

The architecture of EVAGUIDE; a Security Management Platform for enhanced situation awareness and real-time adaptive evacuation strategies for large venues

Dimitris Drakoulis^{1*}, Dimitris Dres¹, Anastasia Eleftheriou¹, George Gkotsis¹, Dimitris Petrantonakis², Dimitris Kanakidis², Paul Townsend³

¹ Telesto Technologies

² EXUS Software Single Member Limited Liability Company (EXUS)

³ Crowd Dynamics International (CDI)

*dimitris@telesto.gr

Abstract. The EVAGUIDE H2020 project envisions a safer and more comfortable experience for people in large venues like the stadia around the world. In the case where an unpredicted event takes place, all the people in the stadium will have a complete picture of how they will evacuate the venue whilst the spectators will only have to worry for their team's performance and not their safety. The EVAGUIDE project focuses on the development of a ready-for-market product that will integrate all subsystems into a commercial EVAGUIDE platform (TRL8). This paper reflects on the architectural cornerstones of the EVAGUIDE solution demonstrating the approach followed towards the integration of all the components developed within EVAGUIDE's lifespan. The main components, constitute: a) The Communication Middleware, to enable the different subsystems and sensing elements of EVAGUIDE to communicate between them; b) The EVAGUIDE Core System, to handle the interconnection with sensing elements, the alarm raising mechanisms and the control of active exit signs and actuators, c) the algorithms for real-time crowd modelling and the calculation of the evacuation route in real time; d) The Mobile Platform, for the safety of spectators as well as for the dispatch of safety personnel/ stewards. The EVAGUIDE project will change the way security companies operate within large venues for sports and entertainment by providing a novel Security Management Platform for enhanced situation awareness and real-time adaptive evacuation strategies. EVAGUIDE has received funding from the European Union's H2020 for Research and Innovation under GA No. 831154.

Keywords: evacuation, security, large venues.

1 Introduction

An evacuation in response to a risk or threat is the movement of people away from a designated area that is under threat to a safer area. The need for evacuation can arise from naturally occurring events, human-induced events (both intentional and unintentional) and events caused by technological failures. The safe evacuation is of paramount

importance for the safety management of large facilities. This need is the most pressing in the case of sports stadia, which routinely host events that gather tens of thousands of spectators and have recently become targets of extremism and terrorism.

An evacuation plan consists of a footprint of the facility, the main safety features (exits, corridors, fire doors, extinguishers), indicating the routes for evacuation to safety zones for every part of the infrastructure and also including the emergency activation methods. The current evacuation plans are static, failing to effectively manage evacuation situations that evolve and change over time. Real-time, dynamic management of an evacuation process is of paramount importance and paper-based evacuation plans are of low value in actual stressful conditions, where human behaviour is unpredictable.

The technology used to assist evacuation incidents, in most cases, is limited to the CCTV monitoring of the areas of the stadium and communication with safety personnel located near the area where an incident occurs, using voice communication over UHF radio.

Current safety procedures are plagued by paper-based, outdated evacuation plans, insufficiently trained personnel and lack of sufficient situational awareness. There is an apparent need for a solution that will support decision-making, increasing the potential for an effective response, and strengthening preparedness of the venue operators.

1.1 EVAGUIDE Platform

EVAGUIDE [1] is a Security Management Platform for enhanced situation awareness and real-time adaptive evacuation strategies for large venues used for sports and entertainment events. The system aims to address the needs of the safety of large facility visitors during complex evacuation processes, following normal and abnormal events (crises) towards the creation of an easily deployable system that will be able to timely identify new threats, designate and sustain a Location based Dynamic Evacuation Route (LDER) that improves all corresponding response times under any circumstances. Moreover, it will support the complete lifecycle of evacuation planning, simulating complex scenarios, training of safety personnel and assessment of the performed actions. It is made up of a number of components, one of which is a Mobile Application that aids the evacuation of spectators and staff in different ways.

The mobile application for stewards is a mobile-based communication and dispatch mechanism for safety personnel inside the venue as well as in the general vicinity around it. It offers rich functionality based on a two-way communication mechanism, which is used during an emergency situation by the stewards and the security officer. Through the mobile application for spectators, the users are notified in case of an emergency about the situation. If an evacuation is required, they are informed about the optimum exit route and are guided through it.

An important prerequisite for the successful implementation of the mobile application, is information about the position of stewards and spectators. Various indoor localisation technologies have been evaluated, concluding that the most appropriate one is BLE Beacons [2].

1.2 Mobile application for spectators

General description

In case of an emergency, the spectators are notified through the application about the situation. The messaging mechanism works through push notifications, meaning that the users are notified about the emergency, even if they are not currently using the application.

If the situation escalates to the point of an evacuation being needed, the application supports the evacuation process by determining the actual position of an evacuee and indicating the route to the nearest safe exit.

It also helps identifying spectators who do not seem to progress with the evacuation, who may thus require assistance (this is also registered at the Security Operations Center to be managed by the safety command chain). It is expected that the Security Officer will gain increased awareness about the progress of the evacuation process, thanks to the connection of the mobile apps with the Common Operational Picture (COP). Even in the case that not all the spectators have downloaded or activated the mobile application, the trends obtained on statistical indices (percentages), based on the situation and whereabouts of thousands of users in an area, will still produce significant value for the situational awareness of the safety authorities.

Description of features

The users of the app have access to the venue's map as well as the various Points of Interest (POIs) within it, such as the nearest cafe. By selecting a POI on the map, they can navigate following the on-screen directions provided by the applications indoor localisation.

Users can also see their location inside the venue, based on the utilisation of the BLE Beacons infrastructure and the localisation algorithms within the app.

Spectators who wish to report an incident that could potentially represent a threat, can do so using the application. The reported incident emerges on the COP screen as an icon, which the COP operator can select to get more details. COP offers maximum awareness to the Security Officer, taking advantage of the mobile-based communication and dispatch mechanism for safety personnel and first responders.

Communication

The application relies on internet connection for the following functionalities:

- Delivering of push notifications in case of an emergency
- Downloading and displaying the venue maps from the map provider (only the first time the application is used)

Following the download of maps, the application may operate while off-line.

Additional features

To increase the users' engagement with the application, we plan to offer tight integration with the mobile content the club offers its fans, e.g. game-specific content for example a video clip from a camera in the opposite side of the stadium from where the spectator sits. Special offers and discounts could also apply for the users of the application while shopping in the venue shops.

1.3 Mobile application for stewards**General description**

The mobile application for stewards offers rich functionality based on a two-way communication mechanism, which is used during an emergency situation by the steward to warn the security officer about existing or evolving threats to safety, and used by the security officer to dispatch a steward to attend a threat.

The mobile based communication and dispatch is used by stewards/field safety personnel in real time evacuation; furthermore, it can also be used for personnel training purposes and stadium inspections from security authorities. A mobile (smartphone/tablet) application prototype has been developed within EVAGUIDE lifespan, in order to be used by the security personnel to report on potential threats and receive notifications to attend to incidents. The EVAGUIDE mobile application is complemented by components adapted from Commercial-Off-The-Shelf solutions (COTS), most significant being the COP

The application allows stewards to have an overview of the venue map. It also displays the tasks that they need to attend to. The stewards can report incidents that are happening in the area of their responsibility via the application. This report creates a new pending task on the Security Officer's application

2 Platform Design and Architecture

The EVAGUIDE system is composed of four main components (see Figure 1 and further analysis below), namely:

- The Communication Middleware, to enable the different subsystems and sensing elements of EVAGUIDE to communicate between them;

- The EVAGUIDE Core System, to handle the interconnection with sensing elements, the alarm raising mechanisms and the control of active exit signs and actuators, the algorithms for real-time crowd modelling and the calculation of the evacuation route in real time;
- The Mobile Platform, for the safety of spectators as well as for the dispatch of safety personnel.
- The Common Operational Picture, an off-the-shelf component that connects to the EVAGUIDE core to provide an intuitive picture of the situation to support supervisors' decision making at the stadium operation centre.

The system is complemented by components and sensing elements:

- a resilient private WiFi communication network used for guaranteeing priority access of security personnel to network resources in case of mobile network collapse;
- Bluetooth beacons infrastructure deployed to support client positioning both outdoors and indoors;
- a WiFi scanner or other people-counting technologies, used to statistically estimate the number of subscribers;
- active exit signs and actuators;

The system will finally attach to and collect generated data from existing sensing elements (temperature, smoke, fire, etc.) and legacy systems available on premise at the large venues where it is intended to be deployed.

2.1 Communication Middleware

The Communication Middleware enables the different subsystems and sensing elements of EVAGUIDE to communicate in an efficient and orchestrated manner. It is based on Apache Kafka, which enables the required connectivity between components for the flow of incoming information messages from sensors.

From publishers' side MQTT message protocol [3] is used to send messages from sensors to the MQTT broker. This message protocol is TCP based and lightweight with minimal packet overhead and it is appropriate for constrained devices with limited resources. The messages are forwarded from MQTT broker to Apache Kafka using connections established between them, each for every plane (status, data, control) specifically configured.

After analysing the functionality of the middleware from publishers' side, the consuming perspective should also be mentioned. At first MongoDB is used as a sink database to store messages that arrive at Kafka brokers for status and data plane. Kafka communicates with MongoDB by using Kafka adapters precisely configured for each plane. Additionally, a JAVA application which implements exit sign client is created in order to consume and represent status published messages of each connected device. Control

messages are handled by the System Management Server which provides remote monitoring to the administrator.

2.2 Location-based Dynamic Evacuation Route Component (LDER)

Normal stadium evacuation routes are static. They are fixed routes from each area to stairs, ramps and exit points of the stadium. The EVAGUIDE system makes the stadium evacuation strategy dynamic by taking the prevailing situation (numbers of people in different areas + incidents or congestion) and forecasting the congestion from the present into the future before an evacuation actually takes place. It would also dynamically change those routes given the situation, to optimise the evacuation time or reduce congestion.

A location based dynamic evacuation route is the passage that spectators will take from a certain location to evacuate the stadium, which is dynamically calculated during the evacuation and can dynamically change during the evacuation as it progresses, if necessary. The LDER component takes data from the system measured from the current situation and uses crowd models to simulate the evacuation, forecasting congestion and to optimise the LDER for the stadium.

Crowd Modelling

The crowd model implemented in EVAGUIDE is based on the network model developed as part of the eVACUATE project. A network is created that comprises nodes (circular or rectangular) and edges (a line of certain width connecting two nodes). These are spaces where spectators can move around the stadium, and this network represents all possible routes that spectators use when evacuating the stadium.

The model is a mesoscopic agent based model. Each agent represents one spectator in the stadium that will move through the network. The mesoscopic nature of the model implies that physical interactions between agents are not modelled, but a localised heuristic measures the density in the vicinity of the agent, and adjusts speed of movement accordingly. Demographics are represented by the 'speed vs density' profile of the agents, which can be calibrated for different audiences.

The model requires the following inputs:

- Location and number of agents for each edge and node in the network
- Which edges are blocked or reduced in capacity

The location and number of people is calculated by the complex event processing engine and is an interpolated count from the actual sensor data around the stadium.

Route optimisation

The initial routing for all areas of the network is based on Dijkstra's algorithm [4] calculated using the distance to travel along each edge/through each node, allowing for each edge to have a cost associated with it that would make certain edges more or less attractive to travel along. This provides the most direct routes for agents without considering the congestion or capacity of routes.

The aim of this is to simulate the normal evacuation strategy of the stadium, which more often than not follows the normal egress patterns of spectators attending the stadium. To ensure that this strategy is followed in the initial simulation, large edge costs can be used to deter agents from taking a particular route unless no other is available. When the initial simulation run is complete, the simulation can be rerun by increasing edge costs on routes with congestion that might be slowing the evacuation down. The simulation is rerun and compared against the original to see if the evacuation time has improved. This process continues iteratively for N runs, after which the most optimised route can be chosen.

A number of situations exist during evacuations whereby having a single route from any one point to another would not result in an optimal situation. When developing optimisation strategies for the stadium evacuation, it is important to bear in mind that perfectly optimum routing is not practical to enact by staff at the stadium. For instance, if the optimal routing strategy was to send 20% of spectators down path 1, 30% down path 2, and 50% down path 3, organising this on the ground is impossible. Therefore, if multiple routes from one area is the optimum, crowds would be split equally (50%/50%, 33%,33%,33% etc.).

2.3 System Management Server

The System Management server's high level functionality can be summarised as follows:

- monitors the status of the EVAGUIDE subsystems in terms of connectivity and functionality
- monitors the health of all the other systems attached to EVAGUIDE, the building management systems, CCTVs, smoke detectors, access control, ticket readers and fire detection systems
- handles the discovery and registration management of sensing elements to the system
- performs geolocation-based association of the exit signs and actuators with the LDER and controls them in terms of activation and management.

2.4 Complex Event Processing

The Complex Event Processor (CEP) constitutes the component of the Core Engine that is responsible for the real time detection of hazardous events, data storage and provision of warnings and alerts. It is one of the core elements, which is closely interdependent with the Crowd Modelling server and the COP module of the EVAGUIDE platform. The CEP subsystem will not only aggregate and combine the different information sources of EVAGUIDE but will also monitor and generate meaningful insights per the operational status of a life threatening incident.

The CEP subsystem, based on the WSO2 Stream Processor, collects events with multiple messaging formats via multiple transports. It uses streaming SQL to process streams, detect complex events patterns and it can also generate and notify the processed results as alerts instantaneously and visualize them via real-time interactive, and user-friendly dashboards.

WSO2 Stream Processor is built as a lightweight, open source, high performance, stream processing platform which understands streaming SQL queries in order to capture, analyse, process and act in real time. This will facilitate the EVAGUIDE system with real-time, intelligent and actionable insights, while at the same time its deployment ease allows for a multitude of different deployment schemes, aimed at adapting to different installation scenarios.

The state-of-the-art Siddhi stream processing and complex event processing engine [5] which lies at the core of WSO2 Stream Processor will allow the EVAGUIDE system to be enriched with build reliable and high performing streaming applications that will detect abnormalities in real time.

This also includes:

- An easy to use streaming SQL language specific to WSO2 (Siddhi)
- A variety of stream processing operators via Siddhi such as filtering, window operations, aggregations and summarizations, pattern machine and event correlations
- Many additional extensions that help developers support more complex use cases
- Out of the box support for consumption of events and publishing alerts through connectors for well-known protocols such as HTTP, Kafka, MQTT and payload wise supporting XML, JSON, text, binary and Key-Value messages.
- Out of the box integration with popular data storage systems, both SQL and NoSQL based ones.

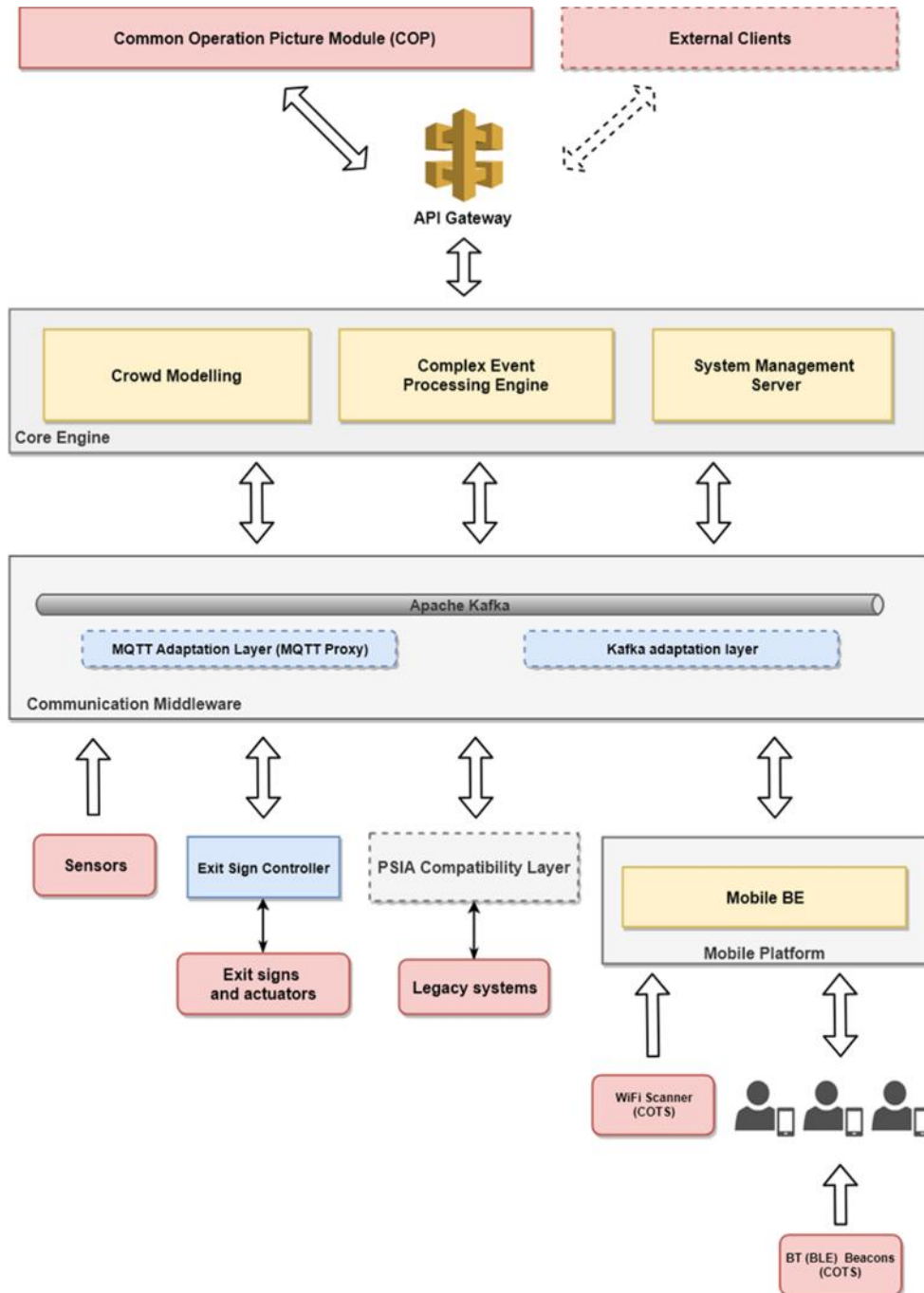


Figure 1 System Architecture, highlighting the core system components

3. Summary and Discussion

The safe evacuation of large crowds from complex facilities is a common challenge for facilities across Europe and globally. EVAGUIDE is a security management platform for the safe evacuation from stadia and large facilities.

EVAGUIDE addresses the safety needs of visitors to large facilities during complex evacuation processes, following normal and abnormal events (crises), and creates an easily deployable system that in real time can identify threats, designate and sustain a Location-based Dynamic Evacuation Route, increase situation awareness and improve response times under any circumstances. Moreover, it supports the complete lifecycle of evacuation planning, simulating complex scenarios, training of safety personnel and assessment of the performed actions.

In EVAGUIDE, the visual representation of the situation in real time is offered by an advanced User Interface that uses a 3D Model of the facility, which the operator can control to better understand the situation; this is the EVAGUIDE Common Operational Picture. All the information available from the CCTV cameras, the sensors, the legacy systems and the stewards, as well as critical information from the spectators is optimally displayed. An intelligent engine raises alarms based on rules that combine data stemming from the aforementioned sources, while crowd simulations are realized in real time taking into account the number and location of spectators as well as other parameters (like blocked doors and blocked routes because of fire, congestion or collapsed structures) to calculate a Location based Dynamic Evacuation Route that changes as the aforementioned parameters are altered. The optimal route to safety is communicated to evacuees via the proper activation of state-of-the-art active signs (using dynamic exit signs, media screens, PA system) that depict the calculated optimal routes within the stadium. The EVAGUIDE mobile application that interacts with the EVAGUIDE core platform, offers spectators the opportunity to get accurate, dynamic, location-specific personalized directions to follow the fastest available route.

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