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A Social Smart City for Public and Private Mobility A Real Case Study

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Abstract

Nowadays, smart city paradigm plays a primary role in the fulfillment of sustainable solutions in the field of urban mobility, both public and private. At the same time, the Internet of Things (IoT) is allowing the development of increasingly advanced solutions for real-time management of collected information related to the management and coexistence of vehicles (i.e., buses, cars, trains, bicycles, etc.) immersed in urban and sub-urban traffic. The Social IoT (S-IoT) paradigm adds a relational connotation between objects typical of human relationships. Objects operate as equals and request/provide information among them in the perspective of providing IoT services to users while maintaining their individuality. Social object relationship enables the design of solutions aiming to improve the exchange of information among network nodes in terms of security from malicious attacks external to the so-called social network of objects. In this context, a new SIoT smart city solution is presented in this article: private and public vehicles together with pedestrians are involved in a real-time collection of data to improve the viability of the city in order to suggest new directions and information to citizens to better organize how to live the city. The developed architecture presented in this article is equipped with an artificial intelligence that process collected traffic data and, thanks to machine learning techniques, evaluate the directions and flows undertaken by vehicles and pedestrians on a daily basis. The authors are also presenting an application that allow both citizens to live the city in a better way and municipal authorities to promptly manage traffic flows. The proposed system was installed in a specific area of Cagliari (Italy) and the traffic flows have been compared with daily traffic data monitored before the installation, observing an average gain of up to 35 percent in daily traffic reduction.

Keywords: Smart City, Social IoT, Heterogeneous Networks, Devices Tracking, Traffic Monitoring, Data Protection.

1. Introduction

In last years, the smart city has emerged as a new paradigm able to involve mobile computing systems through heterogeneous networks dislocated in the urban and sub-urban environment. The goal is to improve the livability of the city using all emerging technologies for traffic control and sustainable resource management [1]. A suitable system design and management can help to stop undesirable cascade effects also enabling favorable kinds of self-organization in the system implicitly leading to improvement of human lives [2]. At the same time, recent decades have seen a rise in the use of physics methods to study different societal phenomena and to improve the ”decision making” process. From this point of view, it can be crucial to study urban development and traffic, the structure of social networks, and the integration of intelligent machines into these networks keeping in mind physicists point of view [3].

Internet of Things (IoT) technology and its heterogeneous devices are typically exploited to collect, manage, and process massive data for real time monitoring and decision making [4]. The Social IoT (SIoT) paradigm [5], evolution of the classic version of an IoT network, assumes that objects are capable of establishing social relationships in an autonomous way [6]. Thanks to the resulting social network, sensors, cameras, smartphones, and other heterogeneous devices are able to cooperate by collecting and exchanging information to perform specific tasks (i.e., individually or collectively). The proposed system is based on the research and testing of a network of fixed devices for tracking vehicles in urban areas. Through the collected information and classification of vehicular traffic intensity, real-time management of traffic light systems was carried out. Simultaneously, a mobile device system was developed for the acquisition of parameters related to the mobility of mobile devices in order to provide input data to planning models of interventions for the improvement of traffic flows. Finally, the system involves sending contextualized information to citizens for optimizing the origin-destination route taken. The integration of specific models in systems for intelligent transport management allows the optimization of public and private traffic flows in urban area implicitly leading to the reduction of polluting emissions. The innovation of the project stands on the application of a "netcentric" paradigm through a dynamic and pervasive network (i.e., Urban Information Grid) whose nodes can be both fixed and mobile, public transport, and equipped operators who are thus transformed into "mobile platforms" through the continuous acquisition of data relating to traffic with great potential for the addition of a number of functions [7] [8].

The Social Smart City system proposed in this paper aims to:

1. profile mobility of users by monitoring information as the real-time position of mobile devices. A anonymization sub-system is in charge for assuring the respect for the privacy of users;
2. redistribution of public transport based on real-time demand allowing to concentrate it where (i.e., both in time and space) there is greater demand;
3. provide tools to support the decisions of public administration facilitating the identification of the most appropriate actions for the implementation of effective policies relating to mobility.

[9] showed how "big data has increased access to sensitive information that when processed can directly jeopardize the privacy of individuals and violate data protection laws". This is the reason why, in this work data protection and privacy-preserving techniques in the context of big data analysis for anonymization such as k-anonymity [10], l-diversity [11], t-closeness [12], and differential privacy [13] were considered to carry out ad-hoc modules for data protection. Another important operation that must be protected is the sharing of data itself.

As discussed in [14], how to share user data safely and efficiently has become one of the most challenging problems in cloud computing. This work is very important because ”it provides a data protection model, and provides a data access detection algorithm, forms a closed-loop control, provides timely feedback evidence for continuous optimization of data access control strategies, and improves data protection’s integrity”. The solution has been tested in a real scenario in the metropolitan area of Cagliari in Italy, although the system can be tested without different arrangements in any other city with issues pertaining to high traffic concentrations. The paper is structured as follows: in section 2, an overview of previous IoT-based works for pblic and private traffic monitoring is presented. Functional aspects are illustrated in Section 3. The architecture and design of the smart solution are described in section 4. The real scenario and the obtained results of the assessment procedure are discussed in sections 5 and 6. Finally, the conclusions are drawn in section 7.

2. Background

This section shortly summarizes solutions previously proposed in literature to manage public and private traffic flows. The goal is to compare these works with the solution proposed by the authors pointing out benefits and weaknesses.

In [15], a centralized traffic light control system is proposed, analyzing the most common types of urban intersections. Direct control routines were implemented for network traffic lights, providing a complete control system for accidents or public events. Comparing this solution with the one proposed in the article, it does not perform real time acquisition of information on the traffic, as well as it is not able to instantly intervene in case of excessive congestion.

In [16], Unnamed Aerial Vehicles (UAVs) are used to support vehicles in accomplishing security tasks. This system allows UAVs to offload and to share intensive computation tasks with other nearby network nodes. Computation response time, energy consumed for the computation, cost of cellular communication, and computation cost were used to model the decision-making problem as a sequential game proposing an algorithm to reach the Nash an equilibrium. [17] describes a responsive and lightweight framework based on 5G and Beyond 5G (B5G) technologies for smart transportation system, employing blockchain for authentication. The solution is compared to the current cloud-based approach in iFogSim, a popular simulation tool for fog computing research. Unfortunately, only simulation results have been presented by the authors, without a deployment of a real system.

[18] describes a system to collect road vehicle information for intelligent traffic surveillance. The method combines a Mixture of Gaussians model (MOG2), to create scale-insensitive Region of Interest (RoIs) from video frames, with a SqueezeNet model (H-SqueezeNet) for vehicle category identification. This solution is limited by the unique acquisition of information using traffic cameras.

[19] In [20], the authors presents a distributed collaborative intrusion detection system based on invariant called DCDIV to identify betray attacks in Vehicular Ad-hoc Networks (VANET). In [21], realistic simulations using traffic data in a real-world network were performed to control the traffic signal for emergency vehicles in order to ensure an expeditious emergency response alleviating the negative influence on the traffic efficiency of conflicting directions. In [22], collaborative edge computing (CEC) in vehicles is proposed to improve traffic efficiency. The social features and connections among vehicles to reduce the average waiting time using multiagent-based deep reinforcement learning (DRL) for the servers that interact with Internet of Vehicles (IoV) and traffic lights to generate dynamic green waves at congested intersections. [23] proposes CoNeCT, a new VANET-based traffic management system to support vehicles' collaboration in analyzing, predicting, and managing congestion with the main objective of decreasing the number of messages by using a novel road segment load assessment that improves traffic flow classification. These solutions involve traffic light management not directly interacting with people and public administration to improve traffic flows in real time, only considering information collected by vehicles without considering other fixed devices to improve the real time analysis. [24] proposes a deep learning-based method that uses social

media data for traffic information in order to prevent jams, illegal behaviors, and emergency recourses on roads. A multichannel network with a Long Short-Term Memory layer (LSTM-layer) and a Convolution layer (Conv-layer) (termed as MC-LSTM-Conv) is proposed, to extract abstract features from input text. Moreover, a series of matching rules are constructed based on the keywords that are related to traffic-jam scenes. This solution only considers data collected by social network without matching information with real monitoring systems. To the best of our knowledge and in accordance with the state of the art, the strict project requirements that led to the drafting of this manuscript as innovative and research solutions did not allow us to make use of commercial solutions on the market. Therefore, it was necessary to develop a hardware/software architecture that met the project constraints with innovative and research solutions. The proposed solution showed a practical, highly scalable and innovative character, overcoming the limitations of existing solutions and converging the needs of municipal police for the control of a large metropolitan area.

3. Functional Aspects of the Proposed System

Intelligent Transportation Systems (ITS) represent a series of technologies and solutions adopted by now on a global scale aimed at adding information and communication means and tools to transport and transport infrastructures vehicles. ITS arises from the need to monitor, supervise, and manage the problems related to traffic congestion through the wise and synergistic use of new technologies of measurement, detection, processing, analysis, and information technology for simulation, real time control, and new networks and communication technologies. The new generation of traffic monitoring systems is based on impulsive cameras and radar. Initially, adopted as part of the active surveillance of Motorways and Tunnels, this new generation of sensors proved to be increasingly effective, convenient and appropriate [25]. These "smart cameras" within the same shooting device can host different coexisting analysis software to ensure precise speed control of vehicles, to know the main characteristics of vehicles (i.e., speed, type, etc.), or to detect the presence of queues, accidents, delays, etc. The benefits produced by the use of technological equipment are tangible, compared to traditional cameras without intelligence on board as the information produced allows real time distribution to all available communication system (i.e., satellite, mobile phones, and message panels placed along the main city roads). These characteristics are essential to have a tool that guarantees punctual real time monitoring of vehicle flows in a given road corridor and its branches.

New techniques and measurement methods allow to acquire data on traffic flow taking into account that users exhibit different behaviors on the road. The proposed solution adds to typical data (i.e., volumes, speed, and direction of travel) information related to the behavior of each single person (i.e., also pedestrian, cyclist, and biker) in the monitored area. In order to formulate a reliable indication of traffic flows, parking, waiting, travel, and traffic congestion times are considered. Currently, there are several solutions for measuring and monitoring the flow of people. For example, there are meters for bicycles, scooters, and pedestrians that use piezoelectric strips for continuous data collection. The most reliable solution for timed monitoring of shared routes and cycle paths on the road [26]. Nowadays, various mobile phone apps are able to record and store users' movement trajectories, which provide a valuable data source for pedestrian network construction. In [27], the authors propose a crowdsourcing-based system for generating pedestrian network that encompasses three key components of crowdsourced walking trajectory: data filtering, pedestrian network construction, and evaluation of pedestrian network. Experimental results demonstrate that the proposed method can accurately and completely extract pedestrian network. Moreover, the pedestrian network can be updated in a timely manner and the data collection application and the relative collected data are available to the public. Another important aspect concerns the mobility and pedestrian safety through pedestrian sensors that allow to adjust the traffic light control at intersections in favor of pedestrians or to increase the visibility of pedestrian traffic. Thanks to dynamic traffic light control and the activation of warning signs, it is possible to make intersections or pedestrian crossings safer and, at the same time, avoid unnecessary delays for both pedestrians and motorists. Current automatic traffic surveys make use of a technology that provides for video recording of the flows to be analyzed and subsequent automatic counting through dedicated software. Therefore, pedestrian flow monitoring systems are based on the use of cameras with data analysis and counting after video acquisition or by means of hardware to be installed as loops and radar under the road surface. The proposed approach overcomes these limitations as it is much less invasive from the hardware point of view and allows the detection of people by analyzing radio signal produced by their smartphone, allowing intelligent monitoring and real time tracking less expensive and with lower computational burden.

In a SC scenarios, also the integration and interoperability of different solutions must be addressed. Many IoT protocols and standards have been established as a result of the adoption of IoT devices. Unlike traditional devices, IoT devices are typically limited in terms of memory and computing power. Additionally, IoT devices may be deployed in areas where there is limited or no access to continuous power, with essential use of batteries or tiny solar panels to power them. As a result, IoT devices now have energy-efficient communication protocols with smaller memory footprints and processing needs.

The acquisition, storage, and management of vehicular and pedestrian monitoring data requires advanced tools that work on the relationships and correlations between the data collected. From this point of view, Internet of Things platforms represent a basic but insufficient tool for migration and interoperability in large deployments. Lysis platform is a SIoT platform carried out for distributed IoT applications involving socially connected objects [28]. Objects are capable of establishing social relationships in an autonomous way with respect to their owners with the benefits of improving the network scalability and information discovery efficiency. The overall architecture of the Lysis platform through four functional levels:

1. the lower level is made up of the “things” in the real world;
2. the virtualization level, which interfaces directly with the real world and is made up of Social Virtual Objects (SVOs);
3. the level of aggregation is responsible for composing different SVOs to set up entities with augmented functionalities called micro engines (MEs);
4. the last level is the application level in which user-oriented macro services are deployed.

4. System Architecture and Design

This section presents the main architectural elements and the design of the proposed SIoT SC solution. The key components of the architecture, shortly described in next sub-sections, are:

- sensors for mobility (4.1): cameras equipped with built-in intelligence, Wi-Fi Access Points;
- crowding control units (4.1): installation on public transport and close to bus stops and traffic lights;
- Lysis-compliant integration modules (4.2): several heterogeneous hardware components have been developed, differing for communication protocols and interfaces, as well as for data format. The Lysis virtualization layer allowed to integrate all these devices;
- Lysis-compliant interoperability modules (4.2): SIoT social relationships allow to ensure interoperability between heterogeneous devices;
- data analysis platform.

4.1. Monitoring devices

The fixed stations are placed in specific points of the city and interconnected to Lysis platform via 4G Long Term Evolution (LTE) transmission system. The data collection part is performed by positioning the fixed/mobile stations in determined points of the urban area of Cagliari, mainly road crossings with traffic lights, near particularly interesting areas, such as university areas and on public transport. The stations are equipped with components for the detection and transmission of data taking advantage of the power supply present at traffic light intersections. The collection of information is performed simultaneously by the different stations, periodically generating a json file with all the measurements captured. Measurements and transmission take place at one minute intervals. This is to preserve a possible use with combined battery/solar panel power supply. These files are then sent through the 4G LTE transmission system to the central gateway (i.e., the ME of the SIoT platform), which will transmit the received data to the upper layer of the SIoT platform that is in charge of classify and cross process them.

A single spatial database (SDB) is dedicated to each installed device presented in sub-section 4.3.1 in charge of collecting information. A SDB is a database optimized for storing and querying data related to objects in space, including points, lines, and polygons, integrating functionalities for processing spatial data types. A processing unit is in charge of analyzing data of the various SDBs to find relationships and to reconstruct the traffic map. A data-set related to 12 consecutive months of acquisition was used for training this unit.The SDBs collected data were subsequently processed through Lysis platform. Thus, unlike what is reported in the state of the art, the proposed architecture carries out a real time analysis. The collected data also allow the provision of services to the citizen, for the optimization of the urban mobility network or the level of vehicular traffic. A further feature concerns the optimization of the use of public transport by citizens. The level of traffic necessarily affects bus routes with obvious repercussions on waiting times at bus stops. Therefore, the analysis of the traffic level combined with the real-time position knowing of the bus, its level of occupancy, and the position of the user, allows the system to optimize the reaching of bus stops, guaranteeing an additional service.

4.2. Lysis-compliant modules

A smart city scenario entails the operation of several devices from various manufacturers with varying computation and energy capabilities. Many are municipal property, while others may be owned by people who participate in the creation of a Social Smart City. In comparison to other IoT solutions, the Social Internet of Things paradigm demonstrates the ability to allow interaction between devices owned by different people, ensuring a high level of trustworthiness of the information providers due to the various relationships between them. Furthermore, Lysis shifts the level of social networks from physical devices to virtualization, enhancing security and privacy while preventing direct connection between devices of different citizens. Lysis supports the breaching of vertical solution barriers through the Virtual Objects social network (SVOs), ensuring a high degree of interoperability. However, Lysis does not provide all device software or logical aggregation engines for the provision of IoT services for citizens. Lysis provides a set of requirements to be followed in order to create virtual objects of devices that may enter the social network and interact with other components, as well as aggregation engines for data flowing from all social network nodes.

In order to exploit the Lysis architecture advantages, the virtualization layer elements (SVOs) were designed and implemented, representing buses, traffic lights, traffic cameras, and smart bus stops. Each bus has its own SVO with which it communicates to send and record information relating to position and internal crowding. This last bit of data consists of three values detected by the sniffer placed inside the vehicle: a hashed ID to maintain the anonymization of the detected smartphone; the strength of the corresponding signal received; and the manufacturer of the smartphone. The traffic light SVO (TL-SVO) provides the API to control the lighting management actuator. Fig. 1 shows each SVO related to all the elements in the system, that is, starting from the left side: traffic camera, traffic light, bus, and smart bus stop. Moreover, all the social connections between SVOs differing for the specific relationship (i.e., red, black, or green line) are specified.

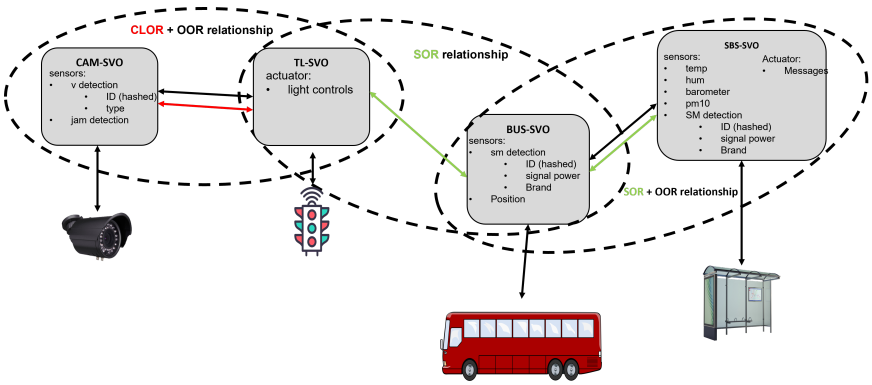

Figure 1: Social connections between the SVOs of the elements of the system.

The Bus-SVO and the TL-SVO, establish a Social Object Relationship (SOR) as a consequence of the encounters that take place during the bus journey. This relationship is exploited at the application level (i.e., by the line management platform) to set actions when buses approach traffic lights along the route. In practice, the Bus-SVO, when the bus enters the geofence set on the traffic light, sends a command requesting the green light to be turned on to the approaching TL-SVO.

The Cam-SVO exhibits two sensors: a vehicle detector that produces as output the vehicle license plate (hashed) and the type of vehicle, and a traffic jam detector.

The Cam-SVO and the Tl-SVO positioned at the same intersection establish a Co-location Object Relationship (CLOR) since they are installed in the same place. They also have a Ownership Object Relationship (OOR) as they belong to the public body that manages the roads. The CLOR relationship is used at the application level to set the management actions of the lights on the traffic light in correspondence with events detected by the Cam-SVO (traffic jam, ambulance or police approaching, etc.).

At the bus stop, a sniffer is in charge assessing crowding like inside the bus. There is also an actuator that controls the screen that shows information to waiting passengers.

The SBS-SVO creates a SOR relationship with the Bus-SVO of the buses passing along the route. In this case, the SOR relationship is used at the application level to set actions on both SVOs. When a bus enters the geofence of a stop, the Bus-SVO notifies the SBS-SVO that the bus is arriving and sends the internal crowding information, shown on the screen to the waiting passengers.

4.3. System design

Traffic data has been collected by various devices located in established points previously selected in a planning phase to accordingly cover a specific area in the city of Cagliari. All these information are transmitted thanks to already existing infrastructures, to be able to archive, process, and make them available by different services. Some of these devices have been prototyped by the authors, as shortly described in next subsections 4.3.1 and 4.3.2. Other data are extrapolated from different detection devices for tracking city mobility located in a specific geographic area:

- cameras;
- various types of sensors;
- mobile devices such as smartphones and tablets.

The proposed system is composed of three main levels:

1. **Level 1: the acquisition level** consists of a system composed of sensors that acquire the data to be processed. The crowding monitoring sub-system is presented in subsection 4.3.1, while the mobility monitoring sub-system is shortly described in sub-sections 4.3.2.
2. **Level 2: the elaboration and transmission level** represents the heart of the designed systems. The acquired data is anonymized and sent over the 4G LTE network to the cloud. Also in this case, the main components for the two sub-systems are shortly described in next sub-sections.

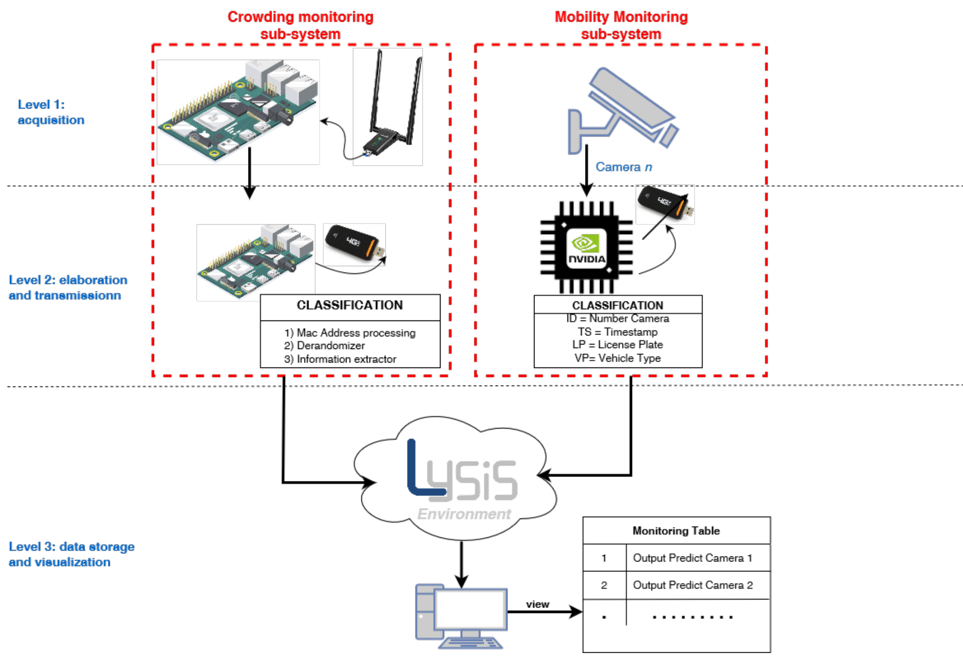

Figure 2: General view of the monitoring system.

3. **Level 3: the data storage and management** collects revenue data from the data processing and transmission layer and stores it on the cloud where it can be processed appropriately for real-time statistics and application of certain actions in order to reduce vehicular traffic saturation.

The complete system is shown in Fig. 2, where the first and second architectural level for the crowding and the mobility monitoring sub-systems are different due to hardware components, while converging to the third data storage and virtualization level.

4.3.1. Crowding monitoring Sub-System

From the technical point of view, an 802.11 Wi-Fi infrastructure capable of capturing a series of frames of the MAC sub-level has been implemented. Generally, MAC addresses are used by network interfaces to establish the physical connection between devices, i.e., the connection among Access Points (APs) and mobile Wi-Fi devices. A prototype for crowding evaluation in a specific area has been implemented (Crowding Monitoring Sub-System in Fig. 2). The tracking method is not based on the counting of individual vehicles but on the number of passengers using APC (Automatic Passenger Counting) techniques that are commonly divided into indirect and direct. Through an external network board connected to a Raspberry Pi device, the Wi-Fi traffic of mobile devices is carried out by "sniffing" the MAC addresses. The system ensures that the redundant MACs will be not counted several times for a more accurate estimation of devices within the area of interest. It has a maximum operating range of about 50 meters and can be used both in indoor (i.e., inside a bus or room) and outdoor (i.e., close to traffic light) environment. The typical use case is the smartphone detection of pedestrians on board vehicles (i.e., buses) moving with speeds of up to 50 Kmph (i.e., urban environment). The project includes neither hard disk nor solid state drive, relying instead on an SD card for booting and non-volatile memory. The prototype has been designed using the Python programming language and using appropriate additional modules linked to both the Wi-Fi technology of public or private networks and LTE technology to transmit traffic data. In order to effectively announce their presence to each other, mobile devices and APs, need to use an active or passive mechanism for association. These mechanisms have been defined by IEEE 802.11. In the passive mechanism, the APs periodically advertise their presence to mobile devices by sending beacon frames, while in the active scanning mechanism, it is the mobile devices that actively search for the APs, transmitting probe requests, to which the APs neighbors will respond with so-called probe response. Probe requests are a particularly vulnerable component of Wi-Fi traffic with regard to the identification of devices. Since each device transmits both single and burst probe requests with certain time and frequency intervals, this makes locating relatively simple. The probe requests include the MAC address and can be addressed in unicast mode to a specific AP (i.e., indicating its SSID), or in broadcast mode to all APs within a specific range. Devices that are not associated with a particular AP periodically send probes requests that contain the unique identifier of the interface (the MAC address) in their header. Multiple sniffing stations have been strategically placed at each road intersection to improve localization accuracy and to conduct statistic evaluation on traffic flows. The probe request frames provide several pieces of information that are appropriately filtered to extract the content of our interest, such as the MAC address of the resource, the timestamp, the date and time of acquisition, and the numeric sequence (i.e., SEQ).

4.3.2. Mobility Monitoring Sub-System

The camera has the task of shooting the scenes in a specific area, understanding and discriminating the vehicles (i.e., object detection) in order to extrapolate its associated license plate from a frame through pre-processing techniques, such as cropping, resize, and zoom. Once the image relating to the plate is obtained, it is sent as input to a neural network opportunely trained to recognize the characters of the plates and this data is converted into a string (Mobility Monitoring Sub-System in Fig. 2). Image processing algorithms are implemented at each shooting point. The software performs a series of algorithms for the identification of the license plate:

- License plate location: this algorithm is responsible for searching and isolating the license plate on the photo.
- Orientation and sizing of the plate: this algorithm compensates for the inclination of the plate and adjusts the dimensions according to the required dimension.
- Conversion: using some image processing techniques it can be converted into a desired format, an instance to have a simpler image processing by converting it from RGB to grayscale.
- Normalization: this algorithm adjusts the contrast and brightness of the image.
- Edge detection: applied to increase the difference between the letters and the license plate holder. A median filter can also be used to reduce visual

noise on the image.

- Character Segmentation: This algorithm finds individual characters on the plate and segments them for further improvement.

- Optical character recognition: is the electronic conversion of images or printed text into machine-coded text.

- Syntactic and Geometric Analysis: Checks characters and positions against country specific rules. Averages the recognized value over multiple fields to produce a more reliable and safe result. Especially since every single image can contain some reflected light or can be partially obscured.

The entire system was developed in accordance with the General Data Protection Regulation 2016/679 - GDPR [9]. Vehicle license plates represent data that can be directly traced back to the person, so they must be handled according to well-defined rules. Specifically, it is prohibited to store and hold this data without the specific consent of the driver or owner of the vehicle. The regulations provide alternatives that have been implemented in the proposed system, avoiding the transmission and storage of license plate data. Privacy was ensured through mathematical processing of the data in real time, avoiding any storage and transmission of the unprocessed data and providing for its immediate deletion after processing. The alphanumeric characters of the license plates were converted to Hash format [29] within the graphics processing unit immediately before transmission to the cloud. This is a mathematical algorithm that maps data of arbitrary length into a binary string of fixed size called Hash value. The Hash function is designed to be unidirectional, that is very difficult to invert: the only way to recreate the input data from the output of an ideal Hash function is to attempt a brute-force search of the possible inputs to see if there is a match. For proper interpretation of the data, the hash string is also associated with the shooting point in order to report where the tracked vehicle has been identified. Subsequently, the data will be transmitted as soon as the hash string is replayed. In this work, the SHA-256 "double" algorithm was used, that is the message is processed twice using the same anonymization technique, then once the first code is produced, it is reprocessed resulting in a new code. The data are encapsulated in a standardized format (i.e., JSON file format) easily deciphered and interpreted by the database for all subsequent processing. Finally, via the 4G LTE network, the data is sent to the Lysis platform where it is cataloged neatly according to the date and time of acquisition along with references on geolocation, license plate hash. The system is composed of various strictly interconnected elements, both hardware and software. Cameras have been used to detect vehicle license plates 24 hours a day. Professional license plate reading cameras were used: IP 3.0 MPX CMOS 1920*1080 outdoor video surveillance for security systems, with variable focal length 5-50mm for high speeds 200 Kmh Max. The camera is connected to the Nvidia Jetson AGX Xavier Developer Kit with the several essential features for the data management using the neural networks. The processing unit is equipped with an Ubuntu-like operating system, where the video stream is processed into images. Neural networks are then applied to the images to extract features such as license plate (i.e., using ALPR) and vehicle type (i.e., using YOLO). The collected data can be sent in two different ways:

- in the first case, each transmission takes place with a predetermined amount of information in terms of mega bytes (MB) in order to previously collect a certain amount of data before sending. This configuration is more suitable for limiting the number of transmissions during the hours when the traffic of vehicles and people is drastically reduced.Only when a certain amount of information is reached, it will be sent to the server.
- the second sending method provides for timed transmission at a certain frequency so that the number of messages is constant over time, regardless of the amount of data to be sent.

Both methods involve criticalities but, on the other hand, have advantages depending on the amount of data acquired. The used algorithm allows the adoption of a hybrid configuration in which both the cases described above are adopted depending on the traffic conditions. In case of high traffic which corresponds to a large amount of acquired data, the data is sent at a predetermined time interval. During the time intervals characterized by traffic reduction (e.g., night), the sending of data is bound to the filling of a buffer in order to avoid many transmissions with very low information content. The acquisition and processing of data takes place in real time, allowing traffic operators and the network of traffic lights to take a smart approach from a SCs perspective. In fact, a processing of the data in real time allows at the same time an instant modification of the traffic management with considerable advantages compared to static traffic configurations. As for the architectural system concerning the vehicle monitoring system, it is based on the concept of object detection and tracking algorithms for vehicle counting which is processed by the intelligence system on board the cameras. The cameras identify the concentration of traffic flow and the average speed of vehicles. The combination of these parameters allows the traffic classification into three classes: low, medium, and high. In case of high traffic, the system switches in real time allowing a longer duration of the green in the busiest directions. In case of homogeneous traffic, the system keeps the situation of equilibrium giving fairness of service to all directions.

5. Real Scenario

In this section, the real scenario considered to evaluate the performance of the proposed solution is detailed. The proposed infrastructure is based on passive capture of signals transmitted/received by devices with Wi-Fi interfaces; passive capture means that the process of information exchange between transmitter and mobile receiver is totally transparent to the involved user. An analogous process requires the use of cameras at traffic light intersections, in order to collect data regarding the concentrations of pedestrians and transport (i.e., public and private) in real time. The peculiarities of the infrastructure are mainly two: first of all, the entire process is able to provide a real-time overview of traffic conditions and concentrations of people within a given area of interest.

Secondly, the continuous collection over time provides timely statistics on both habitual and sporadic citizen habits. Data collection is not simply limited to a "counter" type of functionality but introduces a further level of accuracy being able to discriminate users by structuring a data collection that can determine not only the number of occurrences but also tagging the various occurrences from a temporal point of view (i.e., daily, weekly, monthly, and so on). In this study, the added value is the possibility to enable true tracking of devices moving within a given area covered by sniffing systems. The discrimination of mobile devices and vehicles must be done in compliance with current privacy regulations. However, the possibility of installing urban mobility monitoring and tracking devices passes through the determination of urban security assumptions and possible authorizations. In addition, any technical constraints related to the presence of telecommunications infrastructure for data transmission (e.g., presence of sites equipped with fiber optic connections), existing urban infrastructure (e.g., lighting poles for device installation), or electrical power sources must be considered. Additional factors that positively impact system validation entail the identification of heterogeneous scenarios involving pedestrian areas that are promiscuous with both urban public and private vehicular arteries.

A preliminary study was conducted to identify the best area in accordance with the criteria presented in previous sections. The metropolitan area of Cagliari includes several urban agglomerations and represents a reference basin for the whole territory of Sardinia. As the regional capital, there are substantial residential settlements and the main services, production activities, poles of attraction and a high demand for transport. The concentration of activities, their distribution and urban settlements involving about half a million citizens, involves the daily presence of substantial vehicular flows. Inevitably, in the peak hours (i.e., 07:00-09:00 a.m., 1:00-2:30 p.m., and 5:00-7:00 p.m.) there are phenomena of vehicular congestion with consequent dilation of travel times in the main arteries that cross the city of Cagliari, from and to the central areas to the peripheral ones. A further factor that stimulated this study, derives from the fact that generally the cities have developed over the decades, taking into account the geographical conformation within their territorial boundaries. The adopted solution wants to be applied in any metropolitan context, where vehicular mobility has never been planned in advance. In our specific case, the metropolitan area sees the city of Cagliari located in a south-western position. The municipalities more closely linked to the capital are concentrated in the north-east, east, and south-west representing a very large portion of the mobility demand that moves daily to the city.

The main road 195 (i.e., SS 195 - E25) is undoubtedly one of the three main access routes to the entire metropolitan area of Cagliari. This artery conveys the traffic from the north-west area and represents the shortest way to reach the city center in the south-east direction. The area involves the central "Roma Street", the parallel "New York 11th September" Promenade, and the adjacent area of the port area, for a total of about 10-12 lanes equally divided in both directions. The high vehicles concentrations negatively affect travel and arrival times at destinations along the analyzed stretch, both for local and induced traffic. Currently, the complex of Roma Street and New York 11th September Promenade, is traveled by approximately 48000 vehicles per day in both directions. The distribution in the two directions is not balanced, but is mainly distributed in the direction of entry to the city.

During peak hours, the so-called "bottleneck" occurs due to a much higher number of vehicles than the number the road system in and out of Cagliari can support. The geometric characteristics of Via Roma are those of an urban road connected to a fast-flowing section in the north-west direction, and then branching off in the north, north-east, east, and south-east directions in the city of Cagliari. Fig. 3 shows the map of the considered area on which the preliminary study was done. An additional feature of this scenario is the presence of the port area, which provides an additional transit route complementary to the Roma Street, as well as being an area used for vehicle parking. This area is delimited and includes a unique entrance and exit gate. Therefore, by monitoring these accesses, it is possible to determine the exact number of vehicles in the area. According to the analysis carried out by the Department of Transport

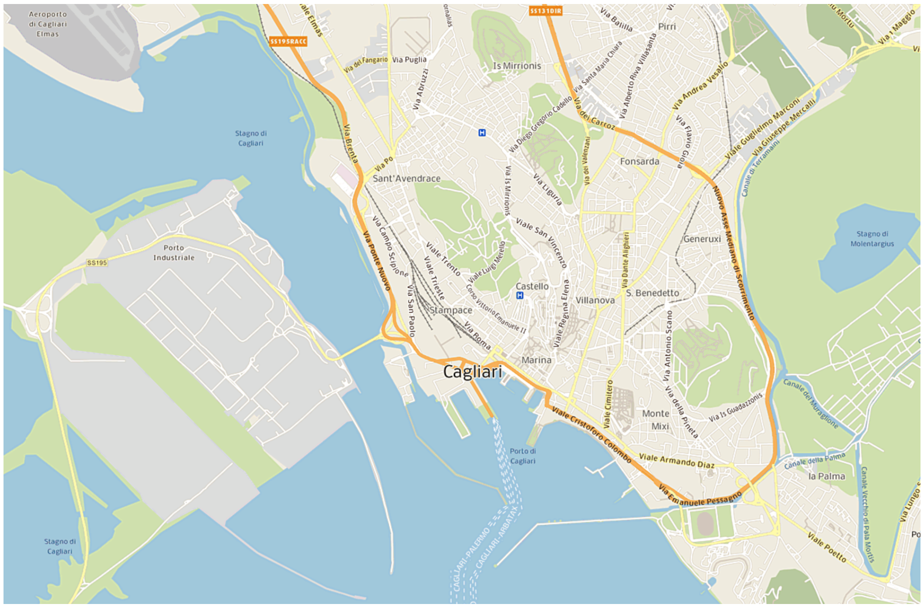

Figure 3: An overview of the area of interest.

Engineering of the University of Cagliari, the complex of the examined streets registers a maximum traffic flow slightly higher than 2400 vehicles per hour (vph) from 7:30 am to 8:30 am. The flow tends to decrease until the interval 13:00-15:00 when the traffic has a dramatic increase due to lunch breaks and exits from schools. A further elevated concentration is verified in correspondence of the exits from the offices in the hourly band 17:00-19:00 and then to diminish again.

Fig. 4 shows the installation placement of pedestrian and vehicular monitoring equipment, that is smart bus stops, Wi-Fi sniffers, traffic cameras, and traffic lights, respectively . The Roma Street scenario represents a key artery for vehicle outflow from the metropolitan area and for traffic distribution within the city. The marina area is home to numerous parking lots and is bordered by several stops of the city's public transport lines (i.e., lines 1, 5, 30, 31, PF, and PQ). The presence of pedestrians, public, and private means of transportation represents a heterogeneous scenario of high interest due to the variability

Figure 4: The Roma Street and New York 11th September" Promenade scenario equipped with Wi-Fi sniffer and Traffic camera.

of concentrations that can occur throughout the day and recur throughout the week. In addition, the study allows a real monitoring with some periodicity and seasonality facilitating the use of predictive vehicular and pedestrian mobility tools geared toward optimizing routes and reducing areas of congestion and high traffic.

The system detects passenger data inside the buses by identifying the number of users getting on and off at various stops. Wi-Fi sniffer end-points were placed near each stop to identify people waiting and getting off the buses. Six Wi-Fi end-points were placed at fixed locations along the bus stops and within the port area. Vehicular traffic with detection of vehicle type and its license plate, consists of four camera system placed at the three entry/exit gates to the port area. Data are collected and anonymized in real-time before being sent to the cloud. In more detail, Wi-Fi sniffer end-points consist of Raspberry Pi 4-type electronic boards equipped with dual Wi-Fi interfaces for connecting to

Figure 5: The implemented Wi-Fi end-point sniffer (left) and Vehicular system (right).

the Internet network and detecting devices with a dual Wi-Fi antenna (i.e., 2.4 GHz and 5 GHz), respectively. The system is connected to the 4G LTE network and is powered by the power line.

The vehicular camera system consists of a box that collects signal processing, and one or two external cameras appropriately placed for vehicle license plate detection. The pole box, contains an NVIDIA NX video card designed for real-time data processing. The card is connected to the 4G LTE network for anonymized data transmission. External to the box are Gifran cameras for detecting vehicular license plates in different weather conditions and throughout the day. Fig. 5 shows the units installed in the scenario of interest: the hardware solution for the Wi-Fi end-point sniffer (i.e., left side) and the Vehicular system (i.e., right side) are presented. All data collected are processed appropriately in accordance with the latest regulations in the manner of privacy.

6. Results

In this section, the results obtained by evaluating the performance analysis of the proposed solution are discussed together with an in deep analysis. Finally, the application carried out to help both citizens to take better decisions considering the real time traffic status and the municipal authority to manage urban and sub-urban traffic flows is described. Fig. 6 depicts the average daily flow of vehicles (i.e., private and public) traveling along Via Roma toward the center of Cagliari. This trend was obtained by collecting data during the six working days (i.e., Monday to Friday) for 3 consecutive months. The first peak (from 8:00 am to 10:00 am) is justified by the simultaneous entrances to public schools (kindergartens, elementary and middle schools) and public and private offices. The second peak is in the vicinity of the 1:00 p.m. to 3:00 p.m. time slot during which there is travel due to work stoppages. Finally, the third peak is attributable to workers' returns from the metropolitan area to the city center. Fig. 7 shows the average trend of vehicles traveling on the streets of the Via Roma complex in the direction of Cagliari exit, highlighting three peaks. The first peak in the 07:00-09:00 time slot coincides with the flow of workers moving from the city center on their way out to scattered activities in the metropolitan area. The second peak coincides with the exit of students from schools and at the lunch break (i.e. from 14:00 to 15:00). Finally, a further concentration is shown in the time slot 18:00-21:00 that corresponds to exits from work positions. Fig. 8 summarizes the monthly average flow of vehicles passing on and adjacent to Roma Street. The data are the results of the year-long acquisition campaign to monitor Roma Street and the port area. As can be seen from the figure, the months from June to September have a higher flow of vehicles due to the summer season and the region characterized by high tourist flow.

Fig. 9 shows the trend of the flow of passengers on bus lines 1, 5, 30, and 31 on Roma Street in the south-east direction (i.e., referring to Fig. 4). The trend of the four lines is basically overlapping and differs in terms of number of passengers. Sniffing devices have been placed within the bus routes to detect the alternation between passengers on board, new entrances, and exits from buses near bus stops. During the acquisition phases, the on-board devices detected a total of 5024, 5245, 3723, and 4256 devices for routes 1, 5, 30, and 31, respectively. The hours of highest daily use are related to peak hours, at the entrance to offices and schools (time slot 08:00-09:00), lunchtime (time slot 13:00-02:00), and exit from work in the afternoon (18:00-19:00). Finally, Fig. 10 depicts the

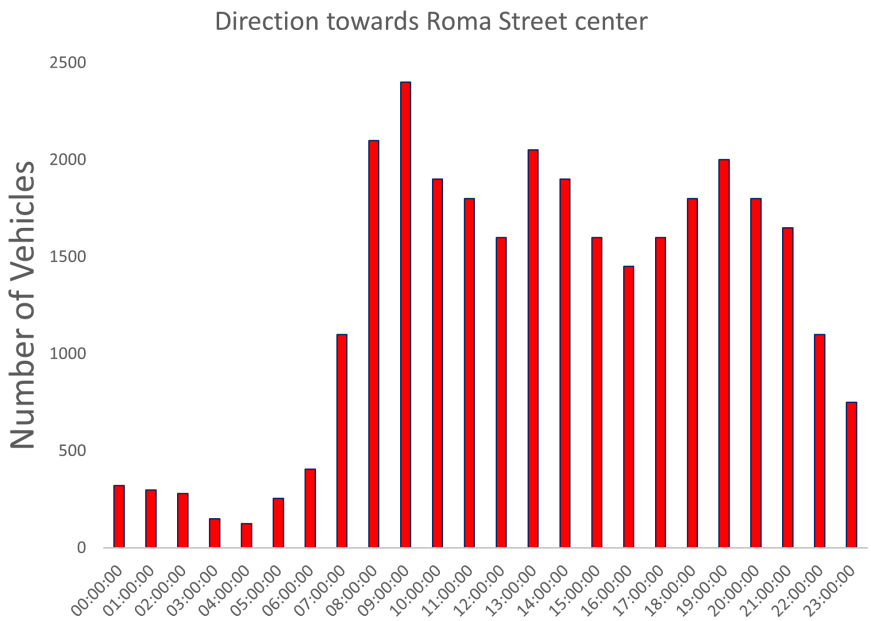

Figure 6: Average daily traffic flow towards Roma Street

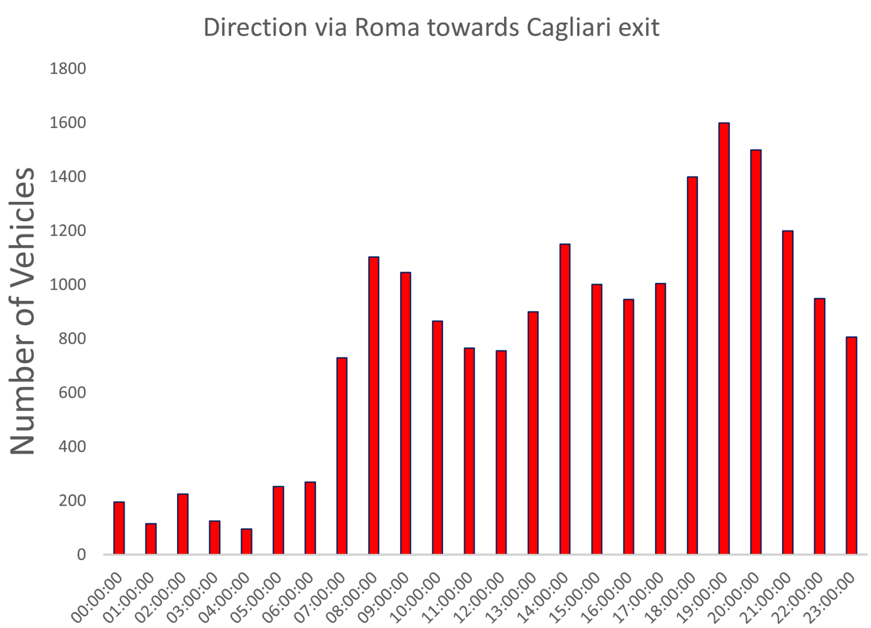

Figure 7: Average daily traffic flow towards Cagliari exit

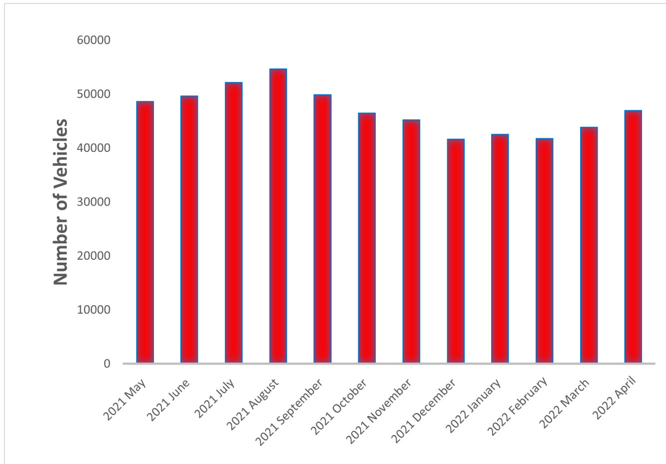

Figure 8: Year Traffic Flow towards Cagliari Street

hourly trend of the use of routes 1, 5, 30, and 31 along the complex of streets around Roma Street in the north-west direction (i.e., referring to Fig. 4). The average daily number of devices detected in the direction of the main bus and train stations for routes 1, 5, 30, and 31 are 2080, 2345, 2204, and 1891, respectively. As in the case of the opposite direction (i.e., south-east), the two curves have basically overlapping behavior. There are two fairly pronounced peaks that correspond to the time periods when more users were detected, specifically between 07:00 and 09:00 corresponding to the commute to schools and offices, 13:00 to 15:00 corresponding to the exit from schools and lunch break.

A very important aspect that emerges from the results, concerns the impact of the proposed system in comparison with the state of the art. Nowadays, monitoring and especially traffic control are done by manual methods involving human personnel for both phases.The monitoring procedure involves the presence of trained human personnel, similar to the management of manually modified traffic light timings on site. The proposed system overcomes these limitations and proposes technical, economic, and social benefits with targeted actions and their implementation in real time with continuous updates resulting from a flexible and adaptive architecture. Fig. 11 shows the comparison

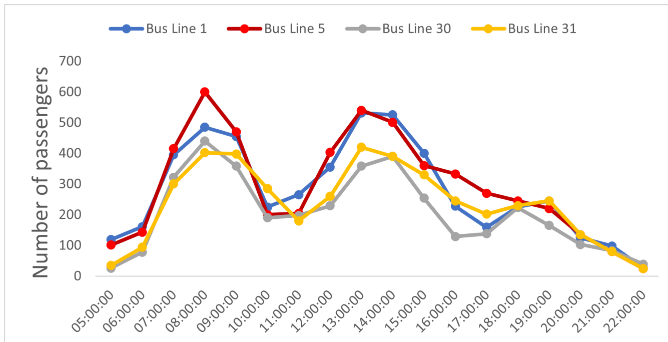

Figure 9: Daily travelers on bus lines 1, 5, 30 and 31 of the urban transport Roma street to downtown.

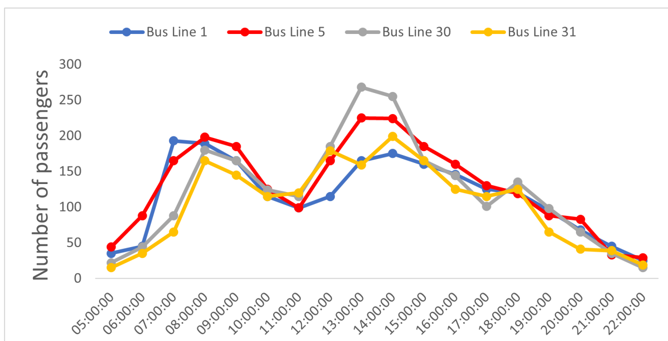

Figure 10: Daily travelers on bus lines 1, 5, 30 and 31 of the urban transport arriving at Roma Street.

between measured average traffic and vehicular flow due to the application of real-time policies on the management of road intersections and crosswalks along the complex of roads around Roma Street. As can be observed, the proposed system acts on timings by directing and distributing traffic flow especially during peak hours, where traffic is heaviest. An average gain of up to 30 percent has been achieved through a distribution of vehicles among the various options and in terms of traffic savings. Given the high scalability of the system, the benefits obtained can certainly be improved through a large-scale deployment aiming at the coverage of an entire metropolitan area. It should be pointed out that the system also provides a direct service to citizens regarding traffic

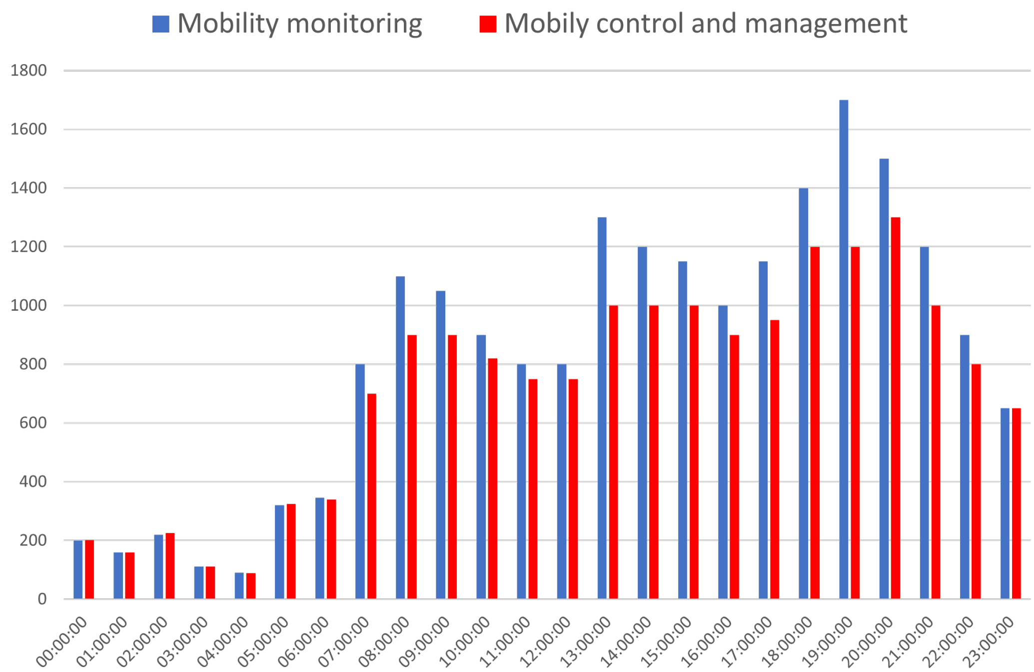

Figure 11: Comparison between average daily traffic flow in Roma Street and the impact of real-time traffic monitoring and control.

conditions and the use of city public transportation services. The value added vis-à-vis the citizen consists of a web, smartphone and tablet application with which citizens can optimize their decisions to move within the city in a timely and time-saving manner. Different programming languages were used, specifically the front-end was developed using HTML, CSS, and JavaScript based on the Bootstrap framework, while the back-end part was developed in Python with the use of the FASTAPI library. Finally, interfaces were made for reading data from the sensors. The best performance and the typical use of it (i.e., taking advantage of all its potential features) can be potentially reached covering the entire city of Cagliari and the corresponding metropolitan area with the cameras and devices previously presented and actually installed in Roma Street area. First, the login procedure allows the application to identify the type of user and related information to be displayed such as the best route to quickly reach a desired destination whether in the case of a vehicular, pedestrian, or public transportation user. The information provided is to support public administration and decision-making facilitating the identification of the most appropriate actions for the implementation of effective mobility policies. Following the login procedure, the application detects the current location of the smartphone via GPS and begins collecting traffic information by querying SDBs corresponding to devices and cameras throughout the city. Users have the ability to train the application by storing the main destinations typically reached each day during an ordinary week (e.g., the daily route to the office, the Wednesday route to the gym in the afternoon, etc.). For each useful bus route to reach the destination, the main information displayed are:

- real time position of each bus;
- the nearest bus stops;
- estimated travelling time considering the real time traffic level path;
- number of on board passengers up to total for each bus;
- number of people waiting close each bus stop;

Fig. 12 shows two screenshots of the developed application and the main information available to final users. The user is identified in the vicinity of a smart bus stop: based on the selected line (in the example, line 5), the user's geolocation, estimated time of arrival (ETA), and vehicle type are provided. Finally, information is provided to monitor and control crowding: the percentage of occupancy and free seats inside the bus before arrival at the stop of interest is estimated. Once the bus is in motion, a new analysis is performed after each stop and the data is updated in the SIoT platform. The application works both on-board and off-board.In both cases, updates occur in real time for both waiting and on-board users. The number of passengers is updated by the algorithm between two successive stops by a signal variance analysis over time. The results were validated through a comparative analysis performed by an operator counting the number of passengers within Line 5 during its route.

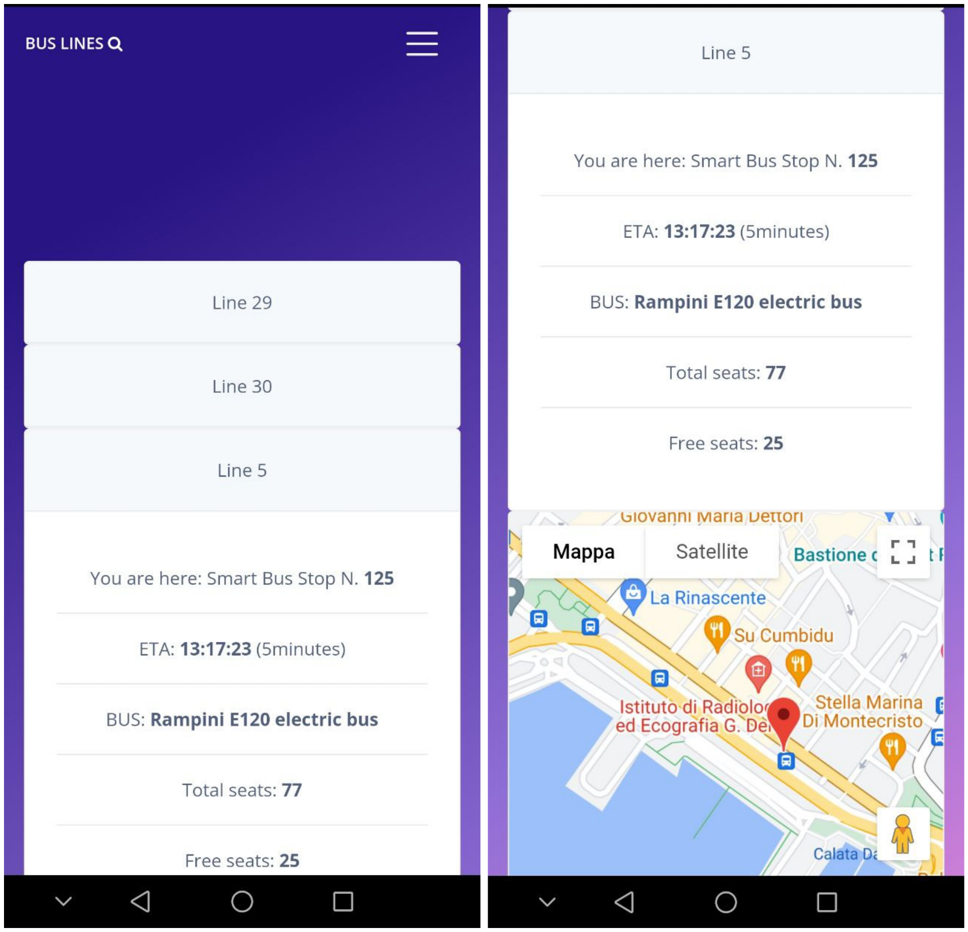

Figure 12: Web-app for urban flow and public transport occupancy.

7. Conclusions and Future Works

This paper presents a new system based on a Social IoT approach for monitoring and better management of pedestrian and vehicular flows (public and private) in Cagliari's Smart City. Real-time monitoring is done through cameras together with mobile and fixed sensors. The proposed system models citizen mobility flows by monitoring the location of personal mobile devices and vehicles with the use of dedicated devices designed by the authors, both people counters and camera-based systems. The analysis of vehicular flows has enabled real-time management of traffic light timings within the port area and streets pertinent to the Roma Street area with significant reductions in traffic flow times. The most striking result the authors hoped to achieve and which has been demonstrated by the collection of data once the system was installed is the reduction in average traffic, which averages around 20% in comparison with the state of the art, but also reaches peaks close to 35% in the evening time slot (i.e., 8 pm). This main result was obtained overcoming implicit limitations of the methods currently used for traffic monitoring and management, obsolete and bound to the activity of operators in the field, with targeted actions and their implementation in real time with continuous updates resulting from a flexible and adaptive architecture. The proposed SIoT Smart City solution aims to provide operators with city traffic management and pedestrian flow monitoring, and to collect data to provide a service to the citizen, able to receive real-time information on traffic conditions. A dedicated artificial intelligence takes into account instantaneous speed, average speed, and traffic type and thanks to the use of machine learning techniques is able to determine the directions and flows undertaken by vehicles and pedestrians on a daily basis. In the near future, thanks to the collaboration with the authorities and the city government, new installations will be carried out in other areas of the city which, from preliminary analyzes, have shown criticality and high levels of congestion. The possibility of crosschecking a greater amount of data and of having a more detailed general picture of traffic flow and dispersion of vehicles in urban and suburban network will allow to further improve both the decision-making algorithms and the effectiveness of the proposed application in achieving better performance providing service to municipal authorities and citizens.

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