Using Vehicles as Fog Infrastructures for Transportation Cyber-Physical Systems (T-CPS):
Fog Computing for Vehicular Networks

MD Muzakkir Hussain, Aligarh Muslim University, Aligarh, India

🆔 https://orcid.org/0000-0002-6371-2545

M.M. S Beg, Aligarh Muslim University, Aligarh, India

ABSTRACT

The advent of intelligent vehicular applications and IoT technologies gives rise to data-intensive challenges across different architectural layers of an intelligent transportation system (ITS). Without powerful communication and computational infrastructure, various vehicular applications and services will still stay in the concept phase and cannot be put into practice in daily life. The current cloud computing and cellular set-ups are far from perfect because they are highly dependent on, and bear the cost of additional infrastructure deployment. Thus, the geo-distributed ITS components require a paradigm shift from centralized cloud-scale processing to edge centered fog computing (FC) paradigms. FC outspreads the computing facilities into the edge of a network, offering location-awareness, latency-sensitive monitoring, and intelligent control. In this article, the authors identify the mission-critical computing needs of the next generation ITS applications and highlight the scopes of FC based solutions towards addressing them. Then, the authors discuss the scenarios where the underutilized communication and computational resources available in connected vehicles can be brought in to perform the role of FC infrastructures. Then the authors present a service-oriented software architecture (SOA) for FC-based Big Data Analytics in ITS applications. The authors also provide a detailed analysis of the potential challenges of using connected vehicles as FC infrastructures along with future research directions.

1. INTRODUCTION

The integration of the information and communication technologies (ICT), cloud computing, Software defined networking (SDN) and Internet of Things (IoT) with century old transportation infrastructures lead to the evolution of Intelligent Transportation Systems (ITS) (Mohd Saqib et al., 2017). With the emergence of ITS application, the number of advanced vehicular applications is growing at ever-fast rate (M. Hussain et al., 2018). Consequently, the challenges to meet the demands from both communication and computation are becoming increasingly prominent. The disruptive IoT technology

will serve as a key driver for the success of data-driven ITS realization (Zeng et al., 2011). The vehicles in ITS network when embedded in IoT technology lead to emergence of Internet of Vehicles (IoV) (Kaiwartya et al., n.d.). IoV ensures real-time connectivity, automation and tracking of on-premise smart objects. It seamlessly integrates information sensing, storage, processing, intelligence, and control capabilities into the physical ITS components, thus forming a Cyber-Physical System (CPS) (Hussain et al., n.d.). The IoT nodes intelligently capture the behaviors and actions of all the entities in the ITS supply-chain to deliver smart, sustainable, and secure mobility solutions, and ensure economical and environmentally sustainable use.

These days, due to advancements in ITS data generation and storage technologies, the connected vehicles became the key driver of IoT (Bonomi et al., 2013). Such vehicles are leveraged with on-board sensor units and build connected networks with ITS sub-systems such as roadside infrastructures (RSU), parking lots, smart vehicle charging stations (Hiraishi and Mizoguchi, 2018), Advanced Metering Infrastructures (AMI), etc. Also, by enabling the IoT technology a global standard and basis for ITS communications, new avenues will be created for maximizing the prospects for future innovations (Muhammad Baqer Mollah et al., 2017). The cyber-machineries in connected vehicular network aims at providing real-time connectivity, automation and tracking of on-premise smart devices, deployed for analysis monitoring and control of the ITS infrastructures. The IoT evolves the legacy ITS architecture into a Transportation Cyber-Physical Systems (T-CPS) (Figure 1) where the cyber half forms the basis of data-driven big data analytics, ultimately focused to manage the operation of physical sub-system (Things 2018). The IoT aided ITS turns into an integrated framework of real and virtual worlds where the attributes from the real (physical) as well as virtual (cyber) world are fed as input to the control/data centers (clouds), to generate simulation models for predicting the future mechanisms and transitions (Birman, Ganesh, and Renesse, 2011).

Since the T-CPS comprises billions of these intelligent communicating devices (vehicles, roadside infrastructures, sensors, etc.) that generate enormous amount of data, and hence performing analysis on this data is a significant task (Zhu et al., 2018). Thus, the growing volume and velocity of IoT

Figure 1. A framework for transportation cyber-physical systems (T-CPS)
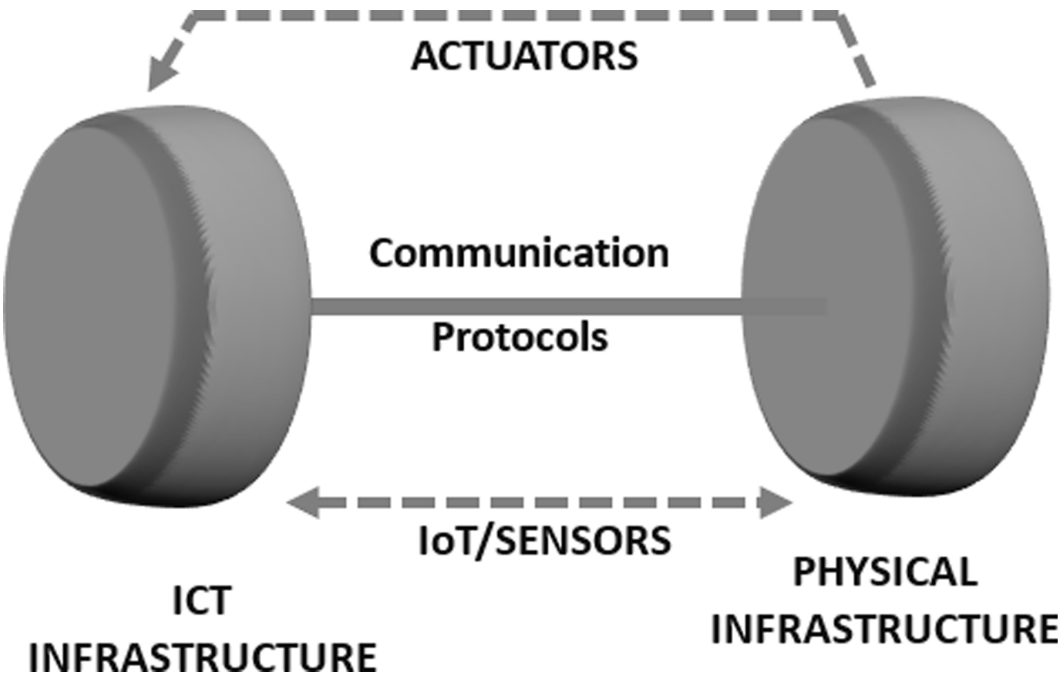
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