Journal of Network and Computer Applications 84 (2017) 55–67

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

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

Tracking pedestrians and emergent events in disaster areas

Gürkan Solmaz[a,b,*], Damla Turgut[b]

[a] NEC Laboratories Europe, Heidelberg, Germany
[b] Dept. of Computer Science, University of Central Florida, Orlando, USA

ARTICLE INFO

Keywords:
Opportunistic communication
Mobile sink
Disaster resilience
Evacuation
Mobility management

ABSTRACT

Most of the existing research on emergency evacuation strategies focus on city evacuation planning that highly depends on the use of vehicles or evacuation from buildings. However, for large areas with limited use of vehicles such as theme parks, evacuation of pedestrians and emergent events must be tracked for safety reasons. As hazards may cause certain damages to services, networks with disaster resilience are needed to achieve mission-critical operations such as search and rescue. In this paper, we develop a method for tracking pedestrians and emergent events during disasters by opportunistic ad hoc communication. In our network model, smart-phones of pedestrians store and carry messages to a limited number of mobile sinks. Mobile sinks are responsible for communicating with smart-phones and reaching the emergent events effectively. Since the positioning of the mobile sinks has a direct impact to the network performance, we propose *physical force based* (PF), *grid allocation based* (GA) and *road allocation based* (RA) approaches for sink placement and mobility. The proposed approaches are analyzed through extensive network simulations using real theme park maps and a human mobility model for disaster scenarios. The simulation results show that the proposed approaches achieve significantly better network coverage and higher rescue success without producing increased communication overhead compared to two random mobile sink movement models.

1. Introduction

Internet has been used worldwide, offering various services which made daily lives of people easier in many ways. However, it is not a reliable communication source during disaster times as accessing the Internet services requires certain infrastructure, which may be damaged due to occurrence of hazards. While relying only on the Internet may cause people suffer in natural or man-made disasters, researchers nowadays focus on the networks resilient to disasters. These networks are supposed to provide and maintain acceptable levels of quality of service during disaster times, as well as accidents or faults in infrastructure in ordinary times.

As the increase in the likelihood of the more intense hazards is expected due to climate change (Hallegatte, 2014), disaster resilience in networks is becoming an increasingly popular research area. Many studies nowadays focus on communication problems in cities damaged by disasters such as earthquakes or floods. These problems also apply to large areas in which the vehicle use is limited such as theme parks and campus environments. Furthermore, the operators of these environments have challenges of evacuating pedestrians, rescuing injured people, and providing them access to ambulances or transportation services. We study the use of disaster resilient networks as a solution to communication and the safe evacuation problems in large and crowded disaster areas. Places which restrain people from using transportation vehicles such as airports, city parks (e.g., Central Park in New York city), shopping malls, fairs, and festival areas are considered in this context.

In this study, we focus on the application scenario of theme parks which are large and crowded entertainment areas due to several reasons. Large-scale theme parks have substantial economic contributions to their regions. While overall popularity of theme parks increases every year, global success of the growing industry is severely affected by disasters such as Hurricane Irene (Theme index: Global attractions attendance report, 2013). A natural or man-made disaster in a theme park may cause damages to regions such as Central Florida having theme parks with highest yearly attendances and also being known as home to natural disasters such as hurricanes, floods and tornadoes.

We model the theme park environment as follows. We first model the area of a theme park and define it as a combination of roads, obstacles and lands. Real theme park maps are extracted for synthetic generation of the theme park models. We use a realistic human mobility model for simulating the movements of the pedestrians in disaster areas (Solmaz and Turgut, 2015). With this mobility model, we are able to simulate the mobility of people in theme parks who aim to

* Corresponding author at: NEC Laboratories Europe, Heidelberg, Germany.
E-mail addresses: gurkan.solmaz@neclab.eu (G. Solmaz), turgut@eecs.ucf.edu (D. Turgut).

http://dx.doi.org/10.1016/j.jnca.2017.02.007
Received 21 April 2016; Received in revised form 29 January 2017; Accepted 18 February 2017
Available online 21 February 2017
1084-8045/

escape from the disaster area to the exit gates by walking in order to reach ambulances or transportation services. Moreover, we model the crowd dynamics and social interactions of the pedestrians during the evacuation by the social force model (Helbing and Johansson, 2010).

In this paper, we use our pedestrian mobility model in Solmaz and Turgut (2015), Solmaz and Turgut (2013) as basis for simulating the movement of pedestrians in theme park during their evacuation. We propose new algorithms for initial sink placement and sink mobility. We comprehensively analyze the proposed tracking evacuation approach which is first proposed in Solmaz and Turgut (2015). Extensive experiments are conducted for five sink mobility approaches to observe the results with various parameter values in in-depth analysis of the network performance.

Handling emergent events is one of the major challenges in theme park environments due to inevitable problems that can occur due to hazards. Therefore, in addition to the technological security measures, theme park administrators also employ many security officers, for some parks more than a thousand, walking on foot or riding bicycles (Report on safety, 2008). We believe that using automated networked systems and mobile sinks can help reducing infrastructure requirements by large team of security personnel.

As a disaster response strategy, we propose using a networked system which includes mobile sensor nodes and a limited number of mobile sinks as described in Section 2. Mobile phones carried by pedestrians can be leveraged as sensor devices which communicate with each other and with mobile sinks. Mobile sinks monitor the evacuation process by patrolling in the disaster area, collecting data from the sensor nodes. They also have the goal of reaching to people who need to be rescued. Mobile sinks can be autonomous robots (e.g., search and rescue robots Manns et al., 2015) or security personnel which patrol by walk or by electronic transportation vehicles such as Segway Patroller (SEGWAY) with a tablet computer attached on it. Sensor nodes create messages when they witness people who need immediate help. They are responsible for storing and carrying the messages, sharing the messages with each other, and delivering to the mobile sinks via hop-by-hop wireless communication.

We consider such formation of wireless sensor networks (WSNs) with mobile sinks as a replacement to cellular networks for providing communication in extreme conditions. The use of mobile sinks enables adaptability of the approach to various environments (e.g., festivals, public parks) where pre-installed infrastructure may or may not exist. In the case of popular theme parks such as Disney World, certain infrastructure such as video cameras can be leveraged in some scenarios when the pre-installed system continue operating during the disaster. Most of the existing studies related to evacuation and disaster management tackle the problems of optimizing evacuation times (e.g., avoiding bottlenecks, finding exit points) or assisting people for their safe evacuation and directing them in indoor (Chen et al., 2015) or outdoor environments (Winter et al., 2011; Iizuka et al., 2011). The output of these solutions include improved evacuation times. Our approach, on the other hand, focuses on tracking the people's locations during their evacuation (without any interference to their behavior). While our approach does not aim for shorter evacuation times, it is helpful for finding and reaching out to the people who may be in emergency situations.

Our approach differs from the existing ones that depend on usage of UAVs (e.g., quadcopters). While drone operations can be helpful in such scenarios, they require certain infrastructure and control of operations. Moreover, they have various constraints including weather conditions, vision-based limitations (resolution, coverage of large area, darkness, etc.), and limited lifetime of the batteries. Considering the disaster scenarios, especially in regions such as Central Florida, adaptability to weather conditions such as having strong winds is a major drawback of such systems. Moreover, the infrastructure requirements for communication during operations are similar to the requirements of Internet services. On the other hand, these approaches can be beneficiary in certain scenarios and the two strategies can work together by eliminating each other's limitations.

Sensor devices are carried by ordinary theme park visitors whose only goal at the time of a disaster would be safely escaping from the area. While we do not assume any control over the visitors, we focus on the effective placement and mobility of mobile sinks in the area to gather more data from the sensor nodes to find pedestrians in need of help in shorter amount of times. For efficient tracking of the pedestrians and emergent events during the evacuation, we propose three heuristic approaches in Section 3, namely, *physical force based* (PF), *grid allocation based* (GA) and *road allocation based* (RA) approaches for mobile sink placement and mobility. PF is inspired by the natural gravitation, in a way that sensor nodes attract mobile sinks, while mobile sinks have negative impacts on each other. In GA, each sink allocates a number of grids as its own operation region. Grids are created on top of the roads in the processed theme park model. Lastly, in RA, each sink allocates one or multiple roads close to each other and operates on top of the allocated roads. After allocation of grids or roads, mobile sinks patrol in their allocated regions by a random movement model. The performances of the proposed approaches are evaluated in Section 4 with extensive network and human mobility simulations and compared with two random mobility models for mobile sinks. We summarize the related work in Section 5 and finally conclude in Section 6.

2. Theme park and network model

In this section, we describe modeling of the theme park environment and the proposed network model respectively.

2.1. Theme park model

Real theme park maps are used to model the theme park environment for disaster scenarios. After automated processing of the map, the model defines a theme park as combination of *roads*, *obstacles* and *lands*. The roads are defined as pedestrian ways containing waypoints. The waypoints are the movement points of the pedestrians. The roads direct the pedestrians to the target locations in the map. Moreover, the mobile sinks travel on top of the roads for patrolling or reaching the regions of the emergent events. The gates are considered as the target locations and they are placed close to the borders of the park. The gates connect the theme park with the outside world and facilities such as transportation vehicles (e.g., ambulances, buses).

The obstacles are categorized into two types. Attractions in a theme park contain man-made buildings and other structures such as roller-coasters, fences, or walls. During evacuation from the disaster area, these structures may prevent free movement of the pedestrians. They are considered in the model as man-made obstacles. Moreover, there may be natural obstacles such as lakes, trees, river and so on. We include both types of obstacles in the theme park model, such that none of the pedestrians or mobile sinks is able to pass through them. The lands are the regions having no obstacle or road. Pedestrians can choose to pass through the lands in certain times such as when they do not have the option to travel on the roads (e.g., road is closed due to occurrence of hazard) or when the lands provide obvious shortcuts.

While the model of the theme park can be created synthetically (e.g., during design stage of a theme park) or using real maps, we use OpenStreetMap (OSM) (Weber, 2008) for existing theme parks and extract their maps. These maps containing the OSM data are parsed to generate the roads, the obstacles, the lands, and the gates. The user-