Computer Communications 120 (2018) 58–70

Contents lists available at ScienceDirect

Computer Communications

journal homepage: www.elsevier.com/locate/comcom

Cognitive Internet of Vehicles

Min Chen[*,a], Yuanwen Tian[a], Giancarlo Fortino[b], Jing Zhang[*,c], Iztok Humar[d]

[a] School of Computer Science and Technology, Huazhong University of Science and Technology, Wuhan 430074, China
[b] Department of Informatics, Modelling, Electronics and Systems Engineering, University of Calabria, Rende 87036, Italy
[c] School of Electronic Information and Communications, Huazhong University of Science and Technology, Wuhan 430074, China
[d] University of Ljubljana, Ljubljana, Slovenia

ARTICLE INFO

Keywords:
CIoV
Internet of Vehicles
Cognitive computing
Vehicular network

ABSTRACT

To fully realize future autonomous driving scenarios, Internet of Vehicles (IoV) has attracted wide attention from both academia and industry. However, suitable cost and stable connectivity cannot be strongly guaranteed by existing architectures such as cellular networks, vehicular ad hoc networks, etc. With the prosperous development of artificial intelligence, cloud/edge computing and 5G network slicing, a more intelligent vehicular network is under deliberation. In this paper, an innovative paradigm called Cognitive Internet of Vehicles (CIoV) is proposed to help address the aforementioned challenge. Different from existing works, which mainly focus on communication technologies, CIoV enhances transportation safety and network security by mining effective information from both physical and network data space. We first present an overview of CIoV including its evolution, related technologies, and architecture. Then we highlight crucial cognitive design issues from three perspectives, namely, intra-vehicle network, inter-vehicle network and beyond-vehicle network. Simulations are then conducted to prove the effect of CIoV and finally some open issues will be further discussed. Our study explores this novel architecture of CIoV, as well as research opportunities in vehicular network.

1. Introduction

Since 1970s, the world has witnessed a rapid growth of vehicles, which have indeed become the most important transportation tool for people's daily travelling. However, due to blocked line of sight, fatigue driving, overspeeding, etc., traffic car incidents could not be effectively reduced from beginning to the end. According to research statistics [1], 90% of traffic accidents are caused by human driving errors or misjudgments. Oppositely, an investigation report published by Eno Center for Transportation reveals that, if autonomous driving technology and vehicular communication cooperation could be adopted, traffic accidents caused by driving errors would be significantly reduced and urban traffic jam would be greatly relieved [2].

Currently, the vehicle industry is going through a huge technological revolution in order to deal with challenges mentioned above. Since 2012, with rapid development of big data technology and Internet of Things (IoT) [3], the first generation of Internet of Vehicles (IoV) has become the key enabling technology to realize future autonomous driving scenarios. Cognition and autonomicity are enabling paradigm for peculiar features of every IoT systems [4,5], and hence also for IoV. According to a report by McKinsey & Company in 2016 [6], the autonomous vehicles in future should be equipped with both intelligence and connectivity, and the sales volume of fully autonomous vehicles will take up 15% of the world's vehicle market in 2030. The new business model in autonomous vehicle market may enlarge the total revenue by about 30%.

Some research has discussed a few problems on IoV at present. Insights on layered architecture, protocol stack and network model of IoV have been put forth in [7]. As to vehicle-to-anything (V2X) communication problems, a joint communication scheme with dedicated short range communication (DSRC) and cellular network has been investigated and evaluated in [8]. Intuitively, IoV can be regarded as a powerful wireless sensor network (WSN) moving without human intervention. However, compared with traditional WSN, many problems remain to be solved due to the extremely strict application requirements for IoV:

(1) **High speed mobility**: the key element in IoV is autonomous vehicles moving at high speed. Due to the complexity and variety of traffic conditions, it is important to guarantee the accuracy in autonomous vehicles.
(2) **Delay sensitivity**: in IoV, communication delay need to be

* Corresponding authors at: School of Computer Science and Technology, Huazhong University of Science and Technology, China.
E-mail addresses: minchen2012@hust.edu.cn (M. Chen), yuanwentian@hust.edu.cn (Y. Tian), g.fortino@unical.it (G. Fortino), zhangjing@hust.edu.cn (J. Zhang), iztok.humar@fe.uni-lj.si (I. Humar).

https://doi.org/10.1016/j.comcom.2018.02.006
Received 15 October 2017; Received in revised form 8 January 2018; Accepted 10 February 2018
Available online 19 February 2018

measured by millisecond. Once a network congestion or long delay happens, due to slow computation or limited band width, a series of life-threatening traffic accidents would take place.
(3) **Seamless connectivity**: in the future, user's requirements on network quality and service continuity would be much higher. Specifically, many computation-intense tasks need to be processed in real time. Therefore, QoS of many vehicular application can be satisfied only if a stable and uninterrupted network connection is guaranteed.
(4) **Data privacy**: large amounts of private information on vehicle owners are involved in vehicular networks, and it cannot be protected by traditional network protection mechanism. Additionally, the urban traffic system needs a secure and robust network environment to guarantee the orderly conduct of autonomous driving.
(5) **Resource constraints**: though self-organizing networks of vehicles may provide real-time communication, the computing resources and network resources possessed by a single vehicle is still limited, especially during a transition period of a semi-autonomous driving scenario. Resources need to be precisely scheduled in real time, based on actual driving course of massive vehicular networks.

In order to solve those problems, the intelligence of IoV need be strengthened in comprehensive directions. Therefore, Cognitive Internet of Vehicles (CIoV) is proposed in this paper to realize intelligent cognition, control and decision-making for future autonomous driving scenarios. In contrast to existing works on IoV, the human-centric CIoV utilizes hierarchical cognitive engines and conduct joint analysis in both physical and network data space. To grasp a concrete idea, we divided main participants in CIoV into intra-vehicle network, inter-vehicle network and beyond-vehicle network in Fig. 1, different scaled networks also focus on different cognitive functions. Main advantages of CIoV are listed below:

(1) **Cognitive Intelligence**: CIoV enables IoV to bear more accurate perceptive ability, through cognition in intra-vehicle network (driver, passengers, smart devices, etc.), inter-vehicle network (adjacent intelligent vehicles) and beyond-vehicle network (road environment, cellular network, edge nodes, remote cloud, etc), it can also provide macrocosmic information and scheduling strategies to the whole transportation system.
(2) **Reliable decision-making**: by introducing cognitive computing into autonomous driving systems, learning ability of autonomous vehicles can be effectively improved. Moreover, the decision-making process of autonomous vehicles will be more thorough and reliable through the cognitive cycle of perception, training, learning and feedback.
(3) **Efficient utilization of resources**: with perception of network traffic status and real-time road circumstance, the decisions derived by analytic technologies such as machine learning and deep learning, can help resource cognitive engine to conduct more effective control over vehicles, and to enhance information sharing efficiency within vehicular networks.
(4) **Rich market potentiality**: in terms of market opportunities, the benefits brought by CIoV are not limited to vehicle market, they are also closely linked to many other aspects in people's life, such as entertainment, healthcare, agenda and so on. Such a feature will also drive many traditional application devices to be transformed into intelligence embedded application devices.

The remainder of this paper is organized as follows. We first present the evolution of CIoV and review its related technologies in Section 2. Then in Section 3, the five-layered CIoV architecture is presented, with a particular emphasis of interaction between data cognitive engine and resource cognitive engine under cloud/edge framework. In Section 4 we explore critical cognitive design issues from three perspectives (intra-vehicle network, inter-vehicle network and beyond-vehicle network), aiming to enhance user experience and performance of traffic system. In Section 5, we simulate a vehicular edge scenario in CIoV to prove the effectiveness of our proposed architecture. Finally, we discuss some open issues related with the implementation of CIoV in Section 6 and draw our conclusions in Section 7.

2. Background and related work

CIoV is proposed as the advanced solution to strengthen cognitive intelligence of IoV. In order to better understand the development of vehicular networks, this section will explain the differences between CIoV and three related concepts, i.e., ITS, VANET and IoV. Fig. 2 illustrates the evolution process of CIoV. Furthermore, key technologies that enables CIoV, including self-driving technology, cloud/edge hybrid framework and 5G network slicing, is further presented.

2.1. ITS, VANET, IoV and CIoV

Intelligent transportation system (ITS) is an extensive conception, put forth before 2000. ITS involves a series of application systems:

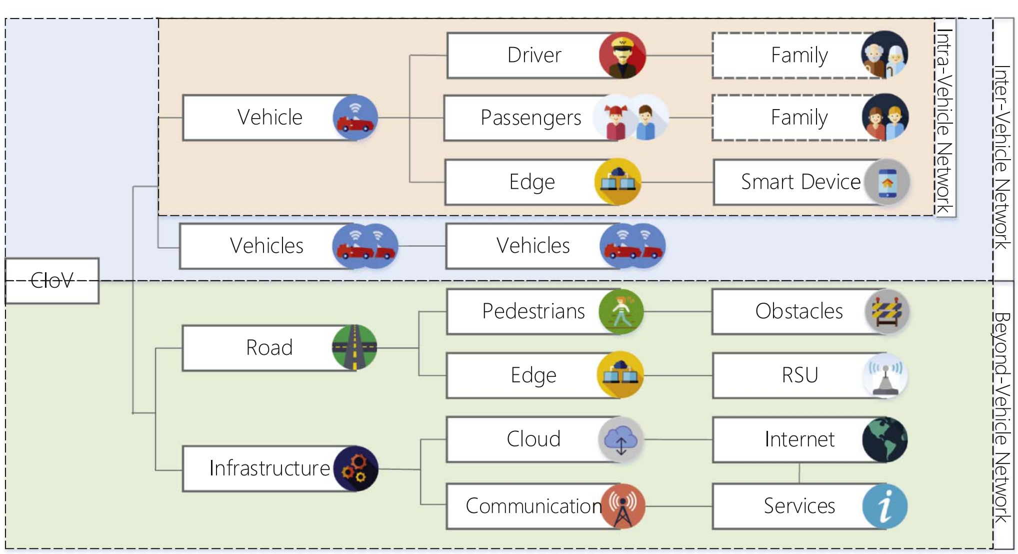

Fig. 1. Participants in CIoV.