E-Flow: A Communication System for User Notification in Dynamic Evacuation Scenarios

Augusto Morales, Ramon Alcarria, Tomás Robles, Edwin Cedeño,
Erno Peter Cosma, Javier Bermejo, and Francisco Perez Arribas

Abstract. Most of the current evacuation plans are based on static signaling, fixed monitoring infrastructure, and limited user notification and feedback mechanisms. These facts lead to lower situation awareness, in the case event of an emergency, such as blocked emergency exits, while delaying the reaction time of individuals. In this context, we introduce the E-Flow communication system, which improves the user awareness by integrating personal, mobile and fixed devices with the existing monitoring infrastructure. Our system broadens the notification and monitoring alternatives, in real time, among, safety staff, end-users and evacuation related devices, such as sensors and actuators.

Keywords: evacuation, communication system, publish/subscribe, MQTT.

1 Introduction and Background

The evacuation analysis of infrastructures is a long-studied problem that has been tackled with route modeling, decision support systems and so on. Some weaknesses of current evacuation plans relate to the way users perceive information using fixed visual, acoustic and light signals regardless of the emergency type, as these signals generally provide the static information and evacuation routes. For example, if emergency exits are unusable during the evacuation, individuals might not be aware of this situation until it is probably too late to react, and this fact affects the overall safety procedures and user awareness. Therefore, it is clear that a number of factors (e.g. humans and environmental) could alter the evacuation scenario, so they shall be considered as factors to take into consideration for a successful evacuation.

Most of the current research in evacuation scenarios has tackled [1][3] decision, route planning, and simulations, but few of them tackle the evacuation from the user awareness perspective. Nowadays, there are technologies that indeed permit wireless sensorized environments to provide information in these situations. Nevertheless, there are also challenges [2] related to the human factor, such as: reducing the reaction time of personnel, reduce the interpretation time, providing easy interaction mechanisms and dynamic signaling. Hence, the aim of dynamic evacuation scenarios is also associated to the availability of flexible user notification mechanisms and the interaction capabilities with the evacuation communication infrastructure in the critical moments.

In this paper we present our communication system for enhancing the user awareness, which has been developed under the E-Flow project [5]. It improves evacuation scenarios by integrating computing capabilities (human or machine-oriented) with end-users in order to improve their chances of survival through better situation awareness. Our system is composed of several communication layers, ranging from nodes in wireless sensor networks to end-user messaging. Therefore, this paper addresses the novelties of our system from a holistic approach and describes the integration of communication enhancements, produced from previous works [7][11]

Most of the solutions that may help to foresee and correctly react to evacuation scenarios are based on simulations [4]. They optimize evacuation plans for specific infrastructures, test them and detect critical points before the building is even planned. Our proposal focuses on the communication capabilities and allows broader situation awareness that lead to better individuals' decisions; so it can work as a complementary input for these solutions. Other approaches regarding implementations of evacuation scenarios take into account the dynamic characteristic by providing adaptation models that enable the fast creation of prototypes based on agent systems [19] or autonomous navigation systems [15]. These systems are often focused on route optimizations that can be based on colony algorithms [16], fuzzy logic [17] and also with algorithms inherited from communication networks. Other approaches also consider the movement of pedestrians as a homogeneous mass that behaves like a fluid flowing along corridors at a specific rate [20]. Our system differs from others, as it offers a comprehensive knowledge of the scenario in real time so it can work on top of other solutions.

The organization of the paper is as follows. In section II we detail the requirements of communication system from the human perspective. Section III states our proposed system. In Section IV we describe our implementation. Section V reviews previous works. Finally, we end with conclusions and future works

2 The Human Context in Evacuation Scenarios

The evacuation of buildings and other spaces is solved by means of static-like evacuation plans. These plans are obtained from the use of regulations and experiences prior to their construction. Evacuation plans can also be implemented over buildings or spaces already built due for example to new regulations or distribution changes. Thus, current evacuation plans associated to buildings barely take into account specific incidents people might face in an emergency [2], and the consequences of particular circumstances (e.g. fire near the emergency exit, changes in meeting points). Also, in many of these plans, both signals and evacuation devices are not suitable for persons with special needs.

Another weakness of current evacuation plans is the fact that the information given, based on labeled signs, acoustic and/or illuminated signals, is displayed in a static way, regardless of the emergency situation. For example, if one of the emergency exits cannot be used during the evacuation, people are unaware of this up to the very last moment, and probably this will probably lead to a late reaction. This non-flexible way to perform the evacuation clearly affects people's safety as it assumes a lack of variance when it is evident that there are plenty of different situations that can alter its progress. Therefore, a *user notification system* can contribute to a broader and flexible view of the whole situation. Currently, communication among the head of the evacuation and the rest of the assigned staff is mostly carry out by using push-to-talk technologies and radio-frequency devices; however, these proprietary devices generally lack integration capabilities with the rest of the communication platform of the site, and are difficult to enhance with new functionalities. Thus, communication flexibility and pluggability merge as needs. Currently, external and emergency response teams are informed through phone calls or the activation of their emergency switchboard. Nevertheless, once these procedures have been initialized the subsequent information feedback is susceptible to the subjective point of view of the safety staff and human error. Hence, a key challenge consists of *offering richer communication capabilities* to arriving emergency services and allowing them to interact with humans and the existing evacuation infrastructure (e.g. communication systems, route signals, smoke sensors and mechanical actuators).

2.1 Motivation Scenario

This motivation scenario describes an example of an evacuation scenario which is tackled by our system. We start from the fact that it is a scenario with many machine-to-machine (M2M) communication links among sensors/actuators. The scenario comprises of a university with scholar buildings with students, faculty and safety staff. In normal conditions sensors provide humidity, air quality and temperature readings. Sensors are connected through several middleware solutions running over low-capable wireless devices. Hence, all the collected data are forwarded to servers which store and categorized them. Security staff can access this information through a mobile application on their mobile devices. Faculty and students also have access to collected data from their facilities. There are three different roles: *standard staff* (faculty/students). The *safety staff* includes all the staff which has safety duties and permission to access and modify the evacuation infrastructure. The *emergency response team* is an external team (e.g. firefighters) that has access to the system upon request of the safety staff in emergencies.

Suddenly, a building goes on fire. Sensors and actuators fail because either they burn or their communication capabilities have collapsed. As some sensors and actuators have lost their connectivity, the evacuation system allows a reallocation of evacuation routes and the corresponding evacuation signals that guide all the personnel to a safe exit. In addition, the infrastructure informs safety staff where the fire originated, and which facilities have more evacuation priority depending on the fire level. In this situation, staff is capable of consuming the information produced by sensors from their respective building, as well as manually communicating with people. Hence the infrastructure disseminates all this generated data to interested parties and allows authorized safety staff to interact with sensors and actuators. At the same time, the emergency response team arrives to a facility, for example a laboratory, which is probably contaminated with poisoning gases. As they need to activate a set of mobile and sophisticated sensors (e.g. a carbon monoxide sensor) the system is ready to plug their data into the content dissemination network without modifying the core communication system.

3 Communication System for User Notification

The core communication system of the E-Flow system is based on a topic-based Publish/Subscribe network, which is implemented using the Message Queue Telemetry Transport protocol (MQTT) [6]. Our system supports a topic-based subscription model which employs lightweight and compatible with M2M protocols. Hence, we include our mobile broker [12] as a functional component in our system which provides pluggable and mobile support for the information dissemination network. In addition, we employ our previously extended topic-based model [17] to enhance the information delivery process whenever subscribers express multiple interests at the same time; so the system can overcome the limitations of single topic-based language while maintaining compatibility with standard MQTT. In order to provide a broader information access, a proxy provides interoperability between MQTT and Web interfaces. Regarding identification, we made use of a topic hierarchy, similar to the WS-topic* specification [13] in order to ensure a common understanding of existing resources through and their identifiers. This hierarchy depends on the level of organization of the information that will be produced and the physical (e.g. floor types, halls), networking (e.g. sensors, networks), or human (e.g. staff roles) resources of the environment (e.g. a school, a hospital). The system integrates sensors and actuators through a *concentrator* which maps these resources to valid identifiers using the topic hierarchy. As resource identification depends on the protocols that are being used, and these protocols could vary from many sensors (e.g. 6LowPan and Zigbee), the concentrator abstracts them while acting as the front-end interface and performing as a MQTT client. It can also modify the behavior of back-end sensors upon receiving a notification from the Publish/Subscribe network. Figure 1, shows the different elements of the communication system.

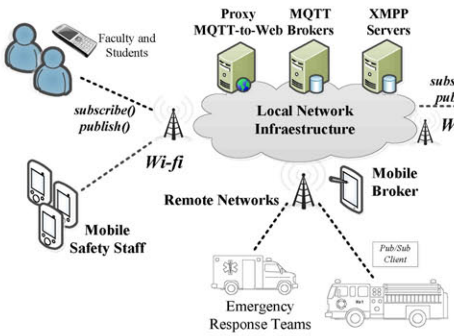

Fig. 1. Communication system for user notification

The system provides updated evacuation information that helps to reduce the reaction time of individuals, minimize the interpretation time, and offer capabilities for interacting with the communication system. The system provides user awareness in two forms: through a native application installed in their mobile devices and using a web-based application. Even if new HTML5/JavaScript technologies have access to mobile devices resources they are still less powerful than native applications. Hence, we use this type of technologies for actions that requires a lower level of integration with the existing resources of the mobile device (e.g. access to sensors). Regarding the user-to-user interaction, the system is designed to allow multimedia communication between several users through the XMPP protocol [10], as well as to consume information from sensors using MQTT. Concerning to safety staff and emergency response teams, the system offers native and web-based applications to detect in real time the status of sensors, and execute actions in actuators. In the native application, if the standard messaging system (through infrastructure of XMPP servers) fails, it automatically switches to modes: local Peer-to-Peer and GSM/UMTS communication (and their SMS and MMS capabilities). Hence, users maintain the same level of information awareness inside the system so they can still pay attention to critical actions.

4 Implementation

Our system comprises of different software or hardware developments, so in this section we clarify them as well as the end-to-end integration.

Sensor integration: All the hardware developments that integrate sensors have been designed from scratch; it includes the printed circuit board and electronic design. The core processor is a low-power OMAPL127 (DSP+ARM) [24] of Texas Instruments. Nodes use the chip PSOC3 [25] of Cypress Semiconductor. The communication between sensors nodes is made following the 802.15.4 standard and a WSN topology based on trees. Central nodes act as data proxies between the WSN and the concentrator. Both are connected using an USB interface and the middleware developed in C++. The concentrator runs Montavista Linux and acts as a MQTT client. The MQTT client was developed in Java using open-source libraries [9]. Its interconnection with the central WSN node is implemented using a Java Native Interface (JNI) and a USB connection. Figure 2 shows the integration of sensors.

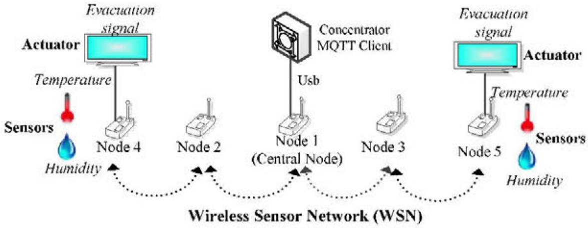

Fig. 2. Integration of sensors and actuators

Communication system: The system provides two functionalities: multimedia messaging using XMPP, and sensor/actuator over MQTT. In our testbed, a virtual machine running Ubuntu 12.04 supports both functionalities. In the first case, we have used the open-source XMPP Openfire 3.8 server [12]. We have set up three groups of standard staff, safety staff and emergency staff with the corresponding persistent chat rooms. Regarding the MQTT broker, we have implemented a modified version of the java-based Moquette broker [9] in order to extend the topic-based support intersected subscriptions [11]. This extension allows staff to have a tailored notification based on their status and location (e.g. status/available&building/a). The MQTT-to-Web proxy has been implemented using Node.js [14] and works with Websockets. It runs on a different virtual machine Ubuntu 12.04 machine than the broker.

User notification and interaction: We developed two applications: a native Android application and a web-based application. In the first case, the application implements three modes: a centralized XMPP, the P2P and cellular network. In the first mode, the application connects to the Openfire, in the P2P mode is built using AllJoyn [22] libraries. In the third case the UMTS/3G messaging is used. This application also integrates a MQTT client [13]. Regarding the graphical user interface we have also set visual and audible signals in order to alert users whenever an emergency occurs. There are also predefined messages that let users quickly publish some emergency warnings such as: "fire", "stair blocked help please".

The second web-based application is focused on evacuation management and decision support; so it is the front-end for fixed safety staff, and emergency staff (upon previous login). It runs together with the MQTT-to-web proxy. The application shows a map of pre-loaded locations and allows collecting information from sensor and modifying actuators' states.

4.1 Deployment

The system has been partially deployed in the Telecommunication School of the Technical University of Madrid. It includes the entries of building and halls. Wireless nodes have been provided with a rechargeable USB battery. In this topology and conditions the average bandwidth between nodes is about 255Kbps and 5ms of delay between WSN nodes. Concentrators and mobile devices are connected using 802.11g, with the local gigabit network that leads to the broker and proxy.

Fig. 3. Physical deployment in: entry of the building; second, boiler room; third, basement

Table 1 shows the information timeliness of our implementation. In this experiment, we use a Nexus S with Android 2.3.7. Case a) shows the delay from the concentrator publishes sensor data until they are received by the web application in a PC. Case b) shows the same case but for a mobile MQTT client and the web application. Case c) show the delay the MQTT-to-Web proxy introduces to the system. We have checked the normality of the three samples with the Shapiro-Wilk normality test [23] and conclude that the three samples came from a Normal distribution (p-value <= 0.05). Differences between fixed and mobile devices are the result of the low optimization level of the libraries and continuous garbage collection processes in the native applications, which increase the delay. Nevertheless, user experience and awareness are still acceptable for these values. This affirmation is based on the work [18] of Jacob et al., which states that delays less than 1.0 second need no special feedback.

Table 1. Information Timeliness (milliseconds)

	End-to-End MQTT-to-Web using Websockets			*Pub/Sub Network MQTT only*		
	Mean	Median	SD	Mean	Median	SD
a) Fixed devices	30,977	29,770	1,056	4,740	4,515	0,904
b) Mobile devices	246,983	250,989	11,893	65,904	66,938	4,111
c) Proxy Delay	4.402	4.520	0.830	-	-	-

5 Conclusions

This paper presents our solution for enhancing evacuation scenarios through user awareness. We outlined requirements of evacuation-oriented communication system from the human perspective and cover them in our system design. We also presented the advantages of our communication model in terms of user notification, M2M integration, resource identification and pluggability. We presented our implementation and show that our system offers an acceptable response rate in fixed and mobile scenarios. As future works we are planning a massive deployment of the system. It also includes evacuation exercises. Regarding the technical part we will improve the WSN nodes in order to directly support the MQTT-S and extract experimental data about their interaction with mobile brokers. We will implement mechanisms for extending the WSN node life and the performance of the mobile applications.

Acknowledgment. This work is supported by the E-Flow project TSI-020302-2011-5, under the TRACTOR Program of the Ministry of Industry, Energy and Tourism of Spain. We would like to thank the ETSIT.

References

1. Hamza-Lup, G.L., Hua, K.A., Minh Le, P.R.: Dynamic Plan Generation and Real-Time Management Techniques for Traffic Evacuation. IEEE Transactions on Intelligent Transportation Systems 9(4), 615–624 (2008)
2. Lovas, G.G.: On the importance of building evacuation system components. IEEE Transactions on Engineering Management 45(2), 181–191 (1998)

3. Georgoudas, I.G., Sirakoulis, G.C., Andreadis, I.T.: A cellular automaton crowd tracking system for modelling evacuation processes. In: El Yacoubi, S., Chopard, B., Bandini, S. (eds.) ACRI 2006. LNCS, vol. 4173, pp. 699–702. Springer, Heidelberg (2006)
4. Galea, E.R., Brown, R.C., Filippidis, L., Deere, S., Peacock, R.D., Kuligowski, E.D., Averill, J.D.: Pedestrian and Evacuation Dynamics. Springer, Boston (2011)
5. Avanza, Proyecto Tractor. E-Flow Project (2011), http://gisai.dit.upm.es/index.php/projects
6. MQTT Protocol Specificacion v3.1, http://public.dhe.ibm.com/software/dw/webservices/ws-mqtt/mqtt-v3r1.html (accessed on June 2013)
7. Morales Dominguez, A., Robles, T., Alcarria, R., Cedeño, E.: A Rendezvous Mobile Broker for Pub/Sub Networks. In: Mauri, J.L., Rodrigues, J.J.P.C. (eds.) GreeNets 2012. LNICST, vol. 113, pp. 16–27. Springer, Heidelberg (2013)
8. WS-Topics 1.3 OASIS Standard, http://docs.oasis-open.org/wsn/wsn-ws_topics-1.3-spec-os.pdf (accessed on June 2013)
9. Moquette MQTT Java, http://code.google.com/p/moquette-mqtt/ (accessed on June 2013)
10. Extensible Messaging and Presence Protocol (XMPP): Core. IETF RFC6120
11. Morales Dominguez, A., Alcarria, R., Cedeno, E., Robles, T.: An Extended Topic-Based Pub/Sub Broker for Cooperative Mobile Services. In: 27th International Conference Advanced Information Networking and Applications Workshops (WAINA), pp. 1313–1318 (2013)
12. OpenFire, http://www.igniterealtime.org/projects/openfire/ (accessed on June 2013)
13. Fusesource MQTT libraries, https://github.com/fusesource/mqtt-client (accessed on June 2013)
14. Node.js, http://nodejs.org/ (accessed on June 2013)
15. Filippoupolitis, A., Gorbil, G., Gelenbe, E.: Autonomous navigation systems for emergency management in buildings. In: GLOBECOM Workshops IEEE, pp. 1056–1061 (2011)
16. Cheng, N.: An Optimization Method for Dynamic Evacuation Route Programming Based on Improved Ant Colony Algorithm. In: International Conference on Intelligent System Design and Engineering Application (ISDEA), pp. 265–267 (2010)
17. Sharma, S., Vadali, H.: Modeling Emergency Scenarios in Virtual Evacuation Environment. In: WRI World Congress on Computer Science and Information Engineering, vol. 4, pp. 759–763 (2009)
18. Jakob, N.: Usability Engineering. Academic Press (1993)
19. Almeida., J.E., Kokkinogenis., Z., Rossetti, R.J.F.: NetLogo implementation of an evacuation scenario. In: 7th Iberian Conference on Information Systems and Technologies, pp. 1–4 (2012)
20. Hamacher, H.W., Tjandra, S.A.: Mathematical Modeling of Evacuation Problems: A State of the Art. In: Schreckenberg, M., Sharma, S.D. (eds.) Pedestrian and Evacuation Dynamics, pp. 227–266. Springer, Berlin (2002)
21. Luh, P.B., Wilkie, C.T., Chang, S.-C., Marsh, K.L., Olderman, N.: Modeling and Optimization of Building Emergency Evacuation Considering Blocking Effects on Crowd Movement. IEEE Transactions on Automation Science and Engineering 9(4), 687–700 (2012)
22. Alljoyn Website, https://www.alljoyn.org/ (accessed on June 2013)
23. Shapiro, S.S., Wilk, M.B.: An analysis of variance test for normality (complete samples). Biometrika 52, 591–611 (1965)
24. Texas Instrument OMAP-L137, http://www.ti.com/product/omap-l137 (Accessed on June 2013)
25. Cypress Semiconductor PSOC3, http://www.cypress.com/?id=2232 (Accessed on June 2013)