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A load balancing module for post-emergency management

Kostas Kolomvatsos *, Kyriaki Panagidi, Stathes Hadjiefthymiades

Department of Informatics and Telecommunications, National and Kapodistrian University of Athens, 15784 Athens, Greece

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ABSTRACT

Research society has developed a number of models and tools to support emergency management. The proposed models are mainly designed for indoor applications oriented to provide guidance directly to people in danger. Only a few of them deal with outdoor scenarios as well as with providing directions to field commanders or rescue teams. Additionally, load balancing techniques for the optimal allocation of a number of entities into a number of resources are understudied creating a gap in the corresponding research. In this paper, we propose a load balancing model oriented to assist field commanders and rescue teams in a post-emergency scenario. The proposed system could be applied either for indoor or outdoor applications. The module builds on top of the solution provided for the known Santa Fe Bar Problem (SFBP). It consists of an intelligent technique aiming to distribute a number of entities into a finite number of resources. A set of predictors undertake the responsibility of estimating the load of each resource. These predictors are adopted to select the appropriate resource for each entity. A case study deals with the distribution of injured persons into a number of hospitals and presents the functionality of the proposed module. Finally, numerical results reveal computational and time requirements of our system.

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1. Introduction

1.1. Motivation

Handling emergency situations is a key research topic for research community. The reason is that efficient solutions positively affect people lives. For instance, evacuation planning for rapid movement of people during an emergency is very important. Evacuation is needed when an area or a building is threatened by a disaster (e.g., hurricane, fire). During emergency, people act irrationally because they feel confused or frightened and need to have access to a safe and secure place. Additionally, evacuation plans should take into consideration the balance in the provided solutions in order to avoid congestions. An unbalanced distribution of people into specific exit points could cause a lot of additional problems.

A special case, in the described scenario, is the distribution of people to a finite number of resources. Resources could be hospitals, safe places, supplies, etc. People should take specific directions in order to be guided to them. Therefore, load balancing functionality is very critical. With the term load balancing, we describe the balanced distribution of people to the available resources in order to avoid overload and minimize the risk of congestions. Load balancing is a networking solution for distributing incoming traffic among a number of available resources. It aims to minimize response time, maximize throughput and, in general, to optimize resources use. A load balancing module takes into consideration people's characteristics as well as resources characteristics. Based on them, the module is capable of distributing the right person to the right resource.

A number of research efforts are available dealing with load balancing models for evacuation planning. The proposed systems are mainly studying guidance under emergency and are combined with sensor technologies for people movement identification. In this paper, we focus on the discussed problem, however, our system is oriented to provide services to *field commanders* (FCs) and *rescue teams* (RTs). FCs are responsible to take the appropriate decisions in order to handle emergencies while RTs have the responsibility of helping people in danger. Our system aims to handle post-emergencies and can be used either for indoor or outdoor applications. It adopts a set of predictors in order to estimate the load of each resource and, thus, to select the best possible result. Our approach is based on the solution provided for the known *Santa Fe Bar Problem* (SFBP) (Arthur, 1994; Greenwald, Mishra, & Parikh, 1998). SFBP was introduced as a framework to investigate how one models bounded rationality in economics. It consists of a problem defined in game theory and deals with the distribution of a finite population of people to finite resources.

In post-emergency situations, FCs and RTs require an efficient, however, fast system to result the appropriate allocation of a number of entities into a number of resources. FCs and RTs are

* Corresponding author.
E-mail addresses: kostasks@di.uoa.gr (K. Kolomvatsos), k.panagidh@di.uoa.gr (K. Panagidi), shadj@di.uoa.gr (S. Hadjiefthymiades).

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responsible to take important decisions during post-emergency situations in order to save people. Imagine an earthquake incident after which a number of buildings are collapsed and a number of injured persons require assistance. FCs and RTs after reaching to the place of incident should decide the allocation of injured persons into the available hospitals. In such scenarios, a tool like the proposed could be very useful. Based on the information for the available hospitals and injured persons, it could result, in the minimum time, the optimal allocation of injured persons. Hence, congestions in the street network as well as hospitals overloading will be eliminated. Our research motivation is to provide the appropriate theoretical and practical models to handle the discussed scenario. The proposed tool handles the increasing demand for resources as well as it alleviates excessive waiting time for people in danger. It provides an efficient, however, simple interface to FCs and RTs in order to facilitate them to insert the required information in the minimum time. Additionally, the proposed tool optimally handles the flow of entities in post-emergency situations via the load balancing technique. The adopted predictors aim to provide a future insight on the load of the available resources through historical information processing. Hence, congestions and overloading will be avoided not only for the affected area and the resources but for the surroundings.

1.2. Related work

Important research efforts have been carried out to develop efficient models for handling evacuation scenarios. Many of them refer to the use of sensor networks for retrieving information about moving objects while only a few consider outdoor applications.

In Hadzic, Brown, and Sreenan (2011), the authors propose a set of solutions for real time evacuation guidance. The proposed technique concerns evacuation from buildings due to a fire. A set of heuristic approaches are presented and analysis on the problem and its complexity is discussed. The authors take into consideration just a single exit during evacuation without examining the load for each of them. A dynamic model for fire emergency evacuation is studied in Tabirca, Brown, and Sreenan (2009) (indoor scenario). The proposed model deals with dynamic navigation graphs in order to handle the hazard spread. The authors assume that the number of people is not too big to exceed corridor capacities. Therefore, similar to Hadzic et al. (2011), load management is not taken into consideration. In Fersch and Zia (2009), the authors present a wearable device, LifeBelt, that helps people in panic, in case of a disaster. LifeBelt is a coordinated navigation device helping individuals to escape from dangerous places. The device adopts the vibro-tactile guidance technology to provide directions. Possible congestions are not taken into consideration. Navigation with the use of *Wireless Sensor Networks* (WSNs) is the subject in Li, Zhan, Wu, Yang, and Chen (2011). The authors propose an efficient *Emergency Rescue Navigation* (ERN) strategy by adopting WSNs as the navigation infrastructure. The proposed approach takes into consideration pedestrian congestion and rescue force flexibility. People movement is seen as network flows on a graph. By calculating the maximum flow and minimum cut in the graph, the system is capable of providing directions to rescue teams and eliminate dangerous areas.

In Li, DeRosa, and Rus (2003), the authors discuss distributed algorithms for self-organizing sensor networks used for providing directions in a specific area. Sensors are adopted to model the danger level across the examined area. Dangerous regions are modeled as obstacles. The paper focuses on finding the escape path form each sensor to the exit, avoiding dangerous places. Load balancing among multiple navigation paths is studied in Chen, Chen, Wu, and Huang (2008). With the assistance of sensors, moving objects are guided to different paths and, thus, congestion is eliminated. Results show that the proposed model can guide moving objects in short time and can effectively handle the direction oscillation problem. In Chen, Kao, Chen, and Lin (2011), the authors propose a distributed flow-based guiding protocol for indoor environments. The congestion problem is taken into account for providing the most efficient guidance directions. Each sensor monitors a path and, thus, holds an artificial potential value determined by moving objects. The authors adopt a traffic flow model for transforming object density to velocity in order to reduce the computational cost and communication overhead.

In Alyfantis, Hadjiefthymiades, and Merakos (2009), the authors discuss a smart spaces system called MITOS. The proposed system suggests to a user the best location to move for obtaining a satisfactory level of service. The system monitors the traffic and user location across the network and formulates the appropriate relocation proposal. The proposed approach borrows game theoretic mechanisms from the known SFBP and utilizes a prediction scheme for load balancing. Hence, the traffic remains at affordable levels and the QoS is increased. LEGS (Chen, Cheng, Kuo, Chiang, & Lin, 2012) is a load balancing emergency guiding system that adopts WSNs. The proposed scheme can provide a fast path to an exit for people in danger. Building characteristics are taken into consideration and the evacuation time is estimated and analyzed. The load balancing module is responsible to select the appropriate guiding tree to the evacuation. Another load balancing framework for emergency guiding is proposed in Chen, Cheng, and Tseng (2012). The scenario involves indoor evacuation and the aim is to find the fastest path to an exit. The proposed framework alleviates the congestion of corridors and exits and, thus, it can lead to a reduced evacuation time. The authors in Neighbour, Oppenheimer, and McLeod (2010) focus on a framework for modeling the spread of contact transmission for infectious diseases. Simulations give the necessary information to a decision making process followed by emergency departments. The study aims to achieve balanced patient loads compared to situations where some departments are overloaded and others are underutilized.

1.3. Contribution and organization

In this paper, we discuss a simple, however, efficient tool for the optimal distribution of a number of entities into a number of resources. Our aim is twofold: (a) to provide a simple light-weight interface for FCs and RTs and, (b) to provide a powerful tool that results the right resource for each entity. The first goal is fulfilled by adopting a front-end layer created by light-weight Web technologies. Hence, FCs can easily run the tool and use it to result the discussed allocation. The tool is going to be used in post-emergency scenarios where there is an increased need for immediately decisions on the allocation of entities. Through this approach, FCs and RTs save time and serve the persons in need in the most efficient way. The second goal is fulfilled by adopting a pool of predictors over historical data for resources load. The aim is to select different predictors for each entity and, thus, to avoid disadvantages of adopting a single predictor. By adopting a single predictor, the system will be affected by the ‘behavior’ of the predictor and no efficient results could be retrieved. Additionally, the module automatically selects the predictor having the highest prediction accuracy in the previous round. Hence, prediction errors cannot affect the efficiency of the final outcome. Other research efforts in the field mainly focus on load balancing techniques for evacuation purposes. These approaches require an additional step for process sensor data adopted to identify people movement. The proposed techniques are heuristic and are affected by the application domain. The following list presents, in short, the differences of our model with other models found in the literature.

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