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Leveraging Emergency Response System Using the Internet of Things. A Preliminary Approach

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***Abstract*—The Internet of Things (IoT) is a new paradigm that is arising in all areas of technology, finding novel applications every day that can improve many aspects of people's lives. Several applications using IoT have been subject to research and development; one of these applications is traffic monitoring and management. In the case of an accident or a medical emergency, we know that a fast response is essential to people's survival. However, in a city where the population increases, but the road space does not, traffic jams are an everyday thing. Traffic jams affect ambulance arrival to the hospital or a fire truck to the fire site. Thus, it is crucial to develop a system that can reduce the response time in case of an emergency. We propose to build an open IoT system over the current city architecture to communicate emergency vehicles to the surveillance cameras network and the traffic-light system to dynamically change their schedule and provide in this way a green wave reducing the response time. In this paper, we study the theory behind our proposed system as a whole. The results presented demonstrate that the subsystem used to identify and locate the emergency vehicles works properly. Also, we discuss the next steps to follow in order to implement all subsystems that need to be integrated.**

***Index Terms*—Internet of things; Traffic lights; Smart city; Response time, Emergency response**

I. Introduction

During an emergency, response time is critical for the treatment of patients and people that need help from any dangerous situation. Because of the almost fixed geography of a city, sometimes there is no alternate route that allows a vehicle to get to a particular place. The current method used by the emergency services for these situations relays only on the sound of sirens to alert people that it needs their collaboration to go faster. However, when the road is entirely busy, it becomes impossible for emergency vehicles to go their way. We propose a hardware/software system that allows the emergency vehicles to "talk" to the traffic-lights nearby to prioritize them over the other cars while maintaining the roads safe. This system should take the current infrastructure (surveillance camera network and the traffic-light system) to coordinate the best route.

This system should connect the surveillance camera network and the traffic-light system to coordinate the best route.

Our main objective is to develop a hardware/software system that allows the emergency vehicles to "talk" with the traffic-lights around to prioritize them over the other cars while keeping the safety on the roads. This system should connect both the surveillance camera network and the traffic-light system to coordinate the best route, as shown in Fig. 1.

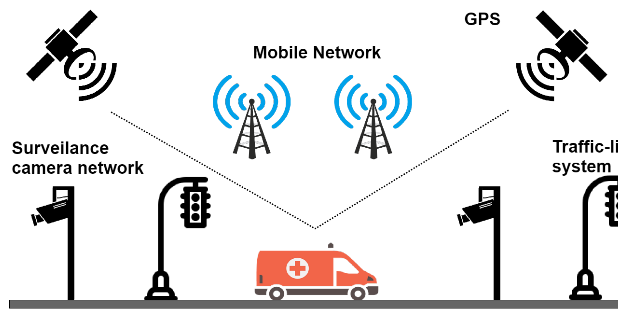

Fig. 1. Current infrastructure.

Fig. 2 shows a basic scenario for the system. Here, an emergency vehicle that needs to go to the hospital. There are two routes that the car can follow to get to its destination, but if there is a jam, the arrival time can be much longer than expected. The driver has the autonomy to choose if they should follow that path or another depending on what they see now, but it is unable to see the whole scenario to make the right choice. The system needs fixed checkpoints around the city to see if the driver follows the proposed route or finds a better one during the execution. Those can be the traffic lights or cameras installed on the streets. These points will confirm the path the vehicle is following and allow the system to provide feedback on the actual route and modify the traffic-lights accordingly in addition to the Global Positioning System (GPS). The system should be capable of identifying the vehicle and make the traffic flow more rapidly in the defined route, so there is no need to stop or being stuck for a long time.

This article is organized as follows. Section II demonstrates the motivation behind this research work. Section IV shows the proposed architecture for our solution. Section V presents the design of the proposed system. Section VI shows the current state of the implementation. Section III presents the related work. Section VII presents the next steps towards the

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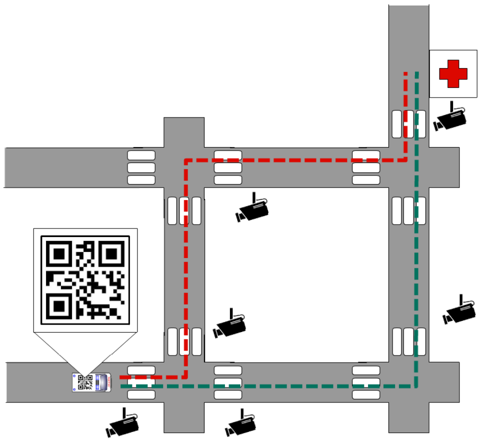

Fig. 2. System implementation. When the emergency vehicle follows the red route but decides to track the green path, the system has to recalculate the new route via checkpoints (camera network).

implementation of the system.

II. Motivation

We cannot predict the impact of emergencies like fires, earthquakes, floods, and medical emergencies, among others, over the people that suffer. However, what we can do is try to make these awful times as less traumatic as possible. Fast attention to the scene in the case of a natural disaster or a medical emergency can lower the affections the victims may have later. We can improve the response time by implementing an Emergency Response System (ERS) according to the city's conditions. Knowing the conditions, geography, and demography of a town, or sections of it, allows better planning for this kind of systems.

Many problems can arise in cities with a population continually growing but with the same infrastructure. It can only cause more traffic going through the same points. In this scenario, it is tough to follow the 8-10 minutes response time recommendation for medical emergencies like a cardiac arrest or a stroke [1], [2]. With crowded cities and few roads, we cannot help but think what happens when the traffic jams prevent this recommendation from being followed efficiently? What if the vehicular flow is just too much? What if there are no alternate routes?

As a result, there are specific critical points in every city where the traffic slows, and it is impossible to take another path to avoid it. This situation makes the emergency response-time to be longer than it should be. The objective is to turn this system from an adjustable one to a dynamic one where the emergency services have priority without collapsing the city's traffic flow.

III. Related Work

The Internet of Things improves various aspects of traffic. One of the most used technologies for this task is Radio Frequency Identification (RFID). Turcu et al. [3], proposed an approach to give a solution for some traffic problems. They included the possibility of monitoring environmental parameters such as air quality, aiming to reduce pollution caused by traffic congestion. They also propose a way to avoid accident risks by the individual identification of vehicles using RFID technology. They claim their solution can provide traffic monitoring that leads to better route planning, a service for rapid intervention vehicles, and adaptively manage traffic lights depending on the traffic flow. In Yu et al. [4], they designed and implemented an RFID tag system for the identification of vehicles to monitor the traffic flow, and to allow better management of the roads. They proposed an anti-collision protocol to avoid conflicts between several tag readings, and data cleaning algorithms for any tag that is read more than once in the same place.

Besides RFID, there are other approaches to control and monitor traffic. Hamed Noori [5], exposed that in the last decade, the importance of aiming to improve transportation activities in terms of safety and efficiency where the Car-to-car and car-to-infrastructure communications are essential components of the intelligent transportation systems (ITS) architecture. The connection between cars and traffic lights is a vital vehicle-to-infrastructure application that helps to have dynamic and automatic traffic lights that can minimize the traffic jams and decrease the response time of the emergency vehicles.

Yinsong Wang et al. [6] proposed implementation of an Emergency Vehicle Signal Preemption System (The "TJ-EVSP") in cooperation with a Vehicle-Infrastructure System (CVIS), where the system provides an appropriate traffic signal preemption for emergency vehicles based on real-time emergency vehicle data, traffic volume data, and traffic signal timings.

Bonomi [7], [8], talks about fog computing, where he describes two cases and the IoT requirements necessary for its functionality. One of these cases is a Smart Traffic Light System (STLS) as an IoT application for connected vehicles. A system like this has three primary goals: accident prevention, collection of data, and maintenance of a steady flow of traffic. They also note the importance of knowing what kind of time scale is required depending on the use of the system. The collection of data for an extended period does not need to have a real-time reaction, and other applications need a real time scale.

Leng [9] presented a traffic management system based on cloud computing. For this implementation, they used a WSN as their middle-ware system and a compound of the three forms of service that a cloud can offer.

Dimitrakopoulos [10] talks about the concept of internet-connected vehicles and many areas of application. One of these applications is emergency management. In the work of Wang et al. [11], explores an ambulance route search. In case there is a traffic jam, the system can change the route monitoring the ambulances with RFID. This system does not consider the difficulties that can arise when there is no alternative route to follow.

Global Traffic Technologies, LLC. It offers a similar solution for emergency medical response called OPTICOM [12]. This infrastructure is GPS/Infrared based infrastructure that has on each signalized intersection a module that processes each petition from the emergency vehicles and uses an independent central management software (CMS) to update and make computes. EMTRAC [13] is an emergency vehicle preempting (EVP) system based on GPS and radio frequency that allows determining when the vehicle is near to a signalized intersection. It has a receptor that receives the alert via radiofrequency.

Sun [14] describes various solutions to increase traffic efficiency using the Internet of Vehicles. One of these approaches includes Vehicle-to-traffic light communication using GSM communication. The application described has the objective of giving the users a more comfortable driving by giving them information about how much time the red or green light will be on.

Our proposal, as Yinsong Wang et al. [6] is an Emergency Vehicle Signal Preemption System in cooperatives Vehicle-Infrastructure System. However, our approach will complement the systems of intelligent traffic lights based on readings of transit through the checkpoints (cameras infrastructure system). Using the technology of the QR code, mobile networks, and GPS for the control and automation of the traffic lights in favor of the emergency vehicles that need to transit through high congestion road zones using the infrastructure explained in section IV and section V.

For most applications focusing on emergency management, RFID technology is the most used. We discarded its use in our solution because we are not communicating vehicles with each other in a network of cars. We prefer an IoT approach instead of using a wireless sensor network (WSN). In this way, we can remove the errors that the system may have because the tag could not detect a vehicle. After all, it was going too fast for the system to catch it.

We use the GSM network to communicate any updates, GPRS to monitor the location of the vehicle, and checkpoints to confirm how the execution of the operation is going. Besides finding new routes depending on the updates of the situation, our solution alters the traffic lights infrastructure for the benefit of the emergency vehicles despite traffic jams.

IV. System Architecture

Fig. 1 depicts the implemented infrastructure. In this scenario, the emergency vehicle (thing) needs a smartphone/tablet (thing) that allows communication (internet) between the ambulance and the ECC (Emergency Communication Center). The ambulance sends the current position and some information about the emergency stage, and then it will receive the best route defined by the ECC to reduce the response time.

The information that the system requires from the emergency vehicle when receiving an alert is:

- Current Position: This data can be the latitude and longitude of the vehicle. With this data, the system can decide which car will respond to the alert.
- Type of emergency: After getting to the site, the response people in charge of the situation need to evaluate the state of the crisis and send updates to the ECC. It decides where they need to go depending on what they find.

This information will generate a response from the ECC:

- Optimal Green Wave Route: This is the defined route depending on the traffic and emergency information provided. The emergency vehicle (thing) and the traffic light system (thing), get the green wave information according to the emergency vehicle's position towards its destiny. This route can change depending on the decision of the driver.
- Notifications: ECC will receive multiple notifications from the checkpoints across the streets, notifying that the vehicle has already passed through the selected route.

V. Design of the System

This section describes the proposed design for our system, dividing it into four elements: the Emergency Communication Center, the emergency vehicles, the checkpoints, and the traffic lights.

A. *Emergency Communication Center (ECC)*

An Emergency Communication Center is in charge of receiving any calls coming from people who need assistance in case of emergency. The system will count on a software application that will take the traffic reports, the vehicle's GPS information and the generated alerts to calculate the route and the green wave. With this Application, we want to include a multimodal contact approach (through Social media, SMS, mail, or apps) to allow people a more natural way to notify an emergency. Fig. 3 shows the ECC reports the emergency corp capable of handling the situation when receiving an alert. Also, knowing the current position of the emergency vehicles, the ECC sends the nearest one to the site and adjusts the "optimal green wave" on the traffic lights involved on the predetermined route.

B. *Emergency Vehicles*

Upon the reception of an alert, and if the vehicle (considered as "things" in our system) is the nearest one to the site, it receives the route, and it's permanently sending its position through GPRS (General Packet Radio Service) to the ECC determined from a local GPS. The vehicles need to be provided with a tablet to be able to interact and send updates to the ECC about the type of emergency. This way, if something happens in the direction of the site (flat tire, mechanical failure, another accident, etc.), the ECC can handle the situation as a new alert.

C. *Checkpoints*

We place checkpoints using camera infrastructure to verify that the vehicle has not changed its path, and also validate the route in case of an error with the GPS. These checkpoints are a set of "things" in our system because they will detect the vehicles on-call through a QR code placed on top of the cars. They notify the ECC that the car has been through the

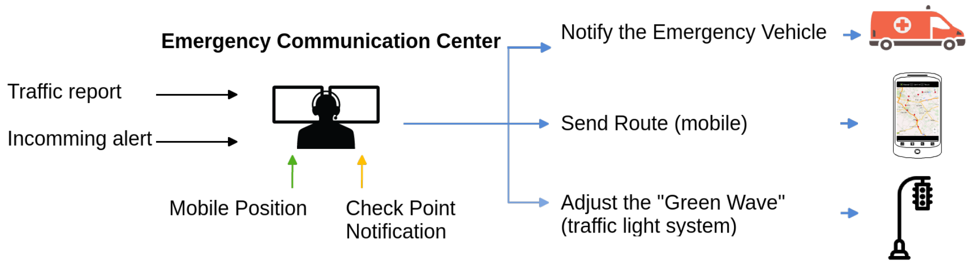

Fig. 3. Operation of the Emergency Communication Center.

established route. The QR code is used due to its high-speed readings, accessible scanning capacity, and error correction capabilities [15]. Fig. 2, shows the location of the checkpoints on our initial scenario.

D. Traffic Lights

To enable an "optimal green wave", it is not just about turning the lights green in the established route and turning the other lights red. It also includes scheduling algorithms to reduce the negative impact of the "optimal green wave". Upon confirmation that the emergency vehicle has passed the zone, the system will return gradually to the normal behavior, adjusting the time of the traffic lights.

E. Other requirements

Besides previous requirements, it is necessary to consider the security of the system, where it needs to fulfill the following security requirements:

- Authentication: It is necessary to authenticate the identity of the emergency vehicles registered in a database and receive and attend alerts. So we need to ensure that no one can pose as an emergency vehicle when it is not, just to have an "optimal green wave" at disposition at all times.
- Access Control: Emergency vehicles are not in service 24 hours a day; there are different shifts to cover the demand of the city. The system needs to identify which vehicles are in service at the time the emergency occurs. Also, it is important to distinguish a real state of emergency, because we can not allow the system to disturb the normal flow of traffic when there is no emergency occurring.

VI. Current State

Integrating a data exchange across the whole operation of the emergency can allow us to model the responses needed to plan the best route to follow in case of any eventuality. Fig. 4 shows the component diagram of our approach. The left part represents the mobile module. The right part shows the external services the system needs. In the center are the ECC services, the core of our work.

TABLE I
Performance of the QR detector subsystem.

Blur (px)	Data Loss (%)	Transform (°)	Amount of Captions
5	15	15	3/3
5	30	15	3/3
15	15	15	3/3
15	30	15	3/3

A. Interface Application/Vehicle

In this state, we can detect through GPS an emergency vehicle and send that position to the ECC with GPRS. This module (left side of Fig. 4) uses an Arduino UNO in conjunction with a SIM908 module, which includes a geolocation tracker GPRS+GPS Quad-band technology. The working principle is simple: the system reads the GPS coordinates (longitude and latitude) and sends them over GPRS by using an HTTP request to our application server. The system uses Google Maps to show the location of the emergency vehicle in real-time, depicted as an external service on the right side of Fig. 4.

B. ECC Services and External Services

We can also identify the emergency vehicles with QR-codification and detect them with the use of cameras on the checkpoints and notify any updates about the operation. We proved the concept by scanning QR Codes via zbar Python Package that enables the reading of barcodes from images or video, and a Raspberry Pi Camera module connected to a Raspberry Pi 3 with OpenCV 3 and Python 3 installed. Our approach is similar to the Car Speed Detection project [16] as well as Hogpracha [17], and Suryawanshi [18]. The camera captures and decodes a QR-code on top of the emergency vehicle. To prove the concept in different scenarios that could occur, we took into account that at certain velocity, the QR code could appear with some motion blur. Also, we consider an scenario where there is data loss (an obstacle could be blocking a part of the code), and some distortion due to the angle in which the camera gets the image. As seen in Table I, the detection is successful even with a data loss as high as 30%. For more details about these results, please refer to [19].

The ECC Services, and the External Services (center and right part of Fig. 4) complement the whole system in the backend. This allows the system to be able to notify the

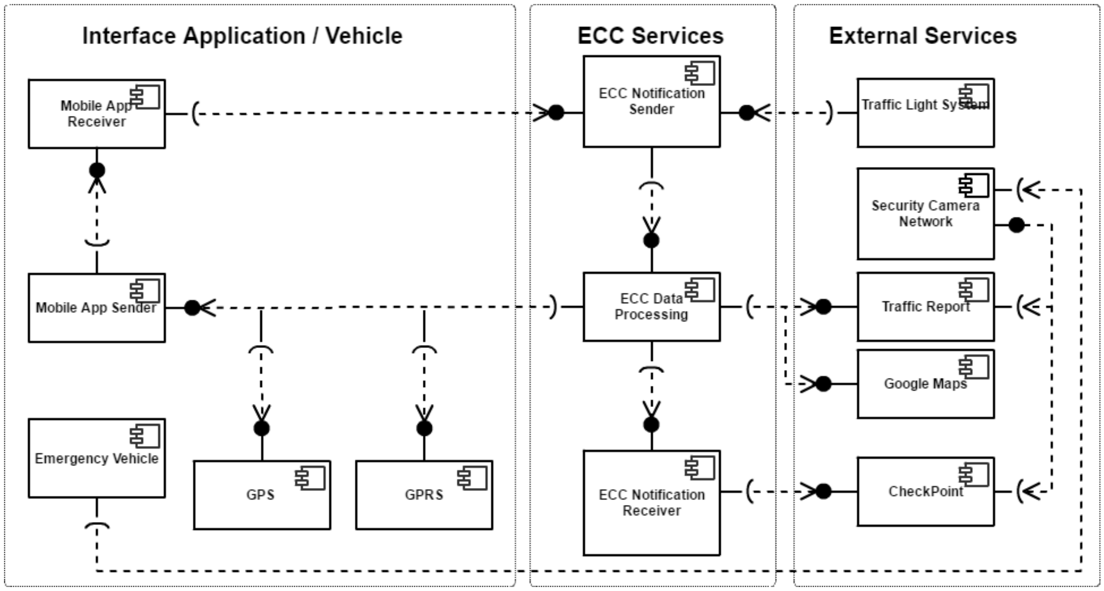

Fig. 4. Component Diagram. The boxes represent the components of the system. A full circle represents an **interface created or provided** by the component. A semi-circle represents a **required interface**. A dashed arrow pointing from a "component A´´ (dependent) at the tail to the "component B´´ (provider) represents a **dependency**. The arrows represent the communication interaction between the vehicle, ECC service, and the traffic light system.

Emergency Vehicle about the location of the emergency or the nearest hospital, the selected route to follow, as well as alternate routes. Depending on the chosen path, a set of checkpoints (Security Cameras) can provide the ECC with the most recent information regarding the location of the vehicle and how the emergency is being taken care of.

Currently, we are in the early process of modeling the traffic-light system. For this stage, we are working on two simulators: PTV Vissim [20] and SUMO [21]. The idea is to simulate the driving behavior of a congested zone. Fig. 5 shows how the PTV Vissim simulation looks. The software simulates an intersection of Cartagena de Indias, Colombia, that is usually congested. This intersection is critical, based on the hospital's location and the peak hours of the city. The PTV Vissim API package enables us to integrate our application to the PTV Vissim simulation to generate our extreme conditions. SUMO, on the other hand, is an open-source traffic simulation package that includes its simulation application. The tool provides traffic management and vehicular communications. The Institute of Transportation Systems at the German Aerospace Center supports the development of SUMO. We have to note that this is the next step of the process of implementing the design of our system. We haven't tested the traffic-light subsystem yet.

VII. Conclusions and Future Work

In this paper, we propose a solution to facilitate the arrival of emergency vehicles where they are needed. The complete solution requires integrating at least three systems: the city's traffic-light, the surveillance camera network, and the emergency response center. By default, those systems are not fully integrated, and sometimes they work independently. We present the design of the system and how is the integration of each component. In this work, we have tested one of the subsystems that compose the entire design, that is, the one that locates the emergency vehicle in the city. Unlike other proposed methods, we opted for an hybrid system that uses both QR code detection and a GPS/GPRS tracking system. With this mixed implementation we are trying to lower the chances of getting errors when detecting the current location and improve the times of response of the emergency vehicle. Also, using this approach is more efficient than using RFID technology, given that we do not need to communicate vehicles with each other, and that in Cartagena de Indias there is no RFID network deployed.

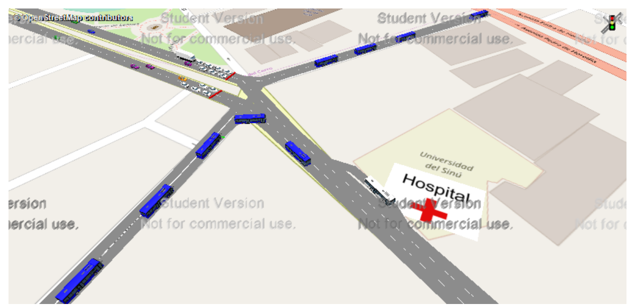

Fig. 5. Vissim sample simulation on a real scenario of the city.

The next challenge is the modeling of the traffic light system before, during, and after the emergency has occurred (center part of Fig. 4). The model would allow an "optimal green wave" to make the traffic flow for the benefit of our targeted vehicle, and after the car has passed the traffic lights, normalize the traffic light's regular schedule. In this model, we also need to include the possibility of more than one emergency vehicle working in the same zone.

The system that we are modeling uses real scenarios from Cartagena de Indias, Colombia; focusing on some critical city routes covered by the camera network system available. At the moment, a simple test over an intersection of the city is ongoing, but not finished. For future experiments, we expect to include more extensive areas and integrate MATLAB to the simulation to measure times.

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