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Modeling pedestrian mobility in disaster areas

Gürkan Solmaz [a,b,*], Damla Turgut [b]

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

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ABSTRACT

Realistic mobility modeling is necessary for testing disaster management strategies as well as performance of disaster–resilient networks. Evacuation of the people from a disaster area depends on the environment and type of the hazard which cause certain changes in the pedestrian flows. Although most models focus on the building evacuations or city-scale evacuation planning, there is a need for a mobility model that captures the pedestrians' movement behavior during evacuation from large and crowded disaster areas such as theme parks.

In this paper, we propose a mobility model of the pedestrians in disaster areas. In our application scenario of theme parks, the main mission of the operators is the evacuation of the visitors and providing access to transportation vehicles such as ambulances. We use real maps to generate theme park models with obstacles, roads, and disaster events. We incorporate macro and micro mobility decisions of the visitors, considering their local knowledge and the social interactions among the visitors. We analyze the outcomes of the simulation of our theme park disaster (TP-D) mobility model with simulations of currently used models and real-world GPS traces. Moreover, using the proposed model as a baseline, we analyze the performance of an opportunistic network application.

1. Introduction

Performance results of mobile networks drastically change with the mobility model used in the simulations [1]. Therefore, accurate modeling of mobility has utmost importance for realistic network simulations and performance evaluation of protocols [2]. With the increased popularity of smartphones and mobile applications, modeling human mobility has become a major area of interest for networking researchers. While there exist very limited publicly available GPS trace datasets, synthetic mobility models which simulate the human mobility are useful for evaluating performances of various network models including urban sensing networks and opportunistic social networks.

Human mobility is based on the combinations of many factors including deterministic and non-deterministic decisions and social factors which depend on the scenario. Since generic human mobility models are not suitable to represent the human mobility behavior in different application scenarios, there is a need for scenario-specific modeling. We consider the application scenario of theme parks due to their certain characteristics such as allowing limited use of vehicles, having large-scale areas and including natural and man-made obstacles. Moreover, theme parks have similarities to other environments with limited vehicle use such as campus environments, airports, shopping malls, state fairs, and so on. By selecting theme parks as an application scenario, we isolate the problem of modeling pedestrian mobility from problems of vehicle mobility and mobility during building evacuations.

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

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Theme parks are large and crowded areas with thousands of daily visitors. Particularly, large-scale theme parks attract visitors from all over the world, and the theme park industry is one of the main contributors of their regions. While overall popularity of theme parks and the size of the industry are growing every year, the global success of theme parks is severely affected by disasters such as Hurricane Irene [3]. Considering the fact that climate change increases the risk of extreme events such as forest fires and floods [4], effect of disasters may cause damages to the regions such as Central Florida. This region has 5 of the top-10 theme parks with highest attendances in the world, while being home to various natural disasters with a history of hurricanes, floods, tornadoes, and tropical storms.

The studies on disaster recovery and opportunistic communication networks have become major research interests due to their prospective contributions on the disaster management strategies. For instance, as an impact of a disaster, communication infrastructures which are pre-deployed in the area may become unoperational. For this reason, communication systems independent from the infrastructures (e.g., [5]) are taken into account in many disaster management studies. Crowd management and evacuation of people from disaster areas are other major challenges which have theoretical and practical interests from the research community. Modeling disaster mobility in theme parks is useful for finding novel methods to solve the evacuation problem in theme parks. In addition, these methods may become the base-case for the evacuation problem of more complicated scenarios such as evacuation of people from buildings and evacuation from big cities.

We consider a wide range of disaster scenarios for theme parks. These scenarios include natural disasters such as tornado, thunderstorm, hurricane, and earthquake. We also consider man-made disaster scenarios such as terrorist attacks which may threaten human lives in crowded places. While effects of these various types of disaster may differ from one another, the main goal of the operators will be safe and quick evacuation of visitors and providing them access to transportation vehicles.

We modeled visitor movements in theme parks to represent daily routine mobility of theme park visitors without any consideration of the disaster scenarios [6]. However, in our previous model and the other currently used theme park mobility models, the movement decisions of the visitors are based on visiting the attractions and exploring the park. Considering disaster scenarios, the movement decisions should be based on the security of visitors. The main goal of the theme park operation include finding easy ways to secure places and quickly evacuating the visitors from the disaster areas.

In this paper, we extend our previous work [7,8] on disaster mobility in theme parks. The main contributions of this work include adding visibility variable to model, extending the model description and simulation study and evaluating the performance of an opportunistic communication network application based on our mobility model.

We model theme park as a combination of roads, obstacles, lands, and red-zones using real theme park maps. To model the visitor movements, we consider the macro and micro mobility decision problems separately. We use the social force model [9] to represent the dynamics of the human motion by the social interactions. We analyze the simulation results of our model and compare it with the currently used mobility models and the GPS traces collected from theme park visitors. The outcomes of the simulation of the proposed model are mobility traces of theme park visitors.

The effects of various possible disaster response approaches can be tested using our mobility model. Placing informative signs in strategic locations to direct the visitors to desired regions, having trained security personnel to manage crowd flows or forming visitor groups by assigning one trained person to lead each group can be considered as examples of disaster response strategies. Furthermore, autonomous robots can be used for missions such as search and rescue. Another use of our model is evaluating performances of networks resilient to disasters such as opportunistic social networks which are formed for broadcasting messages and increasing knowledge of the visitors.

The organization of the remaining of the paper is as follows. We describe the model in detail in Section 2. The simulation results of our model are provided in Section 3. We discuss the recent literature in mobility models, disaster mobility and disaster management approaches in Section 4 and finally conclude in Section 5.

2. Mobility model

In this section, we present the human mobility model in theme parks for disaster scenarios. Let us first describe the characteristics of theme parks and creation process of the theme park models. Later, we will describe the mobility of the visitors in detail.

2.1. Characteristics of theme parks

To give a background on the problem, we first describe the fundamental characteristics of theme parks by looking from the mobility modeling perspective. Theme parks consist of attractions which are entertainment places including rides, restaurants, and places for other activities. Attractions consist of man-made structures (i.e. buildings) and they are connected to each other by roads (i.e. pedestrian ways). The roads also connect the entrance and exit points of the theme park with the attractions. They are usually used only by pedestrians, specific for theme park environment. Each road has a width which determines the capacity of the road for pedestrian flows. For instance, if a road is narrow and there are many people, the density of the people becomes large and as a result people cannot move fast enough on the road.

Theme parks are open-air areas but can also have buildings such as indoor rides, restaurants and gift shops. The area of theme parks include many physical obstacles for pedestrians. The physical obstacles include man-made and natural obstacles. People who spend their day in theme parks have activities such as visiting rides, walking among the attractions along the roads, and eating at the restaurants.