Transportation ecosystem framework in Fog to Cloud environment

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***Abstract*—Traffic congestion and accidents cause cities to be the principal source of pollutant emissions. The TIMON project initiative aims at providing Real-Time (RT) information and cloud-based services through an open web-based platform and a mobile application to the main actors: drivers, vulnerable road users and businesses. TIMON establishes a cooperative ecosystem to connect people, vehicles, infrastructure and business and contributes to intelligent transport, IoT and Cloud computing. In the first part, this paper provides an overview of TIMON and how it contributes to increasing safety and reducing congestion and emissions. The TIMON ecosystem represents the perfect use case of distributed technologies, as it collects data from IoT sensors, open and closed data sources and user engagement data, processes it and provides useful information not only for road users, but also for scientists and technicians who need real systems to study the data, infrastructure and IT safety management. In the second part, the Cloud deployment of the TIMON system is described in detail and a new, more distributed design is proposed to exploit the potential of current emerging technologies of Fog and Edge computing.**

***Index Terms*—Real Time services, Real Time information, Cloud Computing, Traffic Congestion, Hybrid Networks, Cooperative Positioning, Fog computing, Fog to Cloud, Edge computing.**

I. Introduction

The excessive number of vehicles active in urban environments causes cities to be the principal source of CO_2 and other pollutant emissions. The problem of traffic congestion is responsible for 40 % of CO_2 emissions and for 70% of other types of emissions [1]. Moreover, given that the human factor is predominant in traffic accidents, there is an increasing need to intelligently assist drivers since traffic accidents are one of the main causes of congestion, increases in travel times and air pollution.

Road operators and transport companies are realizing the amount of information Internet of things (IoT) devices can generate that can be used to gain an insight into and provide more intelligent systems to manage traffic. This, on the other hand, means that huge amounts of disorganized and heterogeneous data exists, where a powerful system is needed to collect, harmonise and make derived information useful for future intelligent transport systems (ITS).

Other solutions such as [2], [3] or [4], proposed traffic assistant tools to achieve more efficient transportation systems by increasing the accurate scheduling of sensing cycles, providing faster reactions; or a collaborative transport solution to decrease pollution emissions or increase routing efficiency. These solutions, however, do not take into account both drivers and Vulnerable Road Users (VRUs), or safety with multi-modal routing services.

This paper presents the TIMON project[1], a research and innovation project supported by the European Union's Horizon 2020 programme. TIMON collects data from different data sources such as IoT sensors from road infrastructure, open data, on-board units (OBUs) installed in cars and from smartphones carried by pedestrians and cyclists. All this data is harmonised, stored and processed using several key enabling technologies: hybrid vehicular communications, artificial intelligence for traffic congestion prediction, and cooperative positioning techniques. After processing the data, it becomes enriched information that can be served using an open platform and a mobile application to provide real-time (RT) services to the main users in the transport ecosystem: drivers, VRUs, traffic authorities and businesses.

Overall the TIMON initiative contributes to increase safety as a result of the Real-Time (RT) alerts for drivers and the VRU assistance; offers efficient and cost-effective solutions for reducing congestion; provides alternative options to drivers in case of traffic disruptions and cuts down on greenhouse gas (GHG) and other pollutant emissions. It also presents a perfect use case of the distributed technologies as it collects data from IoT sensors, open and closed data sources and user engagement data, processes it and provides useful information for road users, scientists and technicians who need real systems to study the data, infrastructure and information technology (IT) safety management.

The objective of this paper is to present the current technology components which power the TIMON infrastructure and evaluate their readiness to be deployed on future emerging technologies including Edge and Fog computing. The reason for this is that at the beginning of the TIMON initiative, only Cloud technology was mature enough to sufficiently

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[1]https://www.timon-project.eu

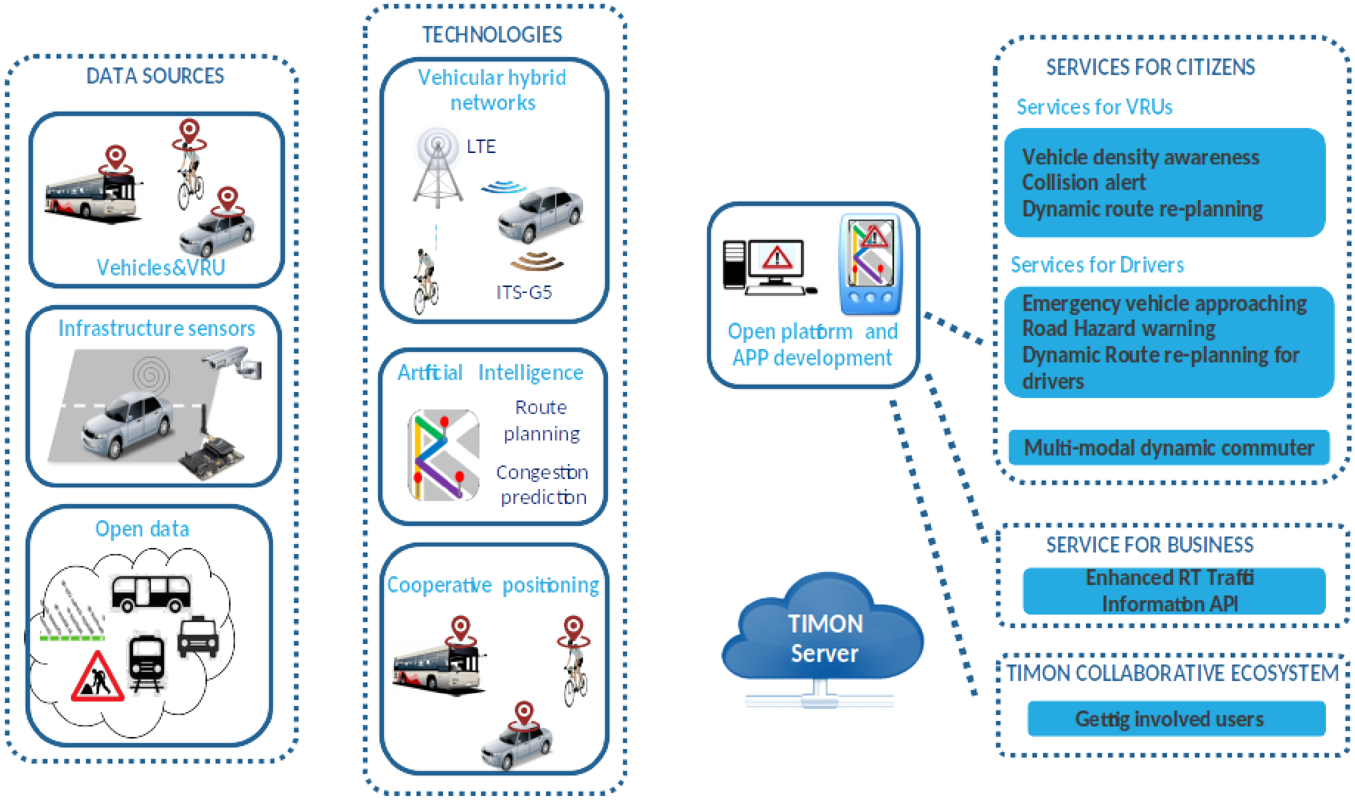

Fig. 1. The TIMON project conceptual diagram

cover the needs of the demands provided by the massive data flows generated by IoT, open data and closed public authority resources. Currently, Edge and Fog providers are presenting their full potential and first implementations are ready to deploy and use. One of them is mF2C[2] [26], [27]

The paper is structured as follows: in Section 2, the main concept of the TIMON project, the main subsystems and the services are presented. Section 3 presents the TIMON cloud deployment which manages all components presented in Section 2. Section 4 provides the mapping of TIMON components to a new Fog-ready environment and proposes a new architecture design. Finally, Section 5 contains the conclusions of our work.

II. Overview of the TIMON Project

The TIMON project provides a layer of services to the main road users: drivers, VRUs, traffic authorities and businesses through a mobile application and an open platform. The TIMON project considers vehicles and VRUs as sensors that provide data to the system and return useful information to those drivers and VRUs. This becomes a collaborative cycle, known as a collaborative ecosystem that will help to improve safety, sustainability, flexibility and efficiency of road transport.

A data flow schema of the TIMON system is shown in Figure 1. Data is acquired from different data sources such as vehicles and VRUs, IoT sensors and open data. Part of this data is collected using hybrid vehicular communications and processed using artificial intelligence and cooperative positioning techniques to produce certain derived information. All of these technologies will be managed by and communicate with a cloud infrastructure. The derived information produced by these techniques is later used by the open platform and the mobile application, providing services for drivers, VRUs and businesses.

A. TIMON key enabling technologies

- Artificial intelligence for traffic congestion prediction [6] aims to predict future states of the traffic at specified time horizons. An algorithm used to working with imbalanced data, provides traffic congestion predictions on four time horizons: 15, 30, 45 and 60 minutes.
- Enhanced positioning module [7] composed of a standalone Global Navigation Satellite Systems (GNSS) and an Inertial Measurement Unit (IMU). Using sensor fusion techniques an accurate positioning system, especially in urban canyon environments, is proposed.
- Hybrid vehicular communications modules [8] provide reliable communication using an ITS-G5 and LTE capable hybrid communication system capable low latency communication. Hybrid communications are used, in this case, for enabling communication between vehicles and VRUs, communicating vehicular network context to the TIMON cloud for traffic analysis.

[2]http://www.mf2c-project.eu/

B. TIMON Services

TIMON provides a total of 9 services through a mobile application connected to a cloud infrastructure that manages all the processes of this solution and provides requested information. These services are classified according to their main road user beneficiary on services for VRUs, for drivers and other services:

1) Services for Vulnerable Road Users (VRUs). Three services can be classified under this category:
   - Vehicle density awareness. This service provides VRUs with an informative map showing the traffic density and average speed, the traffic flow for different types of vehicles and the risk of traffic congestion.
   - Collision alert. This service provides VRUs and drivers with a complete overview of the surrounding users (drivers and VRUs).
   - Dynamic Route Re-planning for Cyclists. This service consists of a route planner that considers cycling lanes, roads with low traffic rates, road inclination, etc. The re-planning of the routes is based on events that alter the initial conditions assumed for the route (e.g. accidents, increased vehicle density, etc.).
2) Services for drivers. These services provide RT alerts to increase safety and to decrease the emissions of the vehicles:
   - Emergency Vehicle Approaching. This service generates warnings for all the road users that are in the proximity of an emergency vehicle.
   - Road Hazard Warning. This service informs users about risky situations that might appear on the road. Figure 2 shows an example where such situations are shown to the user (white arrow) when they are nearby.
   - Dynamic Route Re-planning for Drivers. This service is analogous to the one described for cyclists but adapted to the particularities of the drivers.
3) Other services. These are general purpose services oriented to pedestrians or businesses:
   - The Multimodal Dynamic Commuter Service computes and suggests the most optimal transport route using RT data and by re-planning the route in case of a delay, accident, or an unexpected meteorological phenomenon.
   - The Enhanced RT Traffic Information API service provides information related to traffic density and highly accurate predictions of traffic congestion, information on road closures, etc.
   - The Collaborative Ecosystem service sets up a community of users prone to share their experience using gamification techniques that incentivise data sharing and good practices on the road.

III. The current TIMON deployment

The TIMON idea is instantiated in the TIMON Cloud which provides the infrastructure and the automation of deployment. All services live and communicate in an isolated virtual private network and the crucial services are published as public services when this is required. The collection of data from the open and closed data sources (including IoT sensors), the users (OBUs and smartphones) data and the processing of that information using the key enabling technologies is managed by this cloud.

The TIMON Cloud consists of four basic logical components:

- IaaS: the Infrastructure as a Service (IaaS) provider and its management component.
- Automation: the orchestration component for deploying and configuring services.
- Monitoring and notifying: collecting and processing historical data of servers and services and alerting.
- Access control management: the central access manager controlling the access to service APIs with ability to issue individual access tokens for any subset of services.

These main for components will be further described in detail.

A. IaaS

Most of the services require compute and storage resources that are provided through the IaaS concept. IaaS is provided through OpenStack [9] that is installed over the KVM [10] hypervisor. Smaller services that require less powerful environments than a virtual machine (VM) use Docker [11] images. On top of OpenStack a cloud management software, ManageIQ [12], is deployed to provide enterprise level deploying and monitoring resources. One crucial additional functionality is monitoring resources based on tags which provides the basis for billing and forecasting the resource usage. The TIMON network is logically divided into a management subnet comprising the cloud management and automation tools, and to the TIMON services subnet. This approach creates appropriate security levels and limits the possibility of system breaches.

B. Automation

The real power of the cloud is in its automation component. OpenStack Orchestration is achieved through Heat [13] templates while the whole system automation deployment is done by Ansible [14] with the lifecycle presented on Figure 3. Each service has its own Ansible role describing all dependencies required for installation. The deployment cycle is initiated by the developer pushing the code into its GitLab repository. After that, a hook is triggered making Ansible retrieve the code from GitLab and start the first round of instantiating the service host (VM or Docker) on the TIMON infrastructure. When this step is finished, Ansible is notified to start the finalisation of the deployment. This last step includes the installation of the TIMON service and its dependencies and also publishing of the service into the VPN (OpenVPN [15]), DNS (Bind9 [16], Consul [17]) and monitoring services. Beside the manual execution of Ansible playbooks and GitLab webhooks [18],

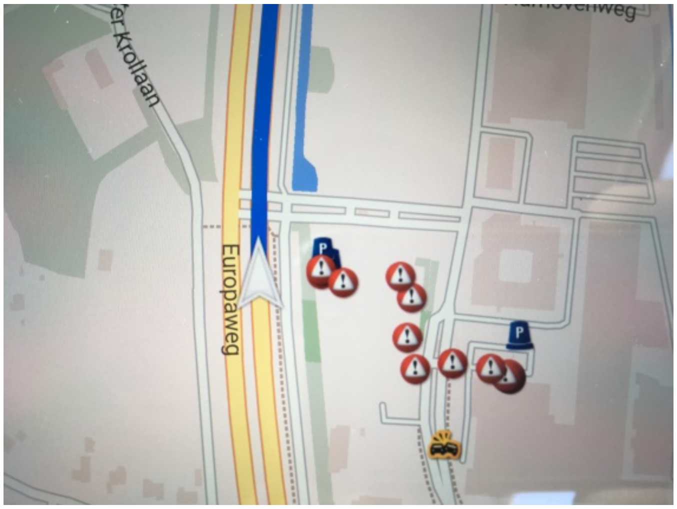

Fig. 2. Visualization of several road events on TIMON APP.

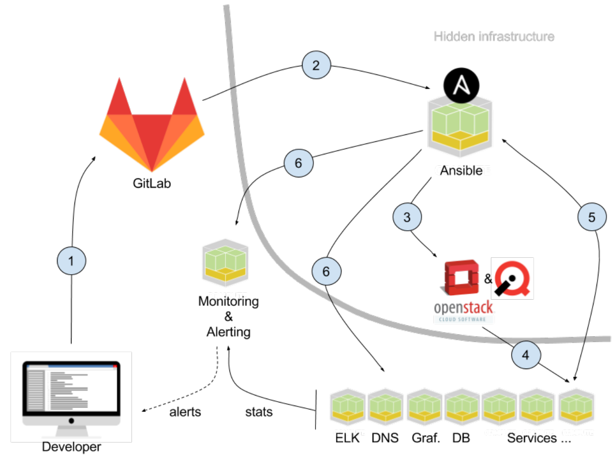

Fig. 3. Lifecycle of the deployment using Ansible.

most of the automation tasks are controlled by the open-source base for Ansible Tower named Ansible AWX [19]. For sophisticated tasks on Docker images and containers, Portainer [20] is used. This also provides easy to use graphical user interfaces for managing nodes and containers.

C. Monitoring and notification

Service lifecycle and cloud health are monitored by a set of tools. Ansible sets up monitoring on each virtual machine to collect metrics, while in case of Docker, a combination of Prometheus [21] and cAdvisor [22] is used to monitor containers. The service vitals (CPU, RAM, load, etc.) over a longer time period are visually presented with Grafana [23] with the status view of entire cluster. Some of the open data and the frequency of collected data from the TIMON services as traffic density, car tracks, weather data and similar, can be visually reviewed using Kibana [24]. The mapping between services, nodes and DNS entries is monitored through Consul [17], which monitors the latencies between the services and removes the a services backend provider if the service appears to have developed a fault. This precaution as a safety feature prevents users or attackers from seeing error pages when the service is down.

D. Access control management

Access to TIMON services can be given to external users by using the proprietary TIMON API Key Management service. The service is a proxy for all API calls and provides time-limited tokens to access internal TIMON Cloud services or data. Administrators of services have fine-grained access control over the access to all API endpoints in the TIMON Cloud. Users with the token can access any TIMON service from the internet. The API Key Management component also collects and logs all API calls to the TIMON services and provides a valuable rate limiting and monitoring to have an insight into the health of the cloud or to debug strange behaviour such as service malfunction or security attacks.

IV. Proposed Fog to Cloud Design

The current state of the TIMON deployment as presented in the previous section is centered on only the IoT and Cloud layers. As the ITS field demands fast and reliable responses between distributed traffic users, digital applications should be prepared for the Fog and Cloud environment. To make a more concrete step towards the introduction of the Fog layer in the TIMON ecosystem, we prepared a Fog to Cloud design for the TIMON deployment. This section will present the service mapping to the Fog to Cloud environment.

For the target reference architecture mF2C [26] was chosen over the OpenFog [25] consortium reference architecture for two specific reasons: first is that both the TIMON ecosystem and the mF2C platform are concrete implementations of concepts and components which makes mapping easier due to better understanding of what each component is made for. In the case of the OpenFog architecture, everything is on a more conceptual level. The second argument is that the OpenFog architecture already assumes quite powerful Fog nodes on the whole stack of deployment, which currently is not the case in the TIMON project, where road side units (RSU) and OBUs would be more or less viewed as very powerful IoT devices instead of Fog nodes as proposed by the OpenFog consortium.

The architecture of the mF2C platform is presented in Figure 4 which shows the hierarchal relationship among Cloud and Fog nodes that together back the devices of the Internet of Things. Each mF2C node can act as an mF2C agent providing the core mF2C functionalities to the applications developed for the mF2C platform.

Each mF2C agent covers functionalities from the following six components:

- **Service Orchestration**, including the SLA manager, Landscaper and Recommender for locating appropriate resources to orchestrate services, and the service lifecycle manager.

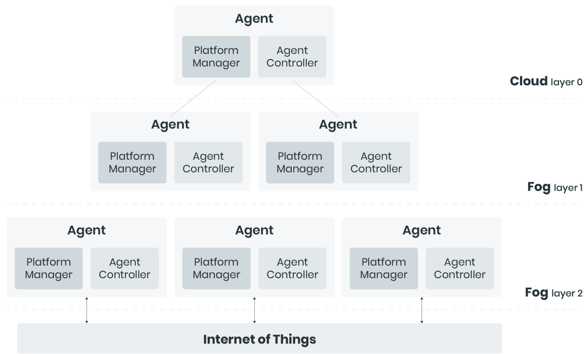

Fig. 4. The mF2C architecture for the first half of the project.

- **Distributed Execution Runtime**, including the Task manager, task scheduler and data manager. This component is specialised for executing (parallel) jobs required by mF2C applications.
- **Telemetry monitoring** is the component that focuses on intelligent hardware monitoring and analyzing such resources.
- **Resource manager**, including a set of sub-services for discovery, identification, categorisation of resources and maintaining them, e.g., monitoring, policies and data management.
- **Service Manager** is an advanced component encapsulating all service metadata including the categorisation, allocation, Quality of service, mapping, etc.
- **User management**, including sub services such as profiling and sharing model.

This key components are available for mF2C application on each agent in the Fog and Cloud segments of the mF2C platform. Platform users use the functionalities in their own applications and the mF2C platform takes care of the optimal deployment and execution.

From the TIMON perspective the mF2C architecture is a good improvement of the infrastructure design. Firstly, the Fog layer would offload some work from the cloud and speed up the transfer of messages in distributed areas. Secondly, developers could exploit mF2C components to take care of service orchestration, resource management and other supportive services.

Table I presents one of the designs unveiling the potential mapping of TIMON services to the mF2C components in a way the would be most beneficial for running or expanding the functionalities from TIMON ecosystem. As the table depicts, in a TIMON Fog design some technical components would be deprecated due to a new mF2C component would take over its functionality, while others would be managed by an mF2C component and some existing components would be improved by or merged with the mF2C component to get the best outcome. In particular, Service Orchestration from mF2C would take care of the majority of the work that is currently done by Ansible and would manage all core components that are managed by TIMON's cloud infrastructure manager. The distributed execution runtime would improve the functionality of services making predictions or planning due to the possibility of offloading and parallelising compute-intensive jobs. The telemetry monitoring component would expand the overview TIMON monitoring services are providing while the Resource Manager would keep resources under control making the TIMON Cloud IaaS component deprecated. The mF2C Service Manager would take over the service catalogues that are managed by ManageIQ and Ansible AWX and the User Management component would make deprecate old and introduce improvements in user management components.

TABLE I
MAPPING OF TIMON TO MF2C ARCHITECTURE COMPONENTS.

mF2C Component	TIMON Component	Status
Service Orchestration	Ansible	deprecated
	Consul	deprecated
	GeoMQTT	managed
	GeoMessagingServer	managed
	Traffic prediction	managed
	Multimodal Traffic Planner	managed
	Traffic Density API	managed
	MQTT Data Collector	managed
	GeoServer	managed
	Databases (PgSQL, PostGIS, ES)	managed
	Backup service	managed
	Datacloud API	managed
	Open/Closed-source data API	managed
	API Key Manager	managed
Distributed Execution Runtime	Traffic prediction	improved
	Multimodal Traffic Planner	improved
	Traffic Density API	improved
	GeoServer	improved
Telemetry Monitoring	Grafana, Kibana	merged
	Graphite, Prometheus	merged
Resource Manager	TIMON Cloud Infrastructure manager	deprecated
Service Manager	ManageIQ	deprecated
	Ansible AWX	deprecated
User Management	LDAP	deprecated
	TIMON Open Platform	improved

The most interesting functionality required by TIMON and offered by mF2C is the possibility of deploying and runing services in heterogeneous environments, combining Cloud and Fog resources. In this way, most of the messaging services—e.g. GeoMQTT, GeoMessagingServer—can run in a distributed fashion, which would improve the latencies on the Edge of the network. Similarly, the one time calculations, such as multi-modal route planning, could be offloaded to the Fog and calculated near the user when resources are available. This distributed computing approach would make TIMON more mature and resilient to the fluctuations in network conditions while providing higher availability to the end user.

V. CONCLUSIONS

This paper presents an overview of the TIMON project, how it is managed using a cloud infrastructure and how a fog deployment should be designed. TIMON provides real-time information and services through a mobile application to the main road users: drivers, VRUs, and businesses. A cooperative ecosystem is established where all these agents are connected, contributing to increased safety due to the real-time alerts and the VRU assistance; improving transport efficiency by offering efficient and cost-effective solutions for reducing congestion; increasing flexibility by providing alternative options to drivers in case of traffic disruptions; and increasing sustainability by cutting down on greenhouse gases and other pollutant emissions.

As presented with the mapping from the Cloud to Fog infrastructure, the TIMON ecosystem presents the perfect use case for the coming of distributed technologies as it supports systems with huge volumes of data and near real-time alerts and notifications. The current system is collecting data from open-source and closed data sources, infrastructure IoT sensors and user engagement data. This data is processed by prediction algorithms and geospatial systems to provide a valuable data-fusion system with practical use for all road users and for scientists and technicians who need real systems to study data, infrastructure and IT safety management.

Up until now, the TIMON project focused in multiple research areas, most notably in intelligent transport, IoT and Cloud computing. In this paper we also indicated the possibility of extending the research towards new emerging technologies such as Fog Computing and support our statement with an example mapping of TIMON services onto the Fog-to-Cloud platform.

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