Enabling Cyber-Physical Systems for 5G networking: A case study on the Automotive Vertical domain

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ABSTRACT

5G is the next generation networking infrastructure with a strong focus on requirements of various vertical domains. 5G brings improvements on networking performance but also introduces new services for deploying software involving networking aspects in an end-to-end manner from the edge to the cloud, affecting the way we will deploy software. One of the most promising verticals is the Automotive Vertical, where 5G will bring characteristics such as low delays and high bandwidth, enabling complex V2X scenarios. This paper reports experiments made using a popular 5G technology, called NFV Management and Orchestration platform, the Open Source MANO (OSM), by remotely placing Virtual Network Functions to Vehicles containing a smart Edge Device for: i) remotely monitoring through the OBD-II interface and ii) video streaming between V2V for assisted overtaking. The described process can be applied to other types of systems containing a smart Edge Device, enabling them as networking resources of future 5G network deployments, demonstrating how future CPSs could be engineered and benefit from emerging 5G services*

CCS CONCEPTS

• **Networks** → Network services • **Networks** → Network types → Cyber-physical networks • **Software and its engineering** → Software organization and properties → Software system structures

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KEYWORDS

5G Networking for CPS, NFV MANO, Vehicle monitoring, V2V

1 INTRODUCTION: 5G and CPSs

The 5G system has the ambition of responding to the widest range of services and applications in the history of mobile and wireless communications categorized in (i) enhanced mobile broadband (eMBB), (ii) ultra-reliable and low-latency communications (URLLC) and (iii) massive machine-type communications (mMTC). Thus, 5G technology aims to provide a flexible platform enabling new business cases and models integrating vertical industries, such as, automotive, manufacturing, energy, eHealth, and entertainment. On this basis, network slicing emerges as a promising future-proof framework adhering to the technological and business needs of different industries. To achieve this goal, network slicing needs to be designed from an end-to-end perspective, spanning over different technology domains (e.g., core, transport and access networks) and administrative domains (e.g., different mobile network operators) including the management and orchestration (MANO) functions. [1]

Cyber-physical systems (CPS), eventually will depend on the availability of technologies, like 5G will offer, to interact with the physical world as well as process and communicate information between the distributed elements of such a system like a Cloud, an IoT or V2X infrastructure in an end-to-end fashion [2]. It is evident that 5G will allow to coordinate physical as well as organizational processes on a local as well as global scale as it is already required from the Cyber-physical European Roadmap & Strategy -- Research Agenda and Recommendations for Action. [3].

5G service solutions build a lot on top of Virtualization and Cloud technologies as well as the concept called Network functions virtualization (NFV) which extends the idea of server virtualization to network devices meant to perform specific functions in the network. With NFV, the network designs and architecture can adapt the same ways as IT virtualization (through reprovisioning, moving, or reconnecting the impacted services). This virtualisation insulates the Network Functions from those resources through a virtualisation layer. The decoupling exposes a new set of entities, the **Virtualised Network Functions (VNFs),** and a new set of relationships between them and the NFV Infrastructure (NFVI). VNFs can be chained with other VNFs and/or Physical Network Functions (PNFs) to realize **a Network Service (NS)** for an end-to-end solution**.** The 5G emerged services defined a reference architecture of MANO which has been standardized by the European Telecommunications Standards Institute (ETSI), thus it will be a standard way of how telecommunication providers will deploy Virtual Functions to offer solutions to various verticals.

In this work we present how we experiment with solutions that 5G offers on the service deployment and flexibility. We describe case studies on how these concepts where adapted to the Automotive vertical domain and in fact we show how future CPSs could benefit from such solutions to easily join 5G networks in end-to-end solutions.

We used the Open Source MANO (OSM) [4] an Open Source Solution that is developed by many industrial and research organizations to promote the flexibility of 5G. Moreover, we combined both Virtualization technologies: Hypervisor and Container based (Docker). There are many reasons, among others, we believe that especially container technology will be key to deploy services for CPSs, especially on the low constraint devices:

1) Low resource requirements
2) Rapidly deploy applications to multiple remote devices
3) Low latency
4) Established provisioning and management tools

2 THE SCENARIOS

2.1 The Vehicle Remote Monitoring Scenario

Modern vehicles contain nowadays adequate computing capacity to perform complex processing. Even powerful processors and architectures used at gaming graphics cards are used within a car to perform AI functionality. In future, on-board units (OBUs) will evolve from specific purpose units designed for services such as speed control, to generic networked nodes, like a network router, providing the ability to connect more devices. Therefore, it is expected that OBUs will maintain connectivity with the infrastructure using wireless interfaces and it is expected that future OBUs will be possibly provided by the vehicle manufacturer as modern connectivity means. Our case assumes that the On-Board Unit (OBU) of the vehicle has some (limited though) capacity (computing/memory) to host and execute container technology such as Docker. Such an OBU is what is also called nowadays in 5G a Mobile Edge Computing device (MEC). This MEC internally will contain a south interface for communicating and retrieving vehicle data through the OBD2 interface, while in the north interface will offer a 5G New Radio interface. Container technology will allow us to deploy services in a secure way and easily configure them with the OBU services like an OBD API service, a GPS, etc.

The north interface of this Automotive MEC offers connectivity from the car to external service providers (e.g. a Mobile network operator) but is also configured and enabled to remotely be provisioned by the operator 5G services.

For the above scenario, which Figure 1 displays, it is needed to create and establish a communication path between the vehicle and the operators cloud, to retrieve monitoring data from the vehicle and store them to services (e.g. an Elasticsearch cluster) located at the operator’s premises. Since this provisioning scenarios are expected to be common cases in future they need to be orchestrated and provisioned by modern 5G service software stacks, like a MANO, to offer flexibility and easy integration with the rest of the operator’s 5G infrastructure. Ideally, the operator from the BSS/OSS (operations support system/business support system) side should create a so-called Network Service Descriptor (NSD), containing Virtual Network Functions(VNFs) that the MANO will automatically deploy to the Vehicle MEC any intermediate components (e.g. fronthaul/backhaul units) until the cloud, thus offering a flexible end-to-end 5G connectivity. That is there should be in place an established control path connection that allows the vehicle MEC to be remotely controlled and provisioned and a data path that is used (by deployed VNFs) while in operation to monitor and store vehicle’s data in the cloud. Section 3 presents how this is implemented with VNF and NSD provisioned through OSM.

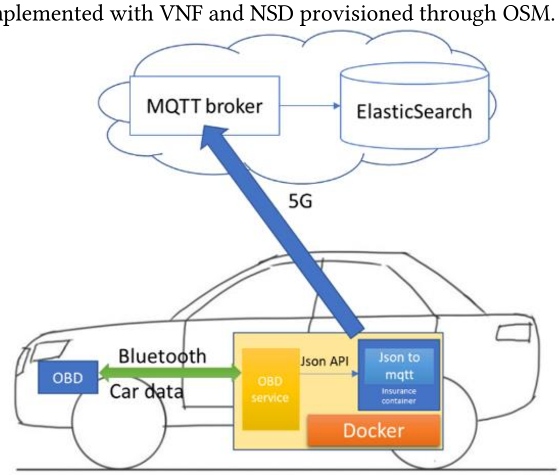

Figure 1 The Vehicle Monitoring scenario over a 5G service deployment

2.2 The Assisted Overtaking Scenario

The architecture of the video camera-based scenario for car overtaking is presented in Figure 2. Each vehicle contains an OBU that provides the communication between vehicles and between each vehicle and the infrastructure. The OBU also connects to an Android device, smartphone, through WiFi, that provides visual information for the driver. The vehicle contains a video camera on its front side. This information will be used by the driver to take decisions on driving, and more specifically on overtaking. In this 5G supported architecture, two VNFs are developed: video transcoding and cellular gateway VNFs. The multi-technology communications support is explored on several experimental situations.

In the first one, the video is streamed from the front vehicle to the rear vehicle through vehicle to vehicle communications, using IEEE 802.11p communication. The OBU in the car receives the video stream and sends it to the visual screen in the car, so that the driver can have real-time access to the visual information of the vehicle. This situation requires the VNF video transcoding to be implemented in the cars, since the video transmission is performed horizontally between the vehicles.

In the second one, the front and rear cars are in range of road side units (RSUs), and the video is streamed to the VNF video transcoding at the edge through the RSUs to reach the rear car.

Finally, cars and RSUs are not in the range of each other, and the video is streamed to the VNF video transcoding at the edge of the network using 4G/5G network to communicate between the cars and the edge network. The 4G/5G network is made available through a VNF Gateway. In this case it is possible to use the VNF video transcoding from the front car to the rear car by traversing the Cloud-Ran at the edge of the infrastructure.

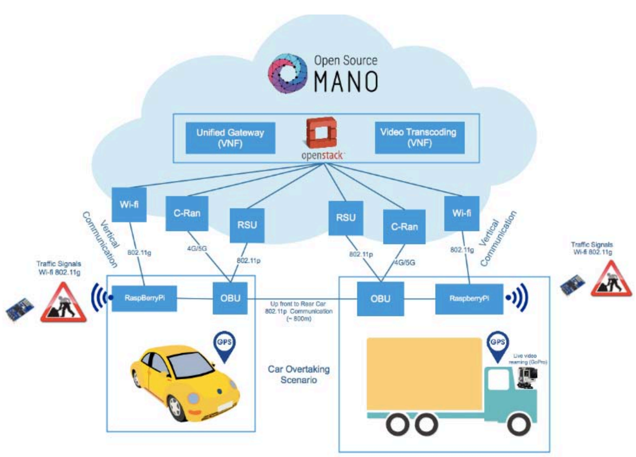

Figure 2 Architecture for Overtaking scenario

3 IMPLEMENTATION DETAILS & PROVISIONING

Since our goal in this experiment is to study and implement the orchestration and deployment of such services over emerging 5G software technologies like a MANO, the main components used was our cloud infrastructure called CloudVille [5] and a BeagleBone Black Wireless used as a smart edge device (see Figure 3). Furthermore, the MANO part of the CloudVille laboratory includes servers connected by 1Gbps Ethernet cards. The MANO stack is provided using OSM for the service and network orchestration and OpenStack for the virtual infrastructure management. The different elements of the test-bed can be flexibly interconnected with a pool of low-power single board computers (BeagleBone Wireless), with Ethernet and WiFi network cards, which can be configured to deploy diverse network functionalities, such as OpenFlow switches, wireless routers, WiFi access points, firewalls or load balancers.

BeagleBone Black Wireless (BBW) offers both a WiFi and a Bluetooth interface, 512Mb of RAM and 4GB storage, while it has enough processing power to host Docker. We configured BBW as Nova Host for Docker [6] to be visible as a computing node by our Cloud. Also, in the BBW we created a (Physical Network Function - PNF) called ***OBD service-PNF*** that connects via Bluetooth to an OBD/Bluetooth device that is connected to the OBD interface of our vehicle. This OBD service is deployed as a container and offers a simple RESTful API HTTP service to GET OBD data via a JSON format. This API is exposed by the container thus it can be used by any other container deployed in the BBW. In our experiments for the control plane connectivity and due to the lack of an available 5G new radio cell, in terms of connectivity, we fallback to BBW WiFi but also to 4G USB dongles, since our goal is to examine service flexibility. The BBW joins remotely our CloudVille via an Access Point connected to the CloudVille OpenStack network (see Figure 3). Next thing is to create the container image to be deployed at the edge BBW device. Our ***OBD monitoring service-VNF*** contains a small java application that will get data from the on-board ***OBD service-PNF*** that reads vehicle data and offers them to the container environment.

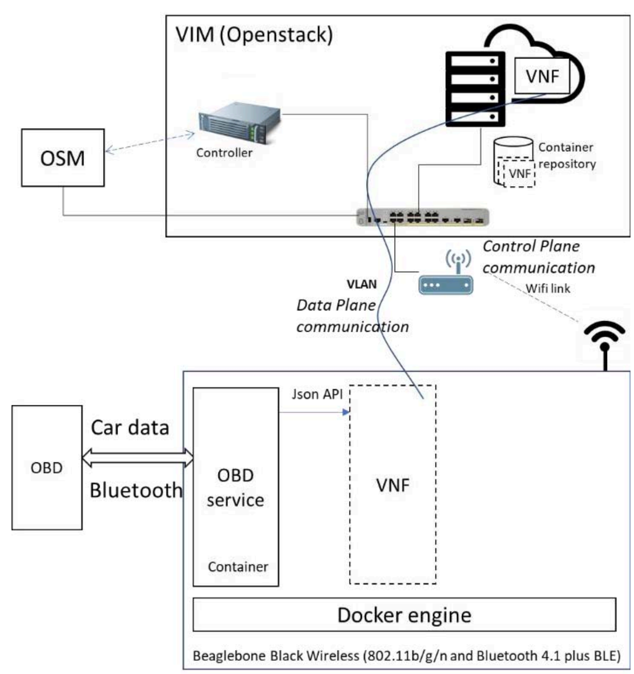

Figure 3 Remote VNF Service orchestration/deployment and operation

In video-based car-overtaking scenario (Figure 2), the front car transmits live video streaming using a Go Pro camera (Hero 4) through MPEG-TS original format. The Go Pro camera is connected through Wi-Fi to the Raspberry Pi, which acts as video capture card connected in the front vehicle OBU. The OBU front vehicle then sends the original video to the VNF video transcoding at the edge of the infrastructure. After the VNF transcoding process, the rear vehicle OBU receives the transcoded video reproduced at the device assisting the driver on car overtaking situations.

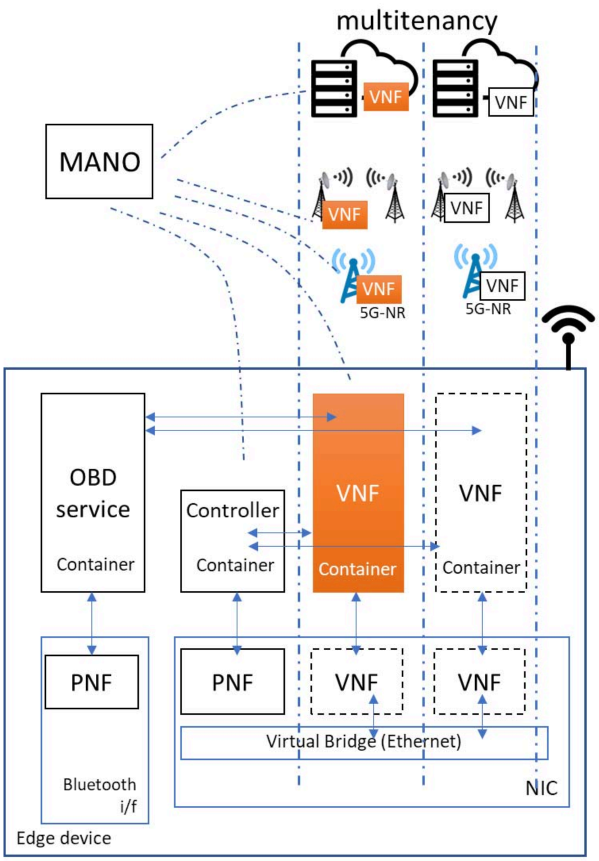

Figure 4 Enabling mutli-tenancy in CPSs

3 RESULTS AND DISCUSSION

The presented use cases, although focused on the automotive domain, provide the potential on how 5G technologies can benefit CPSs. The work also presents aspects regarding the design of future software that will be deployed on such architectures and how networking is now part of the deployment process. This will be better coupled in future with DevOps processes when there is a need to deploy an end-to-end solution from the physical device at the edge towards the cloud.

This flexibility of 5G deployment services can be easily expanded and scale when you must manage for example a fleet of vehicles and demonstrates ways of how one can manage e.g. remote updates of software running on vehicles. Using these emerging 5G technologies one enables edge devices of physical systems to participate to end-to-end slicing or even deploy multi-tenant solutions, a concept displaying in Figure 4. For example running on a vehicle MEC device VNFs from two operators: One from an insurance company connected to their private cloud through a 4G network and one from the Vehicle Manufacturer connected to their telco cloud through another 4G network, while these are isolated but easily reconfigurable, through a 5G MANO solution. An Edge device as Figure 4 displays (like the used BeagleBone Wireless) will offer some PNFs (Physical Network Functions- e.g. connectivity) that will be easily orchestrated (by MANO and Container controller) to create in the device not only the virtual services but most importantly the necessary networking. Towards these directions is a newly developed promising technology, the OpenStack project ZUN [7] that integrates OpenStack with container technology.

ACKNOWLEDGMENTS

Available source code for our works can be found at project open source repository at github [8]
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