Adaptive Wireless Sensor Network and Cloud-based Approaches for Emergency Navigation

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***Abstract*—Emergencies can happen at anytime and anywhere. Governments around the world try to ensure public and private organizations' preparedness for all types of potential emergencies. They usually rely on implementing autonomous systems to deal with unpredictable emergency scenarios. This research proposes and simulates an adaptive emergency evacuation approach based on wireless sensor networks (WSNs) and cloud computing. The proposed approach maximizes the safety of the obtained paths by adapting to the characteristics of the hazard, evacuees' behavior, and environmental conditions. It also extends the WSN-based approach by employing an on-demand cloudification algorithm that improves the evacuation accuracy and efficiency for critical cases. It mainly handles an important evacuation issue when people are blocked in a safe, dead-end area of a building. The demo shows how each evacuation is performed in both WSN-based and cloud-integrated approach. Simulation results show an improved safety and evacuation efficiency by an average of 98% over the existing time-based and single-metric emergency evacuation approaches.**

Keywords—wireless sensor network; distributed algorithms; clouds; emergency services; emergency navigation.

RESEARCH SUMMARY

An emergency is a situation or condition that causes hazard to an environment, life, company, community, or property. Emergency management (EM) is vital for any organization today. It aims to create plans by which communities reduce their vulnerability to hazards and cope with disasters [1][2]. Emergency navigation (EN) concentrates on combining mathematical models or algorithms with the underlying sensing, communication, and distributed, real-time computation to guide evacuees to safety in a built environment [3]. Wireless sensor networks (WSNs) have been widely employed for environmental monitoring and control [4]. Using WSNs, the deployed sensors collect and report results to a central repository. WSNs have been recently integrated with other communication and intelligent technologies, such as cloud computing, smartphones, and robots, in order to implement systems with more powerful, advanced, and accurate solutions [5]. Such integration allows the efficient utilization of WSNs' advantages and overcomes almost all WSNs' limitations, including limited processing power, limited communication, and low accuracy for localized decisions.

The idea of integrating WSNs with cloud computing (CC) is quite promising [5]. A typical WSN consists of a large number of low-cost, low-power, multifunctional, and resource-constrained sensor nodes. Cloud services are a powerful, flexible, and cost-effective framework that provides real-time data to users with vast quality and coverage. A cloud typically consists of hardware, networks, services, storage, and interfaces that enable the delivery of computing as a service [6]. Clouds are designed with the flexibility to withstand harsh environmental conditions in some cases. Integrating CC with WSNs allows virtualization, which facilitates the shifting of data from WSNs to a cloud. Accordingly, it also allows cost-efficient applications and service provisioning in WSNs. Using cloud, all WSNs' resources can be virtualized and provided as services to third parties depending on their demands. However, integration should be well-designed and modeled in order to provide efficient, robust, and scalable infrastructure for several critical applications, including emergency management.

Fig. 1 shows a typical architecture for integrating WSNs with CC for emergency and evacuation management. The figure shows that WSNs act on the base plane, where low-cost sensing nodes are densely deployed in the targeted area. Sensing nodes collect and transmit data to control nodes. Control nodes are more capable than sensor nodes, as they have higher computation and communication capabilities. However, they are usually deployed less-intensely than sensor nodes to minimize the cost and communication overhead. Connection to the cloud gateway on the middle plane is done through control nodes to tackle complex computations or provide remote information. The cloud plane is connected to the upper service (or control) plane through another gateway(s).

In this research, a real-time, autonomous emergency evacuation approach that integrates cloud computing with wireless sensor networks in order to improve evacuation accuracy and efficiency is proposed. Our approach is designed to perform localized, autonomous navigation by calculating the best evacuation paths in a distributed manner using two types of sensor nodes. In addition to distributed path finding, sensor nodes identify the occurrences of a common evacuation problem that happens when evacuees are directed to safe, dead-end areas of a building. These areas are characterized as safe because they are far from the incident, but they are also far from the exit. Eventually, these areas become no longer safe, especially if the incident is intense. When such a situation is identified, our approach employs cloudification to efficiently and carefully handle this problem.

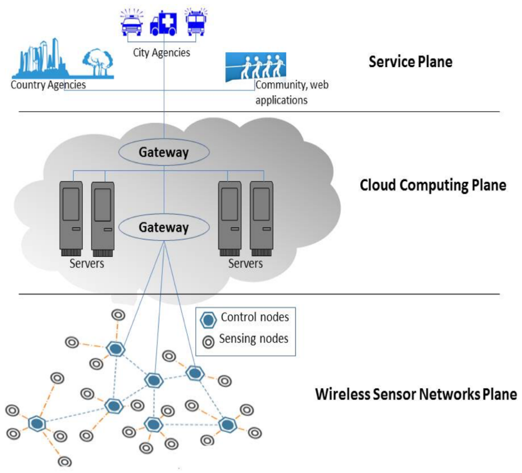

Fig. 1. A typical architecture of integrating WSNs and CC for emergency and evacuation management.

In order to evaluate the performance of the proposed approaches in terms of adaptivity and real-time decision-making accuracy, we implemented our own event-driven evacuation simulator using MATLAB. The simulator simulates an exemplary building model presented in Fig. 2. It aims to study and compare the performance of the proposed localized WSN-based evacuation approach to its cloudified version in terms of number of survivors, evacuation time, and efficiency. It also compares the performance of our two approaches to one of the existing, widely used evacuation approaches that relies on a distance metric to find the shortest path to the closest exit. Different simulation scenarios were considered and proposed. A number of simulation variables are considered here in a way that mimics real-life problems, including location and intensity of the hazard, number of evacuees, and evacuation area. The presented results represent an average of 30 simulation runs with different levels of randomness. Simulation shows both proposed approaches have improved evacuation efficiency and accuracy. This demo shows how each navigation approach acts and performs under different evacuation conditions. We modelled the underlying evacuation area using a similar building model to the one described in [3]. We used two types of wireless nodes: basic sensor nodes (SNs) and control or decision nodes (DNs) in order to sense and process the information needed to locally calculate safe paths for the evacuees.

The conceptual model for the overall behavior of the proposed integrated approach, called adaptive real-time clouded wireless sensor network-based (ARTC-WSN), is presented in Fig. 3. The ARTC-WSN emergency evacuation approach is triggered when a hazard is detected. Sensor nodes periodically collect and report data on hazard source, intensity, and evacuees' movements to the DNs. Consequently, DNs gather and combine data received from the nearby sensor nodes with the information provided by the cloud. Then, DNs employ the ARTC-WSN approach to locally find evacuation paths. The calculation of evacuation paths at DNs is done in a distributed manner.

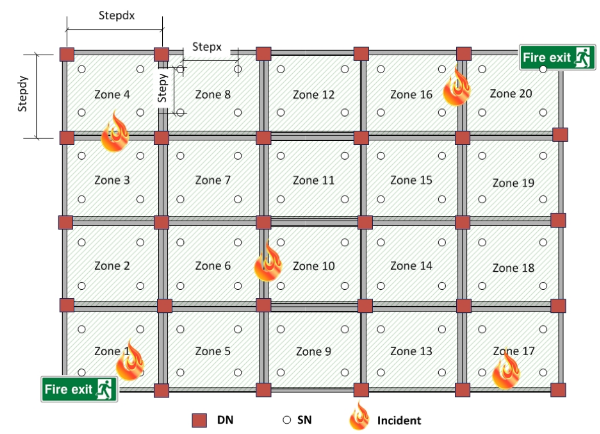

Fig. 2. A Graphical representation of an exemplary building model where the ARTC-WSN evacuation approach could be employed.

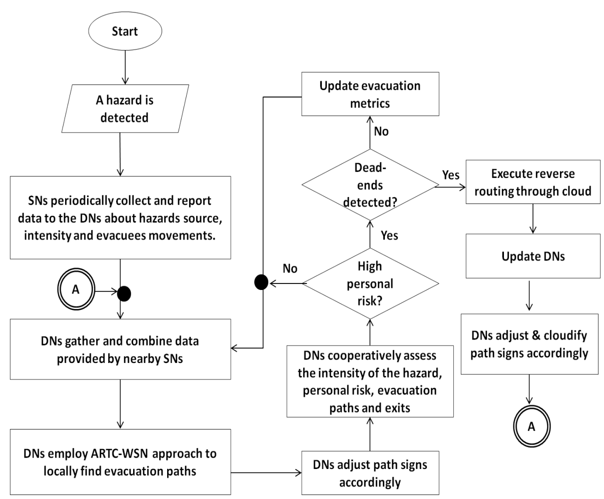

Fig. 3. Conceptual model representing the overall behavior of the proposed approach

The demo shows the considered simulation variables and their values used in the different simulation scenarios including: Hazard location which is randomly generated in each simulation run. It also shows the impact of changing the hazard intensity when the intensity of incident changes—3, 5, 7, and 9—in order to assess the behavior of the proposed approaches under different minor and major impact hazards. The intensity value 9 represents the highest. It means the hazard expands 9 units of area, i.e. meters, in each unit of time, i.e. seconds, in all directions. The demo also shows the impact of changing number of evacuees which allows a comparison of the performance of different approaches under different evacuee densities. The number of evacuees varied in some scenarios; 100, 300, and 500 evacuees were the numbers considered.

The evacuation area is also investigated in this demo. the performance of the proposed approach was studied in small, moderate, and large evacuation areas. More specifically, the performance was evaluated for a small evacuation area of 100x100m, a moderate area of 200x200m, and a large area of 300x300m. For exit availability, the demo examines the behavior of the proposed algorithm in several situations where only one exit was found and available.

Based on the above-described scenarios and simulation variables, the performance of the proposed approach is compared to one of the evacuation approaches presented in [14], which is a Dijkstra's shortest path (DSP) algorithm with time and distance metrics. The performance was examined in five different experiments to investigate the potential improvements offered by the proposed algorithms.

The first three experiments were designed to determine the performance of the algorithms for small-scale, moderate-scale, and large-scale evacuation areas of 300 evacuees with respect to different hazard intensities.

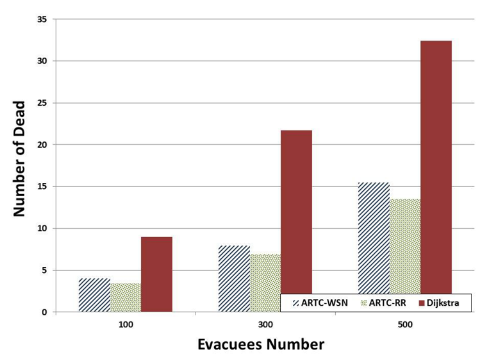

Fig. 4. Comparison of the number of fatalities when the number of evacuees ranged between 100 and 500.

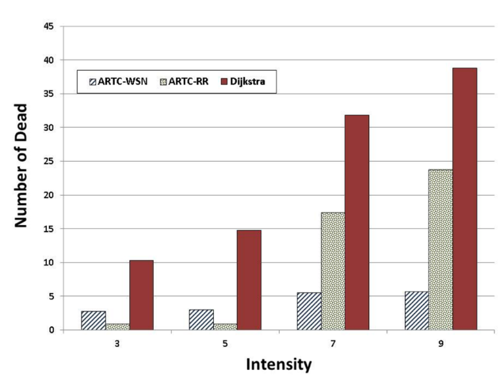

Fig. 5. Comparison of number of fatalities of different approaches in large evacuation areas when number of evacuees=300.

Experiment four was designed to measure the performance of the three algorithms over crowded areas with different occupancy rates: 100, 300, and 500 evacuees. Finally, the fifth and last experiment was designed to measure the performance of the algorithms when the number of exits was minimized to 1.

Table 1: The percentage of survivals for the three approaches when evacuation area ranged from small- to large-scale areas.

Evacuation Area	Hazard Intensity	Evacuation Approach		
		ARTC-WSN	ARTC-RR	Dijkstra
Small-Scale Area	3	97%	98%	93%
	5	96%	96%	85%
	7	95%	96%	83%
	9	96%	93%	87%
Medium-Scale Area	3	99%	99%	96%
	5	99%	99%	96%
	7	99%	99%	92%
	9	98%	99%	89%
Large-Scale Area	3	99%	100%	97%
	5	99%	100%	95%
	7	98%	94%	89%
	9	98%	92%	87%

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