Pervasive Emergency Support Systems for Building Evacuation

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***Abstract*—An emergency situation taking place inside a confined space, such as a building, is a challenging task due to the presence of dynamic conditions. Pervasive systems can prove beneficial for the evacuation procedure, as they can provide directions to the evacuees regarding the best available exit. In this paper we describe two pervasive systems geared towards emergency support, which are deployed inside a building. Both systems use simple communications in order to collect and disseminate information regarding the best evacuation paths. We use a multi-agent simulation platform to demonstrate how the use of the systems improves the outcome of the evacuation procedure.**

***Keywords*-pervasive systems; emergency simulation; disaster management; building evacuation; opportunistic communications.**

I. Introduction

In emergencies that take place inside an urban area, people located inside the area have to be quickly informed of the situation in order to minimize their exposure to hazards. They would also have to decide on which is the safest path to choose in order to reach an exit, which is a demanding task, especially without knowledge of the area and of the locations affected by the hazard [1]. Moreover, the condition of paths can change as the hazard spreads in different locations inside the area.

In this paper we propose two pervasive systems which are able to provide guidance to people during an evacuation procedure. Both systems are designed to operate inside confined spaces, such as buildings, and use wireless communications to gather information regarding the ongoing situation and to calculate the best evacuation paths. The first system is based on static nodes which calculate the best evacuation paths in a distributed manner, using local communications. The second system uses mobile nodes that employ opportunistic communications.

II. The Distributed Building Evacuation Simulator

Our proposed systems are implemented inside the Distributed Building Evacuation Simulator (DBES) [2]. The basis for the simulation environment is the JADE platform, which allows for the development of applications which comply with the FIPA specifications for intelligent multi-agent systems. Our goal is to reduce the complexity of our approach and to ensure its compliance by using a comprehensive set of agents and services. The DBES is a discrete event simulator that has the ability to operate in real time, which enables the integration of external components such as a real sensor network.

We have modeled the disaster area using a collection of graphs. Each graph contains nodes with different attributes, such as entrances to an area or staircases that connect different areas. Fig. 1 depicts two areas with five exits and three staircases. Each dedicated simulator, responsible for controlling an area, is only aware of its own area of interest and how this is connected via graph bridges to other areas.

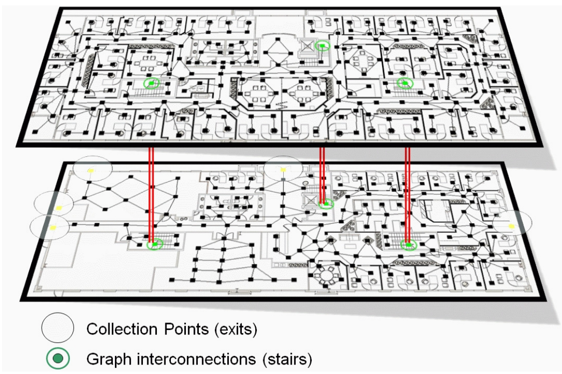

Figure 1. Two areas with 5 collection points (exits) and 3 graph bridges (staircases)

The actors that participate in the simulation are modeled as agents with different individual characteristics. This enables us to simulate a number of entities such as civilians which evacuate the building, robots exploring the building, immobilized civilians in various locations inside the building etc. Each entity has a state which is defined by a location, a health level and a personal goal. As the simulation progresses, these parameters can be modified by both other agents and the environment. A fire, for example, which is spreading inside a building will change the health level of entities and will also change the state of paths. Moreover, each entity has a personal view of the world which changes as entities move inside the simulated area. As an entity traverses the graph, it updates its perspective taking into account the current surroundings.

III. Description of the Navigation Systems

While designing our pervasive systems we made assumptions that were closely related to the operating environment, which in our case is a multi-storey building. Our first assumptions is that a graph $G(V, E)$ is used to model the area inside the building. The vertices V represent locations where people can congregate, such as offices, doorways and rooms. Edges E of the graph represent actual physical paths that can be followed by a civilian in order to move. The length $l(i, j)$ of an edge is the physical distance between vertices $i, j \in V$ while $h(i, j)$ represents the hazard intensity along this edge. We have defined the "effective" length $L(i, j)$ of an edge as $L(i, j) = l(i, j) \cdot h(i, j)$. This is a metric that expresses how dangerous an edge is for a civilian to traverse. In the case where there is no hazard present on an edge, $L \equiv l$ and the effective length is equivalent to the physical length of the edge. As the value of h increases, an edge becomes more dangerous to traverse.

Our second assumption is related to the presence of **sensor nodes (SNs)** in the building. Each SN is installed in a specific location inside the building and monitors an edge of the graph. SNs are simple devices, equipped with short-range wireless communications and with low memory and computing capabilities. When a hazard value is requested from a SN, it sends the $h(i, j)$ value for the corresponding edge.

A. Intelligent Evacuation System

Our first system is called Intelligent Evacuation System (IES) [3]. It relies on static devices positioned at specific locations in the building, at each graph vertex. Each of these devices, which we name **decision nodes (DNs)**, are equipped with a processor, memory and short range communications capability. The role of a DN is to calculate the safest direction towards a building exit and to communicate this to evacuees or other entities in its vicinity. In order to achieve this, each DN has a dynamic panel which can use arrows to present evacuation directions to the evacuees. Information regarding the hazard is provided to a DN by its neighbor SNs. This information is propagated through the network of DNs by using a distributed algorithm. Each DN, located at vertex u, stored the following information:

- the effective edge lengths to neighbors: $L(u, n)$, $\forall n \in V \mid (u, n) \in E$
- the effective lengths of the paths to an exit for all neighbors: $L(n, e)$, $\forall n \in V \mid (u, n) \in E$ and e is a building exit,
- the effective length of the shortest path (SP) from u to an exit e: $L(u, e)$,
- the next suggested DN d (i.e. the next hop along the SP from u to an exit).

Each DN periodically runs a distributed algorithm [3] which updates the executing DN's neighbors and the DN itself. The algorithm is inspired by the distributed shortest path algorithm [4] and adaptive routing techniques such as the Cognitive Packet Network [5]. The algorithm's output is the next hop along the SP to a building exit. Since the metric used combines both physical distance and hazard intensity, the IES gives directions that minimize the exposure to hazardous areas. Fig. 2 shows the IES simulated inside the DBES. Each arrow corresponds to a DN's dynamic panel.

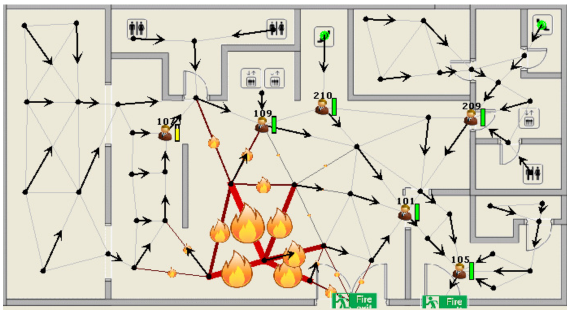

Figure 2. The IES as simulated by the DBES

B. Opportunistic Communications based Evacuation System

Our second system is called Opportunistic Communications based Evacuation System (OCES) [6]. It's main building blocks are **mobile communication nodes (CNs)** which the evacuees are able to carry. In other words, we assume that each evacuee is equipped with a portable device, such as a mobile phone or PDA, which is able to process and store information. This device should also be capable of short-range (up to 10m) wireless communications. CNs form an opportunistic network since devices come into contact as a result of the vicinity of other humans and their mobility. We should note that delivery of messages is not guaranteed and a CN may have to carry messages for a long durations. This is due to the nature of the opportunistic network (oppnet) which can be disconnected for long time periods.

Each CN receives information regarding the hazard from the SNs located in its vicinity. These values are used to update the global building graph which is stored in a CN. Hazard information is disseminated in the form of *emergency messages (EMs)*, using opportunistic communications. We used *Epidemic routing (ER)* [7] for the dissemination of EMs in the oppnet. Each EM is disseminated among all the CNs in the OCES. When a CN receives a hazard observation for the first time, it treats it as an alarm and notifies the respective civilian that there is a hazard and he should start evacuating the building. The directions of a CN are communicated to a civilian using audio-visual signals.

Upon reception of an EM, the CN uses the information received to update the edge costs locally stored in its building graph. This also triggers the re-calculation of the evacuation path from the location of the CN to the nearest building exit using Dijkstra's shortest path (SP) algorithm.

Similarly to the IES, the OCES uses “effective” length values for the SP calculation, which results in a path that minimizes both the travel distance and the exposure to the hazard. CNs use the SP to direct each civilian towards the next hop on the SP. The localization of a CN is achieved by using the SNs. Each CN that moves inside the building requests a location tag from SNs in its vicinity. Each SN that is within communication range, replies with a a *localization message (LM)* which contains its location. The CN uses the LMs and its movement history to find out its location inside the building.

Fig. 3 shows the OCES simulated inside the DBES. Each circle represents the maximum communication range of a CN.

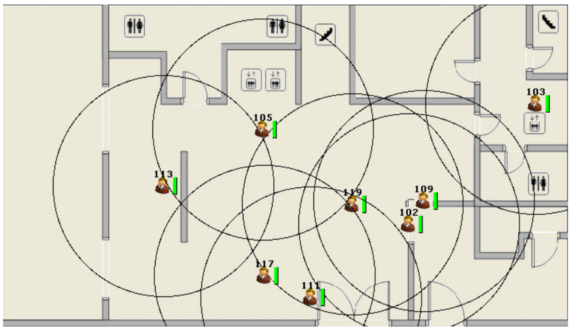

Figure 3. The OCES as simulated by the DBES

IV. Demonstration Scenario

Our demonstration scenario will involve the evacuation of a multi-storey building, as depicted in Fig. 4, while a fire is spreading. The three floors are connected by three staircases, one at each end of the floors and one in the middle. The two exits are located on the ground floor. The DBES will be used to simulate the evacuation procedure as well as the operation of the proposed pervasive systems. The users will be able to see how the evacuation procedure evolves, while a hazard is spreading, and how the use of the pervasive systems benefits the overall outcome. The users will also be able to use the GUI in order to change simulation parameters such as the location of the fire, the building population size and the type of the emergency support system in use.

The demonstration requires the use of one large size monitor or TV with VGA/DVI input and a wall outlet to provide power to our laptop.

V. Conclusion

We have presented two pervasive systems that are able to provide civilians with navigation services during an emergency situation. The first system relies on static devices called decision nodes (DNs) which calculate the best evacuation paths in a distributed manner, using local communication and computation. The second system (OCES) relies

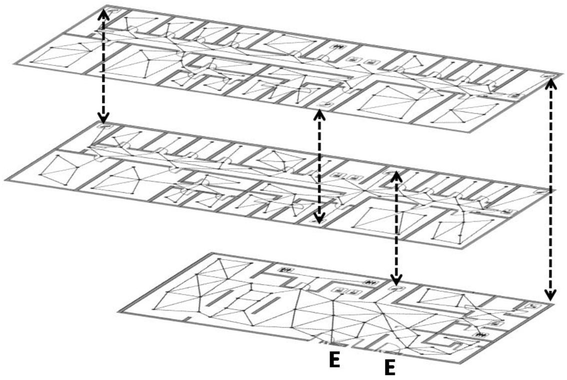

Figure 4. The three-storey building used in the demonstration, depicting the stairways and building exits.

on wireless communication nodes (CNs) that the civilians carry. CNs exchange emergency messages by forming an opportunistic network. These messages are used for guiding the civilians during the evacuation. A network of sensor nodes (SNs) supports both systems, by providing information regarding the hazard. We demonstrate the operation of our systems and their beneficial effect on the evacuation procedure using our distributed simulation platform (DBES).

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