MEC Empowered Internet of Vehicles for Smart City Optimisations

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***Abstract*—With the growth of data driven services, vehicles are moving one step beyond their connected nature by becoming an intelligent part of the Internet of Things ecosystem. The concept of Internet of Vehicles (IoV) stems from this development describing the network of humans, vehicles and things as a means of achieving an intelligent urban infrastructure. With the next-generation communication technologies promise of providing ultra low latencies, one of the major obstacles in achieving highly-performing smart city is the distribution of computing power where the vehicles computing power is no longer sufficient for the increasing multimedia based services and the cloud introducing unacceptable latency for real time scenarios. As multi-access edge computing (MEC) can be employed to overcome these issues by co-locating additional computing power with the communication access points, the main goal of this paper is to investigate the performances of this complex MEC empowered IoV ecosystem to support the development of smart cities. Our analysis shows that large scale urban scenarios can be created to simulate all relevant aspects of the ecosystem as a whole, but more work is needed in optimising the underlying technologies and their performances.**

***Index Terms*—internet of vehicles, multi-access edge computing, smart cities simulation**

I. Introduction

The integration of smart devices connected to the Internet and the creation of the Internet of Things (IoT) ecosystem has been rapidly changing the landscape of everyday life and whole industry sectors in the last years [1]. The IoT ecosystem today covers a vast range of diverse interconnected devices that gather and share different types of data using their integrated sensors. Starting from small data sources such as temperature measurements, the IoT device characteristics in terms of capability have grown lately and are moving towards larger data streams and wider bandwidths. The multimedia oriented IoT [2] is now changing the traditional IoT landscape by demanding acquisition and communication of multimedia traffic in many real-world applications such as smart homes and smart cities, surveillance and monitoring systems, as well as emergency response systems, traffic monitoring and rescue vehicles.

In the area of smart transportation and vehicles, the concept of using data gathered from sensors to learn more about the vehicle status, and its relationship to other vehicles as well as roadside elements, such as road signs, traffic lights, etc. has initially been introduced into the so-called connected cars. The idea of connected cars is to enable all transportation devices to continuously share data, enabling them to gather important safety and mobility information [3]. In this way, dynamic networks of vehicles and transportation infrastructure are being built allowing for the exchange of information to flow between vehicles (vehicle to vehicle - V2V) or between the vehicle and the infrastructure element (V2I). Both types of communication may be present when building the Vehicular Ad Hoc Network (VANET) which enable the data exchange outside the vehicle.

With the growing number of smart sensors in today's vehicles, as well as the connections made between the car system and the passengers' smart devices, the vehicles become a focal point for IoT data acquisition and fusion [4]. Herein, the central vehicle smart system becomes the central point for the intra-vehicle network. Via the VANET networking possibilities, the communication transforms to vehicle to everything (V2X) and incorporates lots of different types of data that is being gathered and exchanged, from sporadic events reported by sensors, to full blown real-time multimedia traffic managed by the vehicle infotainment system.

This versatile connectivity to everything has evolved the traditional VANET environment with the possibility for building complex communication patterns around the vehicle introduces the concept of Internet of Vehicles (IoV) [5] wherein the vehicle has augmented communication and computation capabilities and enables the creation of a complex ecosystem interconnecting things, humans and vehicles. Another enhancement in addition to the interconnection is the augmented intelligence capabilities of the vehicles in the IoV, or, in other words, using artificial intelligence and machine learning that will enable the support of services leading to smart transportation and smart cities such as the optimised management and real time incidence of urban vehicular traffic.

One of the steps towards the creation of IoV is the integration of vehicular communication technologies with 5G enabled IoT technologies by using 5G as an enabler for vehicle to infrastructure communication mode [6]. In this way, the IoV can take advantage of ultra low latency offered by the 5G network ($<$ 1ms) to handle real-time services, but also expand the service portfolio with a growing variety of data hungry multimedia oriented services [7].

However, the intelligence aspect puts a lot of pressure on the already limited vehicle computing power. To support computing power demanding services that require deep learning or other machine learning implementations, it is essential that the IoV ecosystem extends into the multi-access edge computing (MEC) infrastructure [8]. By using the MEC infrastructure, the vehicles can offload their computing intensive tasks to nearby MEC servers located in the edge of the 5G network. In this way, the combined capabilities of 5G together with MEC will enable the creation of an IoV ecosystem where the vehicles will have access to both high bandwidth, low latency network for interconnecting with everything, and extra computing power for running demanding services.

Thus, when investigating the performances of an IoV/IoT environment in smart cities aiming to overcome traffic congestion, or provide intelligent transportation services and alike it is necessary to analyse the IoV immersed in a 5G-MEC scenario with the vehicles using V2X 5G communication. The main contributions of this paper can be summarised as:

- discuss the 5G-MEC architecture for the IoV,
- present the possibilities to build an IoV enabled smart city simulation scenarios using a combination of 5G and MEC infrastructure,
- analyse the relationship between the different 5G-MEC system components,
- provide an initial set of results analysis that can pave the way forward on creating large scale realistic simulation scenarios.

Our simulation results show that care must be taken to understand all actors in the IoV ecosystem in order to be able to jointly optimise the performances and build services that will reach the envisioned potential for the Internet of Vehicles.

The rest of the paper is structured as follows: section II discusses the 5G-MEC architecture for IoV, while in section III we describe how to build large scale complex scenarios for IoV enabled smart city simulations. In section IV, we show the obtained results for a use case scenario and we discuss the observed implications regarding the performances of the IoV services. Finally, section V concludes the paper and outlines the future work efforts.

II. 5G MEC Architecture for Internet of Vehicles

The evolution of the Internet of Vehicles is supported with the technological advancements and developments in the areas of communication and computation made with the rise of the Internet of Things. In essence, the rapid deployment of next generation wireless networks in the past years has lead to significantly improve the performances in terms of higher bandwidth, support for terminal mobility, decreased latency and seamless connectivity and setup. This is transforming the idea of setting up a dynamic ad hoc network between moving vehicles into the concept of seeing vehicles as mobile terminals that act as hubs for the on-board devices and exchange all necessary information about the environment via the wireless infrastructure network. In other words, IoV is transcending the concept of VANETs into a much larger network that brings together people, vehicles and things thus enabling services for smart cities or smart regions. In this context, IoV is defined as an open system comprised of multiple users, vehicles, things and networks that can be managed and controlled [5].

To be able to make such a system operational the two main aspects that need to be provided are connectivity and computing power, as they are the pillars on which the IoV system integration can be achieved and intelligent vehicles behaviour can be implemented. Thus, to be able to define a high-performing architecture for the implementation of smart city applications of the Internet of Vehicles, both of these aspects need to be carefully considered.

Regarding the connectivity aspect, the intra-vehicle networking can be implemented using wireless sensor network technologies for communication with the vehicle smart built-in sensors and actuators together with wireless personal area network technologies for connecting all in-vehicle devices to the vehicle communication hub system. However, the main issue for IoV is implementing a high performing wireless connectivity between the vehicle and the environment, i.e. the vehicle to anything - V2X communication. While attempts have been made to use 3G and 4G technologies as the network connectivity of choice for the communication between the vehicle and the environment (both for inter-vehicle VANET communication and vehicle to infrastructure V2I communication) the results have been received with mixed success as latency and bandwidth issues do not allow using the full potential of IoV [9]. However, with the rollout of the 5G mobile networking the encountered issues are expected to be addressed successfully, as this new generation specification for cellular networks defines ultra high performances regarding all aspects relevant for IoV: high data rates of up to 10Gbps, ultra low latency of up to 1ms, ultra wide bandwidth, support for a large number of devices, 100% coverage and ultra reliability [10]. The technical requirements for the implementation of different advanced vehicular use cases using 5G technologies have been analysed in [11] as well as by other bodies such as the 5G Automotive

Association (5GAA) that are aiming to take advantage of the opportunities for implementing novel V2X services [12]. As the 5G, and later on 6G, network is seen as the communication technology of choice for a wide variety of vertical markets and use cases with different service requirements that transcend vehicular environments and IoV while putting high demands in terms of use of multimedia services, the issue of separation, control and Quality of Service (QoS) must be efficiently solved in the 5G architecture. Software Defined Networks (SDN) and Network Function Virtualisation (NFV) are seen as the solution that will enable efficient control and management of the available 5G network resources ensuring optimal QoS for each provided service [13]. These technologies are the main enablers for the implementation of network slices that can be used to build application-aware networks for network-aware applications. This effectively means that the IoV services can exist in a separate slice that is defined with the specific IoV characteristics and requirements ensuring end-to-end continuous QoS levels. An example of this type of implementation of the V2X ecosystem can be found in [14].

Computing power is the second important aspect that is required for the successful implementation of IoV. The computing system integrated in next generation vehicles today does not provide enough computing power necessary to implement advanced intelligent services that are based on swarm intelligence and the application of artificial intelligence as the concept of IoV is elevate the vehicles intelligence and implement intelligent transportation systems in smart cities using cooperative cognitive intelligence. In essence, the IoV is expected to be one of the drivers for extending V2X with big data and artificial intelligence in the upcoming 6G systems [15]. As vehicular service applications have strict requirements when it comes to latency [12], the use of cloud providers for supplying the necessary additional computing power is not a viable option for the IoV. To ensure the requirements for low latency and implementation of real-time or near real-time smart vehicular services, the required computing power must be located as close to the vehicle as possible, i.e. on the edge of the network. Thus, the implementation of smart cities and intelligent vehicular systems is one of the recognised vertical markets for the rollout of Multi-access Edge Computing (MEC) services that are hosted on servers at the edge of the network [16]. Using MEC to augment the computing power of the vehicles in the IoV entails the reservation and use of virtualised computing entities that reside on physical servers, hosts, co-located next to the wireless network access point to which the vehicle is connected. Taking into account that the IoV is a highly dynamic system due to the constant mobility of the vehicles, to ensure that the provided MEC services are able to continuously augment the vehicle capabilities in real time, it is imperative that the MEC system management and orchestration implements the so-called follow me behaviour. With the follow me behaviour, the MEC service is continuously being migrated to the nearest available MEC server as the vehicle moves from one serving location to another, see Fig. 1. This migration is performed using a high speed optical network infrastructure that interconnects the clusters of servers placed on different locations in the edge of the network of the MEC service provider.

Fig. 1. 5G MEC architecture for the implementation of Internet of Vehicles.

Putting together these two aspects, the Internet of Vehicles and the V2X intelligent communication can be implemented by taking advantage of a 5G MEC ecosystem similarly to the massive Internet of Things scenarios [17]. As the combination of 5G and MEC is becoming an ever more widely adopted combination of technologies for the implementation of future IoV [18], the research body is turning towards solving the issues in this environment related to the implementation of IoV based smart cities [19]. Taking into account the specific scenarios and constraints for real life implementation of intelligent transportation systems there are still many open challenges that need to be addressed.

The implementation of smart city intelligent transportation systems requires high QoS guarantees in a dense, dynamically changing environment. The number of devices and vehicles in a typically urban scenario can easily reach a number of thousands of vehicles, particularly in peak hours and traffic jam situations. In addition, the mobility in smart cities scenarios must conform to the strict street layout and current traffic rules. On the other hand, most of the research done on the topic of 5G vehicular communication and MEC services management and resource optimisation is analysed for small scale scenarios (tens of vehicles), in relatively simple mobility and traffic conditions (multi-lane highway segments, one crossroad, etc.) such as [20] and [21]. Thus, it is of paramount importance to test the existing proposals for efficient task offloading and MEC resource optimisation in a highly mobile environment under realistic smart city conditions including increased vehicular density, expanded service area and complex layouts and traffic conditions. The results from this massive scale analysis can showcase the expected performances of the state-of-the-art approaches in the area of IoV implementation using 5G MEC, but also point out any weaknesses or problems that need to be overcome in order to be able to work towards the real life implementation of intelligent transportation systems for smart cities. For these purposes, in the next section we present a simulation based approach for the analysis of the performances of IoV based smart city scenarios.

III. IoV Enabled Smart City Scenarios

For the purposes of creating a realistic simulation for IoV based smart city scenarios we have combined several well-known simulators, each providing a key feature for the smart city 5G MEC infrastructure.

To model the specific constraints in terms of mobility and traffic rules in an urban area we have opted to use SUMO [22], a mobility simulation tool that can read the simulation area characteristics using OpenMaps description and generate random mobility vehicular scenarios with various density. Using SUMO one can successfully implement all traffic conditions including traffic lights, roundabouts, speed limitations, one-way streets, queuing, traffic jam, etc. This approach ensures that the smart city representation reflects the typical real life conditions that can be observed in a chosen urban area.

To model the 5G mobile network infrastructure on top of SUMO, OMNET++ with the special Simu5G extension module has been used [23]. This library enables simulating 5G networks in OMNET++ providing logs that enable end-to-end performance evaluation in terms of bandwidth, delay and reliability in the wireless communication from the end user to the service provided in the 5G core infrastructure. For the purposes of our simulation scenario the end users are the vehicles generated by SUMO, while the services are MEC services provided for each vehicle.

One of the key components of the MEC environment is resource optimisation, in terms of efficient use of the available hardware hosts collocated with the 5G base stations, optimised provisioning of virtual resources for requested MEC services and optimised quality of services throughout the MEC service lifetime. For a mobile urban scenario this entails ensuring that the hosts are used in a consolidated fashion for energy efficiency, and using live migrations to ensure that the MEC service is always located in the nearest host based on the current vehicle location, i.e. implementing the follow-me behaviour whenever a vehicle changes to a new serving base station (see Fig. 1). For these purposes we have used MEC extension for CloudSim that implements this behaviour using a hierarchical multi-objective optimisation algorithm [24].

A workflow [25] has been created around these three simulation tools so that one can define a 5G MEC IoV based smart city scenario at the beginning and obtain the end-to-end performance analysis based on the simulator outputs. The tools themselves are integrated together so that the output of one simulation tool becomes input for another. For an example the output mobility trace from SUMO is used by OMNET++ as a definition of the current location of the end points, while the output from OMNET++ is used as input to CloudSim defining the current serving base station based on which a selection of host is to be made, and notifying of all handover events that trigger a migration process for the corresponding MEC service. Upon completing all simulations, the outputs of all tools are combined together in a joint dataset to produce the end-to-end performance analysis. The workflow details on how to integrate the tools and verify the overall simulation results is presented in [25]. The approach in this paper differs to the workflow presented in [25] in only one major differences that is the use of the Simu5G module for the simulation of the 5G network components.

By combining these simulation tools together, we are able to create large scale realistic urban scenarios for the Internet of Vehicles implementation in smart cities using 5G networks as means of communication and MEC services to augment the computing power of the vehicles.

IV. Results and Discussion

In this paper we present a case study of MEC resources optimisation analysis for an example IoV based smart city scenario defined in the city of Alicante, Spain. The simulated area represents the city center (2 km x 2 km) in which the vehicles are moving according to the traffic rules imported from OpenStreetMaps. To cover this area with the 5G network we used 9 strategically placed base stations. Co-located with each of the base stations are a number of servers that can host MEC services. These servers are interconnected using a typical datacentre optical network infrastructure using 10 Gbps links, that also connects each group of hosts to the co-located base station.

TABLE I
Variable simulation parameters used in the case study

Simulation parameter	Values for different scenarios
Total number of vehicles (for 1 000 s simulations) and SUMO density parameter	49xx [4900, 4999] - period 2 57xx [5700, 5799] - period 1.75 69xx [6900, 6999] - period 1.45 85xx [8500, 8599] - period 1.16
no. of MEC hosts per base station	5, 7, 9, 11 or 13
types of MEC hosts	type 0: 4 CPU cores, 8 GB RAM type 1: 6 CPU cores, 12 GB RAM
MEC service VM sizes	1 CPU cores, 2 GB RAM 2 CPU cores, 2 GB RAM 2 CPU cores, 4 GB RAM

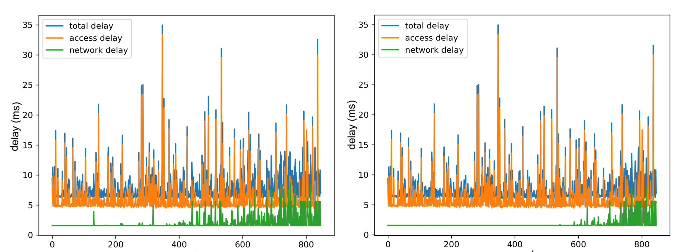
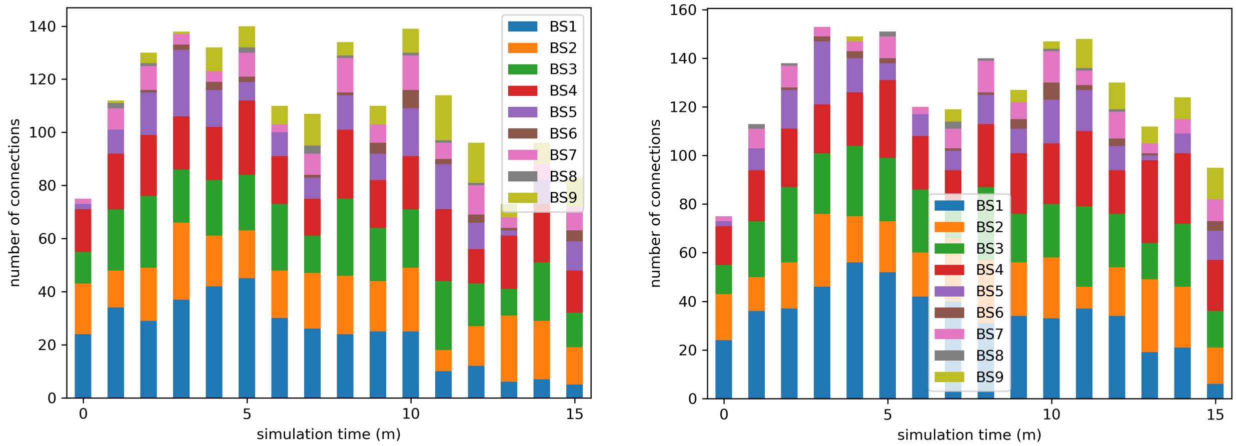
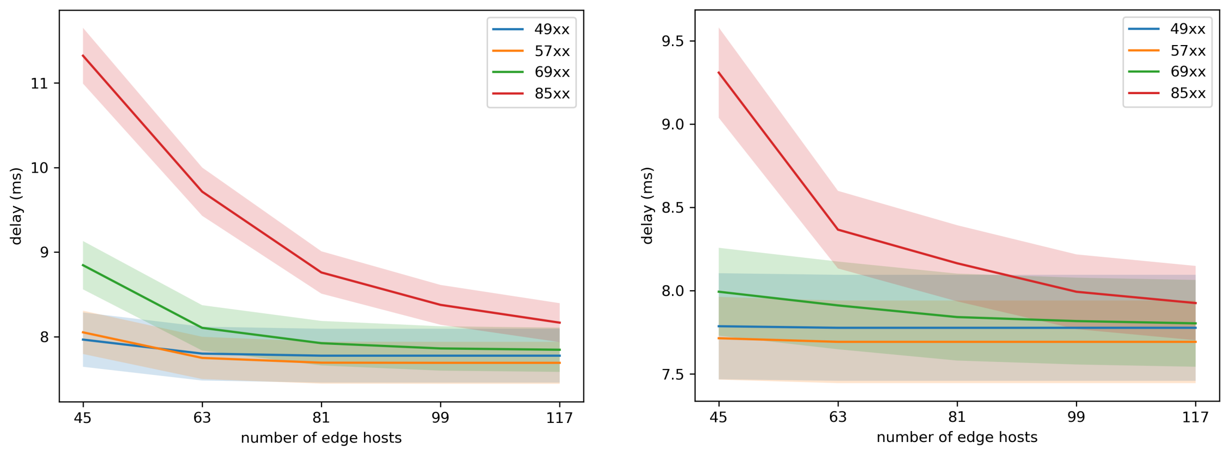


Fig. 2. Average delay for the 117 edge host scenario and 847 cars (host type 0 vs. host type 1).The figure represents the 5G access network delay, the edge infrastructure network delay and the sum of both delays.



(a) Host type 0 (b) Host type 1

Fig. 3. Evolution of MEC connections per 5G base station during simulation time in the scenario composed of 45 hosts and 680 vehicles. The figure compares the effect in the number of connections per base station when considering different host capacities at the MEC micro datacentres (host type 0 vs. host type 1).



(a) Host type 0 (b) Host type 1

Fig. 4. End to end mean delay and 95% confidence intervals of the whole urban scenario simulations set. The figure shows a comparison of the global delay considering different host capacities at the MEC micro datacentres (host type 0 vs. host type 1).

Each vehicle that enters (or starts to move within) the simulation area requests a supporting MEC service in the form of a randomly sized VM and uses this service as long as it is moving in the simulation area (minimum of 300m travelled). The main goal of the case study is to analyse the joint performances in terms of end-to-end delay of the 5G and MEC infrastructures that are affected by the traffic density (number of MEC services) and the mobility handling on both the 5G side (frequent handovers) and the MEC side (frequent migrations to implement the follow-me behaviour). For these purposes a series of simulations have been done by varying the input parameters as presented in Table I. All simulations have been run at least three times and the presented results in the next section show the averages of these runs. The simulation time for all simulations has been set to 1000 s.

We show in this section some images that sum up the results obtained by simulating the whole end-to-end urban environment. On one hand, we present in Fig. 2 the obtained access, network and total delays for the most dense scenario that includes 13 hosts per edge datacentre. We can observe how the network delay increases with the sequential number of new cars entering in the coverage area, being the capacity of hosts the only difference between both images. So, we can notice that the edge datacentres that are composed of type 0 hosts (image on the left) experiment higher network delays because VM migrations are more difficult to be optimally allocated and the user equipment - VM communication suffers an extra network delay compared to type 1 hosts (image on the right).

The effect of VM allocations and non-optimal VM migrations when MEC hosts are congested can also be observed in Fig. 3, that depicts the distribution of user equipment connections per edge datacentre (each of them connected to a base station). Differentiating between host capacities while observing the figure, it is possible to analyse that some migrations cannot be optimally performed and, hence, some cars' virtualised entities are left behind penalising the network delay as we already observed in Fig. 2. Therefore, the distribution of connections per base station is different when considering hosts with different computing power at the edge level.

Finally, we have computed the end to end delay obtained in the experiment by combining the delays obtained by all used simulators and we show it on Fig. 4. Lines represent the global average delay obtained in the whole set of simulations performed and the coloured shadows represent their 95% confidence intervals. The performance of the proposed approach is summarised in this last image that shows how the system reacts to the workload in terms of edge connections depending on the computer power of the edge datacentres and obtaining global latencies that are lower than 12 ms on average for all considered cases.

V. Conclusion

The Internet of Vehicles paradigm enabling the use of vehicles as a central hub for connecting to the rest of the network and services shows a growing promising potential when coupled with the advancements in mobile networking brought by the 5G standards and continued in 6G and beyond. The increased support for high mobility, capacity and reliability make the 5G network a very good candidate for all vehicle to anything communication. Taking into account that the requirements for computing power are heavily increased in the IoV, 5G needs to be coupled with MEC in order to satisfy both the networking and computing aspects.

Towards this purpose, in this paper we have presented the implementation of IoV based smart city simulations that enable the end-to-end study of the combined 5G MEC infrastructure as a vital supporter for IoV services. The obtained case study results show the symbiotic relationship between the two systems and enable the analysis of the influence of a wide variety of simulation parameters in a large scale realistic urban scenario. The performed analysis has shown that more work is needed to ensure that the simulation scenario can support very large scale investigations by playing with parameters such as increasing the vehicle density or the number of base stations and coverage area size. Our future work on this topic will be focused on analysing the performances and tuning the 5G-MEC system based on the results obtained from large scale urban simulations.

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