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Mobile Edge Computing versus Fog Computing in Internet of Vehicles

Eugen Borcoci, Marius Vochin, Serban Obreja
University POLITEHNICA of Bucharest
eugen.borcoci@elcom.pub.ro
marius.vochin@upb.ro
serban@radio.pub.ro

Objectives

- **To identify general aspects related to**
  - usage of the **Edge computing** technologies in the **Internet of Vehicle (IoV)** environment
- **Specific cases of technologies** (which one to use in IoV?)
  - Multi-access (Mobile) Edge Computing
  - Fog Computing

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1. Introduction

- **Vehicular networks** evolve in **Internet of Vehicles (IoV) -** aiming to solve the current and novel challenging needs of transportation systems
- **Edge computing (EC)**
  - **move cloud computing** capabilities close to the data sources/sinks
  - **EC:** distributed architectures, fast response, context awareness, minimization of the data transfer to the centralized data centers
  - **EC- natural support for IoV**
  - **Multi-access (Mobile) Edge Computing (MEC), Fog Computing (FC), cloudlets,** etc. – candidates to support IoV
    - These architectures and technologies have overlapping characteristics but also differences in approach
    - Today – open issues:
      - **not yet a full convergence between EC technologies**
      - **which solution could be the best trade-off** to be adopted in IoV context and for which use cases ?
- **This paper:**
  - **is not a complete survey**
  - attempts a **preliminary evaluation** of some of the currently proposed **MEC/Fog solutions for IoV**

1. Introduction

- **IoV**
  - **extends VANETs** to a global span of a vehicle network
  - special case of **Internet of Things (IoT)**
  - connects the **vehicles** and **Road Side Units (RSUs)** through different **Wireless/Radio Access Technologies** (WAT/RAT)
  - traditional Internet/heterogeneous networks cover the wide area
  - IoV : supports large range of apps/use cases, including those coming from **Intelligent Transportation Systems (ITS)**, V(A)NETs and other novel ones
    - Safety and vehicular traffic management, Business oriented
- **IoV** can take benefit for **Cloud Computing (CC)** combined with **Edge Computing (EC)**
  - **MEC, Fog, …**
- **Auxiliary technologies (oriented to virtualization)**
  - **Software-defined networking (SDN)**
    - decouples the Data vs. Control plane and logically centralizes the control.
  - **Network Function Virtualization (NFV)**
    - moves into SW many network functions traditionally implemented by dedicated HW
  - Advantages: flexibility, programmability, abstraction, dynamicity, management, etc.

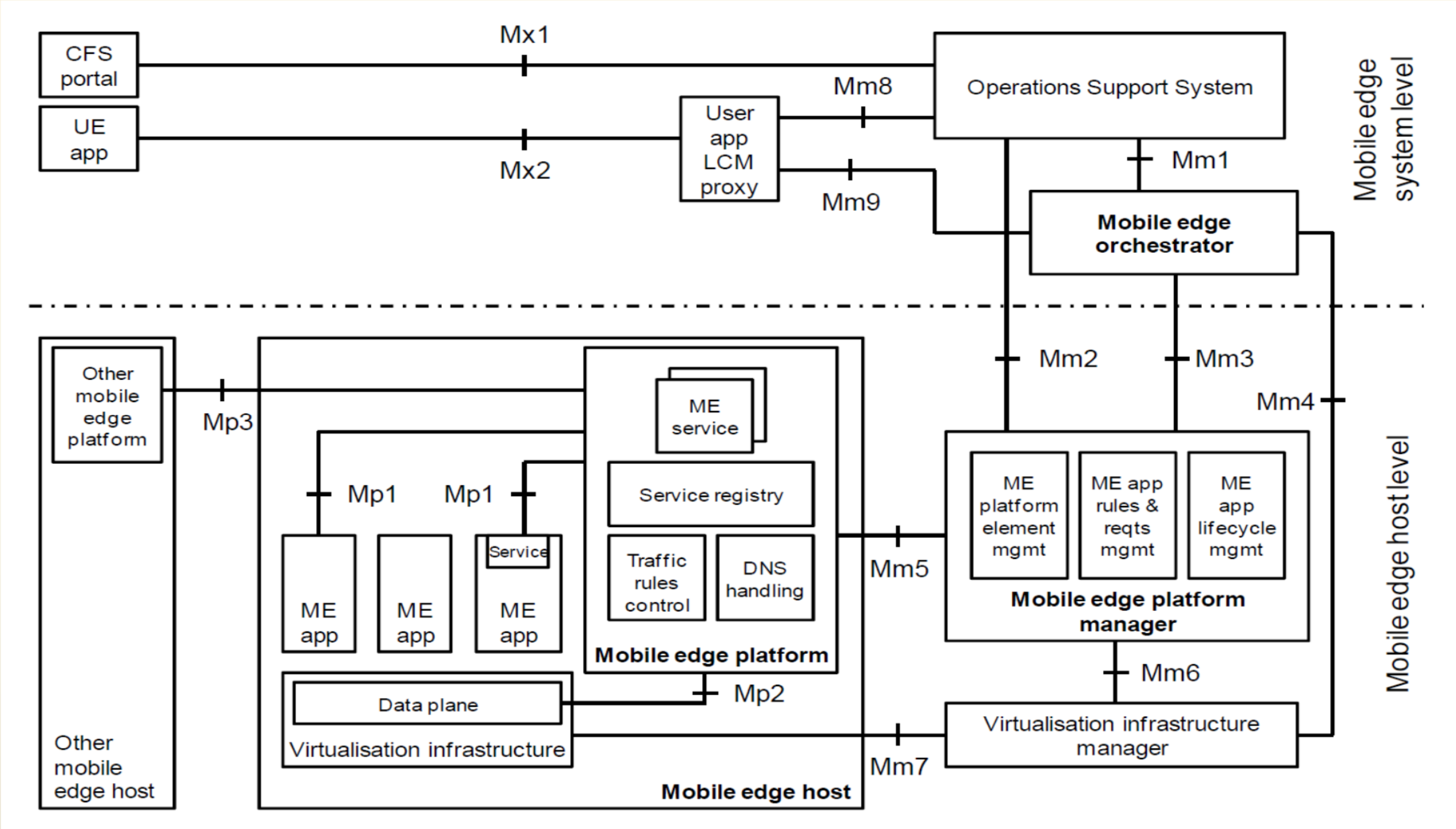
2. Edge computing architectures- examples

- **Multi-access (Mobile Edge Computing (MEC)**
  - **ETSI - 2014 the MEC ISG** - first specs **Mobile Edge Computing**
    - 2017- extended to Multi-access Edge Computing - to include non-cellular and fixed access cases
  - MEC offers typical EC advantages
  - MEC resources - placed at the network edge (e.g., in **Radio Access Network – RAN**, i.e., 4G/LTE Base Stations, or in aggregation points, 3G/RNC, etc.)

  - **MEC Reference architecture – ETSI**
    - **Mobile Edge Host (MEH) -** plays the key role of an **application server**
      - integrated in RAN; provides computing resources, storage capacity, connectivity, and access to user traffic, radio and network information
      - **MEH includes**
        - a virtualization infrastructure (based on **Network Function Virtualisation Infrastructure** – **NFVI** (ETSI NFV framework) and
        - **Mobile Edge Platform** (MEP), supporting the execution of mobile edge applications
  - **MEC management** – borrowed from NFV management framework - ETSI

2. Edge computing architectures- examples

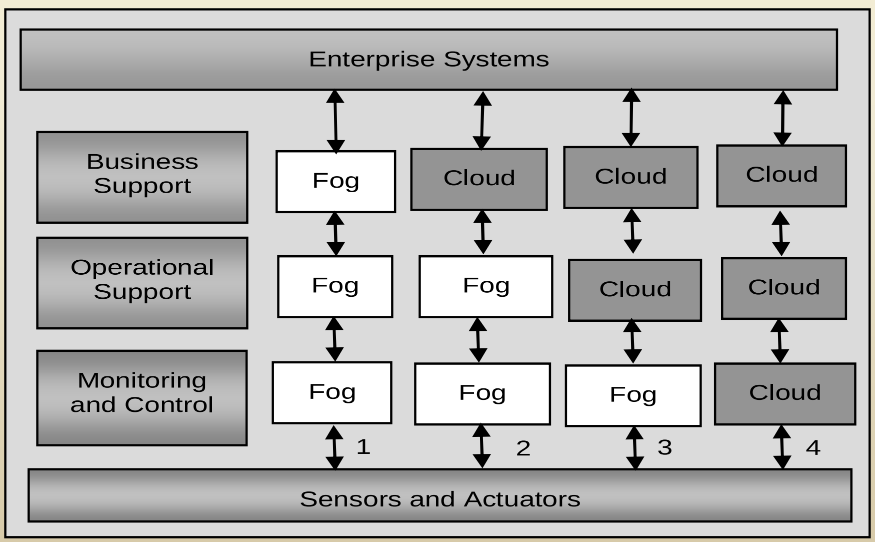
- **Multi-access (Mobile Edge Computing (MEC)**
  - Architecture (ETSI)



Source: "Mobile edge computing (MEC); Framework and reference architecture," ETSI, Sophia Antipolis, France, Mar 2016. Available: http://www.etsi.org/deliver/etsi_gs/MEC/001_099/003/01.01.01_60/gs_MEC003v010101p.pdf

2. Edge computing architectures- examples

- **Fog Computing (FC)**
- Initially the term has been coined by CISCO (2012)
- **OpenFog Consortium (OFC)**
  - definition: FC is a **system-level horizontal architecture** that distributes resources and services of computing, storage, control and networking ***anywhere along the continuum*** from a cloud data center down to things
  - **Note:** MEC, originally targets only the very edge part of the network (e.g., RAN)
  - OFC defined a **flexible deployment hierarchical model** for FC, **IoT oriented**
    - capable to accommodate various degree of *fog entities* distribution and offering appropriate architectures for different use cases



Adapted from Source : OpenFog Consortium (2015), OpenFog Reference Architecture for Fog Computing, http://www.openfogconsortium.org/resources/#definition-of-fog-computing

3. Relevant Internet of Vehicles architectures

- **Several variants** for layered IoV architecture **have been published;** some relevant ones are shortly described here (see other examples in the paper)

- **Bonomi et al.** [3]   4 -layered architecture, for connected vehicles and transportation
  - **L1 (end points)** : vehicles, and their comm. protocols (basically for V2V comm., using the IEEE 802.11a/p)
  - **L2 (infrastructure)-** interconnects the IoV actors (via WiFi, 802.11p, 3G/4G, etc.)
  - **L3 (O&M)-** verifies and ensures compliance with policies, to regulate the information mgmt. and flow
  - **L4 (cloud- public, private or enterprise)-** where the high level on demand services are defined

3. Relevant Internet of Vehicles architectures

- **Kayvartya et al**. [4] : IoV 5-layer architecture, for enriched set of vehicular comm.- V2R/V2I, i.e., *Vehicle-to-Personal* devices (V2P) and *Vehicle-to-Sensors* (V2S).
  - ***Layers: perception, coordination, artificial intelligence, application* and *business*.**
  - ***Perception (PL)*** - physical layer functions and some additional for sensing and actuating actions
  - ***Coordination (CL)*** - virtual universal network coordination entity for hetnet technologies (WAVE, Wi-Fi, 4G/LTE, satellites, etc.)
  - ***Artificial intelligence (AIL)*** - generic virtual cloud infrastructure, working as an information processing and mgmt. centre
  - ***Application (AL)*** - smart applications (e.g., for traffic safety and efficiency, multimedia-based infotainment and web based utility)
  - ***Business (BL)*** includes IoV operational management functions, basically related to business aspects
    - *O. Kaiwartya, A.H. Abdullah, Y. Cao, A. Altameem, and M. Prasad, "Internet of Vehicles: Motivation, Layered Architecture, Network Model, Challenges, and Future Aspects" IEEE Access, Special Section on Future Networks, Architectures, Protocols and Applications, Vol. 4, pp.5536-5372, September 2016*

- **Other examples - in the paper**

- **Question: How MEC or Fog computing can be embedded-in or harmonized-with IoV architectures?**

4. MEC and Fog solutions integrated in IoV

- **Different specific solutions are proposed; no unique vision exists**
- **Examples**
- **(1) MEC-based model of a vehicular network**, K. Zhang, et al. [5]
  - The architectural levels are:
    - *Virtual Computation Resource Pool*- incorporating the network and cloud resources outside the MEC
    - *MEC level* –MEC servers placed in the RAN
    - *RSUs units* placed on the roads; mobile units (vehicles)
  - A special focus is on the computation off-loading process, to preserve the service continuity in the mobile environment

- **(2) SDN-enabled network architecture assisted by MEC,** J. Liu et al.[6]
  - The architectural components are (top-down hierarchical list)
    - Remote Data Center; Backbone network, Regions (each one contains MEC servers collocated with a SDN controller, BS and mobiles organized in VANETs)
  - The MEC servers can inter-communicate via a mesh of fixed network links

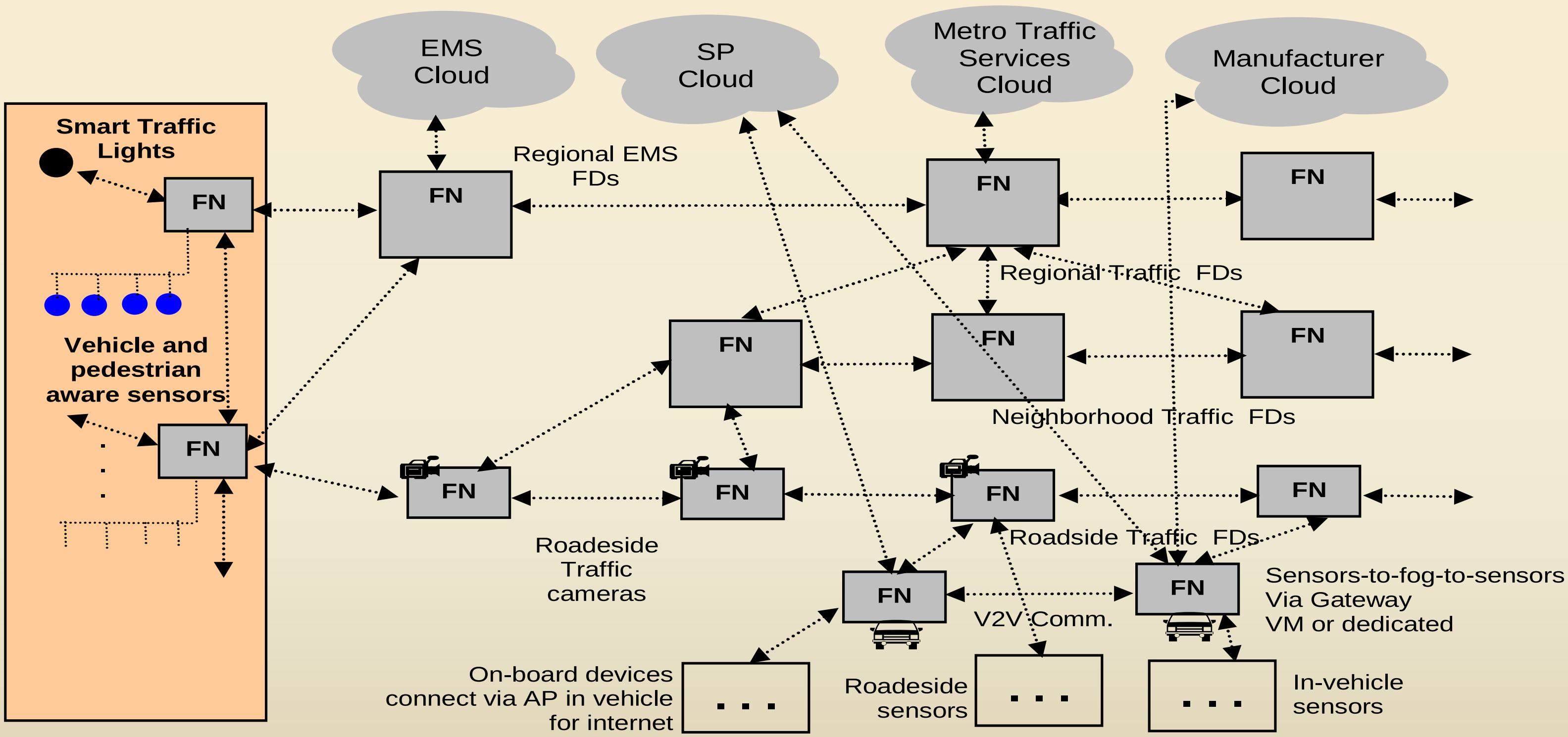
4. MEC and Fog solutions integrated in IoV

- **Different specific solutions are proposed; no unique vision exists**
- **Examples**
- **(3) Fog-SDN architecture (FSDN) for advanced VANET**, Truong et al. [7], for V2V, V2I and Vehicle-to-Base Station communications.
  - The FC supports well delay-sensitive and location-aware services
  - SDN components (top-down listed):
    - **SDN Controller** -it controls the overall network behavior via OpenFlow –I/Fs; it also performs Orchestration and Resource Management for the Fog nodes
    - **SDN RSU Controller** (RSUC) (controlled by the central SDN controller
      - each RSUC controls a cluster of RSUs connected to it through broadband connections
      - The RSUC can forward data, and store local road system information or perform emergency services. From Fog perspective RSUC are fog devices)
    - **SDN RSU** (it is also a Fog device)
    - **SDN Wireless Nodes** (vehicles acting as end-users and forwarding elements, equipped with OBU)
    - **Cellular Base Station (BS)** performing traditional functions (they are SDN-controlled via OpenFlow protocol and can also offer Fog services).

4. MEC and Fog solutions integrated in IoV

- **(4) General cloud-fog-based** example system for transportation scenario (smart cars and traffic control)- from OpenFog Consortium, [2]

EMS- Element Management System; SP- Service Provider; FD- Fog Device; FN- Fog Node



Adapted from Source : OpenFog Consortium (2015), OpenFog Reference Architecture for Fog Computing, http://www.openfogconsortium.org/resources/#definition-of-fog-computing

5. MEC versus Fog in IoV

- **Question :** “selection of **Mobile Edge computing, versus Fog** computing for IoV system”
- **Our opinion : there is no unique general answer**
  - **a realistic specific selection could depend significantly on the IoV services needed** - out of a large set described in Introduction section
  - **MEC/FC – many common characteristics**:
    - edge-orientation; low latency; support for r.t. interactions, location awareness and mobility and large number of server nodes; geographical distribution proximity to the end devices service location; various working environment outdoor (streets, base stations, etc.) or indoor (houses, cafes, etc.); wireless communication access: WLAN, WiFi, 3G, 4G, ZigBee, etc., or wired communication (part of the IP network), weak dependence on the quality of core network; low bandwidth costs and energy consumption.
    - Both MEC and FC
      - can use SDN and NFV in different architectures
      - can be compliant with the layered architectures described in Section 3

5. MEC versus Fog in IoV

- **There are also differences between FC and MEC from several points of view**
  - These should be considered in specific cases – to make a selection MC/Fog
  - **Table 1: MEC versus FOG Differences**

Criterion	**MEC**	**Fog computing**
Placement of node devices	Servers running in Base stations Network Controller/Macro Base Station	Anywhere - between end devices and cloud data centre: Routers, Switches, Access Points, Gateways
Compute Distribution and Load Balancing	Employ a strategy of placing servers, apps or small clouds at the edge	Broader architecture and tools for distributing, orchestrating, managing and securing resources and services across networks.
Software Architecture	Mobile Orchestrator based (strongly specified)	Fog abstraction layer based (only partially specified)
Standardization/ specifications	ETSI/	/OpenFog Consortium
Context awareness	High	Medium
Proximity	One hop	One or multiple hops
Access Mechanisms	Mobile networks: 3G/4G/5G	Wi-Fi, Mobile networks, etc.
Virtualization and management mechanisms	Strongly specified by ETSI (NFV framework)	Larger view of virtualization. In progress at OpenFog Consortium

5. MEC versus Fog in IoV

- **Table 1: MEC versus Fog Differences (cont'd)**

Criterion	MEC	Fog computing
Hierarchical structure of the overall system	Possible	Yes: multiple levels of cooperating nodes, supporting distributed applications
Horizontal scalability	Medium	High
Internode Communication	Possible - between Mobile Edge Hosts	Native support for communication between Fog nodes
Communication with Cloud Computing data center	Possible	Fog-cloud is usually considered necessary
Modular architecture with multiple access modes	Edge deployments are typically based on gateways with fixed functionality. However they can be made more flexible and dynamic by using NFV.	Highly modular HW&SW architecture; every Fog node is equipped with exactly the resources its applications need; it can be dynamically configured.
Topology of server nodes	Less flexible (limited by RAN spread)	More general and very flexible
Specifications compliant with 5G	Full compliancy	Work in progress

6. Conclusions

- For a given set of use cases to be provided by an IoV system, the **problem of selecting MEC or FC approach** is a **multi-criteria one**.
  - Table I: examples of selection parameters, where **appropriate weights** should be assigned
  - **Multi-criteria optimization algorithms** and techniques can be applied

- **General guidelines:**
  - **MEC**
  - **(-) approach is more restricted than FC** in terms of network dimension and vertical hierarchy
  - **(+)** but the IoV based on MEC can benefit from: detailed elaborated specifications coming from ETSI for MEC; **powerful virtualization support defined by NFV** technology which is fully compliant with MEC; **SDN/NFV approach can be naturally applied in MEC implementation**; resource management, mobility and task offloading are aspects better defined in terms of solutions in MEC framework than in FC

6. Conclusions

- **General guidelines (cont'd)**
  - **FC for IoV**
  - **(+)** is more general in terms of hierarchization, flexibility, geographical span, extension on the core network of FC capabilities.
  - **(-)** However, an FC solution for IoV has additional challenges vs. traditional FC
    - the **edge nodes can be highly mobile** causing possible intermittent loss of connection to the remote cloud servers
    - the **computation can be based on vehicular control engines**, and therefore accuracy and safety criticality must be ensured
    - **access control** should be enforced sometimes in real-time mode to prevent delays of some critical decision related to traffic
    - **failure or sporadic behaviors of a few sensor** nodes may affect the control decisions taken over a fog (ensuring correctness of the local computation needs to be ensured for intelligent or autonomous vehicles).

  - **Near future**: to be aware of the cooperation between different organizations, towards a convergence of vision in the domain of edge computing (including MEC, Fog, Cloudlets, etc.)

Thank you!

Questions?

References (short list)

1. “Mobile edge computing (MEC); Framework and reference architecture,” ETSI, Sophia Antipolis, France, Mar. 2016. Available: http://www.etsi.org/deliver/etsi_gs/MEC/001_099/003/01.01.01_60/gs_MEC003v010101p.pdf
2. OpenFog Consortium (2015), OpenFog Reference Architecture for Fog Computing, http://www.openfogconsortium.org/resources/#definition-of-fog-computing,
3. F. Bonomi, “The smart and connected vehicle and the Internet of Things”, San José, CA: WSTS, 2013, https://tf.nist.gov/seminars/WSTS/PDFs/1-0_Cisco_FBonomi_ConnectedVehicles.pdf,
4. O. Kaiwartya, A.H. Abdullah, Y. Cao, A. Altameem, and M. Prasad, “Internet of Vehicles: Motivation, Layered Architecture, Network Model, Challenges, and Future Aspects” IEEE Access, Special Section on Future Networks, Architectures, Protocols and Applications, Vol. 4, pp.5536-5372, September 2016
5. K. Zhang, Y. Mao, S. Leng,Y. He, and Y. Zhang, "Mobile-Edge Computing for Vehicular Networks- A Promising Network Paradigm with Predictive Off-Loading", IEEE vehicular technology magazine, pp. 36-44, June 2017
6. J. Liu, J. Wan, B. Zeng, Q. Wang, H. Song, and M. Qiu, "A Scalable and Quick-Response Software Defined Vehicular Network Assisted by Mobile Edge Computing", IEEE Communications Magazine, pp. 94-100, July 2017.
7. N. N. Truong, G. M. Lee, and Y. Ghamri-Doudane, “Software defined networking-based vehicular ad hoc network with fog Computing”, Proceedings of the 2015 IFIP/IEEE International Symposium on Integrated Network Management (IM’15), May 2015, Ottawa, Canada. Piscataway, NJ, USA: IEEE, pp. 1202-1207, 2015.