Computers and Electrical Engineering 56 (2016) 810–830

Contents lists available at ScienceDirect

Computers and Electrical Engineering

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

A cloud-based architecture for emergency management and first responders localization in smart city environments☆

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ARTICLE INFO

Article history:
Received 30 August 2015
Revised 14 February 2016
Accepted 15 February 2016
Available online 3 March 2016

Keywords:
Smart city
Hybrid cloud
Crisis management
Location-awareness
Indoor positioning

ABSTRACT

Homeland security represents one of the most relevant application contexts for smart cities, attracting the interest of both authorities and the research community. In case of a crisis event occurring in the urban area, authorities are responsible for effectively managing response operations. A critical challenge in emergency management is the lack of real-time coordinated reaction capabilities driven by integrated decision making facilities based on the information obtained by first responders acting on the crisis site. This work aims at supporting coordinated emergency management in smart cities based on the localization of first responders during crisis events. We present a hybrid cloud architecture for managing computing and storage resources needed by command & control activities in emergency scenarios, complemented by a first responder localization service relying on a novel positioning approach which combines the strength of signals received from landmarks placed by first responders on the crisis site with information obtained from motion sensors.

1. Introduction

The Smart City paradigm originates from the recent advances in ubiquitous communications and Internet of Things, applied in an urban scenario with the aim of creating new fully integrated ICT infrastructures covering next-generation cities. Such cities will massively provide innovative services for the optimization of traffic/transportation flows, smart energy management, smart touristic and public services, intelligent lighting/electricity control and monitoring, as well as public surveillance, fire and incident detection, advanced healthcare and emergency response/crisis management.

The aforementioned ICT infrastructures, introduce important modifications in both city governance and citizen involvement in public services, through the substantial improvements in communication and information management services, integrated information intelligence, collaborative decision making, distributed monitoring and remote control facilities, resulting in a perceivable socio-economic growth and an enhanced quality-of-life in urban areas.

In such an extremely integrated and collaborative scenario, the management of emergency and crisis events affecting the urban area becomes one of the most interesting and useful services that can be provided within the smart city context.

☆ Reviews processed and recommended for publication to the Editor-in-Chief by Guest Editor Dr. F. Xhafa.

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http://dx.doi.org/10.1016/j.compeleceng.2016.02.012
0045-7906/

These events point out the vulnerabilities that exist in urban areas and in critical infrastructures and may bring significant threats to society values and its associated life-sustaining functions, by introducing an urgent need for effective responses, often under critical uncertainty conditions.

One of the main requirement in case of such events is the real-time availability of incident control and crisis management intelligence, with the need for collecting, integrating and processing all the possible data coming from the crisis scenario. In particular, supporting of First Responders (FRs) represents one of the most critical activities during crisis events, requiring the timely collection of relevant location-aware information for the command & control centers, in order to perform the necessary analysis and to coordinate relief efforts. Resiliency in the ICT infrastructure supporting smart city services is another fundamental requirement since both the loss of processing capabilities in command & control centers and the damage (or worst, the loss) of communication capabilities together with the poor efficiency of positioning systems, are the main current drawbacks. Multiple redundant command & control centers can be deployed to cope with the first challenge, also empowered by mobile/ubiquitous computing and communication technologies, resulting in different Mobile Emergency Operation Centers (MEOC) involved, under the control and coordination of a single Command Emergency Operation Center (CEOC), i.e., the headquarter. Therefore, during rescue operations, there is still a gap among the situation of forces on the ground (e.g., police, firefighters etc.), the partial overview at the different MEOCs, and the overall overview at the CEOC.

Cloud computing technology, based on the concepts of converged infrastructure, unlimited scaling and shared services, can be the immediate response for the high dynamicity, resiliency and adaptivity needs characterizing the processing and storage capabilities of the command & control centers. Such runtime and storage capabilities are of paramount importance for implementing integrated intelligence facilities in crisis management by transforming the traditional service provisioning models and facilitating access and storage of emergency domain data, coming from a large amount of heterogeneous sources, as well as providing on-demand IT resources for MEOCs, and allowing their integrated processing and analysis at the CEOC level through the use of flexible pools of IT resources available on-demand.

On the other hand, the other fundamental enabling technology for providing crisis management services in the smart city area, and, more specifically, supporting all the on-field activities needed in first responder localization, is wireless communication, involving a large number of heterogeneous mobile smart sensing devices interconnected through Wireless Wide Area communication (WWAN—e.g., LTE, UMTS, HSDPA, Satellite Cellular) or Wireless Local Area Networks (WLAN—e.g., Wi-Fi, Bluetooth or ZigBee) facilities. Such devices may range from dedicated landmarks or sensing equipment to citizens' smart phones involved participatory and opportunistic sensing or signaling activities. Whereas the first responders localization problem in outdoor environments is straightforwardly solved by combining the Global Positioning System (GPS) capabilities and the available mobile satellite-empowered communication technologies, the positioning/localization of devices and people within indoor environments (e.g., houses and office buildings) mainly characterizing smart city scenarios, is still the subject of many research and development efforts [1]. In particular, the interworking between the WWANs and the current generation of WLANs, allowed leveraging these wireless network technologies for provisioning of location-based services relying on the communication capabilities of multiple heterogeneous sensing devices. More specifically, the spreading of wireless hot-spots into urban areas and the availability of positioning solutions based on Wireless Sensor Networks (WSN), as well as the current generation of mobile devices supporting several technologies used for localization, have fostered the development of new indoor positioning systems based on pre-installed (fixed) infrastructures [2]. Unfortunately, during a crisis or disaster, the presence of pre-installed landmarks or operational anchors nodes in the involved sites could not be assumed as guaranteed, and the training data needed to calibrate the positioning systems could not be available, fostering the need for landmark-free systems, that can perform self-localization without relying on any external landmarks. However, in landmark-free systems errors may be accumulated due to sensor noise, if no landmarks are available for recalibration. So, at the state of art, there are no commercially available positioning solutions that can be reliably used by FRs in the contexts in which they operate. For this reason, it is mandatory to investigate solutions for combining the landmark-based and landmark-free technologies, according to the danger area in which FRs have to operate. Starting from the above considerations, in this work, we explore an effective emergency management solution for smart cities based on a hybrid decentralized service-oriented cloud platform for managing command & control activities in urban areas and acquiring, through mobile communication and smart sensing facilities, the location-aware information necessary to support the FRs in crisis scenarios. No assumptions can be done about the working conditions (presence or absence of landmarks etc.) because of unpredictable events that can affect both the location of command & control centers and the availability of fixed positioning infrastructures. On-field activities involving the FR localization services, are based on a hybrid positioning approach, managed at the remote sensor level and supported by the cloud runtime/storage facilities, that combines the strength of signals received from landmark nodes, which have to be manually placed by FRs within the crisis area (e.g., at the building entrance and along a flight of stairs), and the information gathered from motion sensors, such as gyroscopes, accelerometers and compasses available on the crisis scenario. Specifically, landmarks are used as navigational support through relative positioning, whereas motion sensors can be used for inferring the action of the FR (such as speed and orientation), in order to achieve a more accurate positioning in a quite short time.

The work is organized as follows. Section 2 presents the needed background information together with a perspective of the related experiences available in literature. The architecture of the proposed hybrid cloud for managing emergency in smart cities has been presented in Section 3 whereas the details of the associated first responders localization service are reported in Section 4. Some specific security aspects are discussed in Section 5, and the effectiveness of the proposal has