in disaster scenarios, while Section 2.2 is devoted to reviewing prior research on mobility models for disaster scenarios.

2.1. Deployment problem

In this study, we propose the use of artificial intelligence based algorithms, such as evolutionary and local search algorithms, to address complex deployment problems. A thorough survey on the application of evolutionary algorithms in disaster scenarios can be found in [7]. Among the problems described in [7], the ones related to location are most pertinent to this paper. The location problems in disaster scenarios are focused on finding the best positions for fire stations, medical services, shelters, etc. These optimization problems are based on the study and analysis of the topography of a disaster area. The mentioned problems are related to the work presented in this paper, e.g., the deployed facilities should cover a large number of victims in a disaster scenario.

In [8], the authors use genetic programming for search tasks of multiple UAVs. A team of UAVs is tasked with exhaustively covering a pre-defined search area, which is divided into target beacons, and then returning to a base location. This work is more