A Survey on Fog Computing Applications in Internet of Vehicles

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***Abstract*—As the technology of network, wireless transmission and big data computing develops rapidly, the society has entered the Information Era. Internet of Vehicles, the important part of the Internet of Things, is the inevitable trend of urban traffic in the future. Fog computing emerges as a new technology of distributed computing, which is suitable for applications in the Internet of Vehicles. Internet of Vehicles based on fog computing can solve the problems of traffic congestion, transportation efficiency and security. In this paper, we review the recent work in this topic and analyze the architecture and scenario of fog computing in the Internet of Vehicles. Three aspects of applications are proposed in this paper: VANET, big data processing and security. At the same time, we discuss the technical details and challenges in these applications. Fog computing has excellent processing power in real-time big data and a high mobility environment, which reduces the latency of data processing, makes the deployment between vehicles and roadside units more reasonable and enhances the security of information interchanged in the Internet of Vehicles. Fog computing devices will become an indispensable part of the future construction of Internet of Vehicles.**

Keywords—internet of vehicles, fog computing, vanet, big data security

I. INTRODUCTION

With the development of network technology, wireless transmission and big data computing, the society has entered the Information Era and the Internet of Things arises. As the embodiment of urban traffic network, the Internet of Vehicles (IoV) can be integrated into the city through information services, and process all kinds of data through wireless communication, so as to establish intercommunication between vehicles and the transportation network, between vehicles and vehicles, between vehicles and the road [1]. A new computing model named fog computing has been presented for the application of IoV, which solves the problems of traffic congestion, transportation efficiency and security by deploying the fog computing node in the vehicular network. Fog computing is a new research hotspot that can bring significant value to constructing future vehicle networks of the next generation.

In this paper, we give a survey of fog computing applications in Internet of Vehicles. The contributions of this paper are summarized as follows:

- The key technology of IoV and the architecture of fog computing model are summarized. Three aspects of fog computing that can be applied to vehicle networking environment are proposed in this paper.
- The advantages of applying fog computing in VANET are discussed; the end-to-end delay and throughout performance with varying connections of users are analyzed.
- The cooperative fog computing model of processing big data in four types of IoV scenarios is proposed, and the hierarchical architecture of a real-time intelligent transportation system big data analytsis based on fog computing is introduced.
- The flaws and needs of IoV security, the current research on improving IoV security mechanisms and the challenges with possible solutions for solving them are proposed and discussed.

The rest of this paper is organized as follows. In section 2, the related work of applying fog computing in IoV, the key technology of IoV and the structure of fog computing are given. Section 3 presents three possible applications of IoV based on fog computing and gives the details of the structure and technique. Section 4 discusses the probable challenges and future work in what has been illustrated in section 3. Finally, conclusions are given in Section 5.

II. RELATED WORK

A. The Key Technology of IoV

The Internet of vehicles is an intelligent network of vehicles that establish transmission channels between vehicles and targets based on several key technologies.

a) Intelligent traffic: Intelligent traffic technology integrates the computer, data communication and control technology comprehensively into a ground transportation management system of IoV, providing diversified services after collecting and processing data effectively. Equipped with intelligent traffic, IoV can not only transfer and receive data but also reduce traffic load and improve the level of management.

With the development of big data, machine learning and other technologies, vehicle-road collaboration, autonomous driving, intelligent travel based on Artificial Intellegence (AI) become the key directions of the development of intelligent traffic in the next stage [2].

b) Cloud Computing: Cloud computing possesses a shared pool of resources that can allocate computing to a large number of distributed computers, where workers can get access to the result in the network without complicated management. The data center is similar to the Internet, having supercomputing power, good scalability and virtualization.

Applied in IoV, cloud computing can effectively deal with large amounts of data flows and give feedbacks according to users' requirements. For example, if the road is congested, the driver can check road conditions on the IoV and make a new route planning with strong cloud computing in real-time.

c) Sensor: The vehicle needs data transmitted from the sensor to collect information on fuel consumption, braking performance and traffic condition, requiring the sensor to receive all kinds of information, carry out effective identification and fusion and send commands to all parts of the vehicle. Wireless transmission technology can transfer the information collected by the sensor on the IoV, and then implement information communication and remote control. Moreover, accessorial vehicle-locating technology based on sensors is an essential part of the IoV, which provides more accurate and real-time traffic conditions.

B. Fog computing

a) Hierarchical Structure: Fog computing is deployed in multiple layers and the architecture can be divided into the end-user layer, access network layer, fog layer, core network layer and cloud layer [3], as is shown in Table1.

TABLE I. MAIN DEVICES AND FUNCTION OF FOG COMPUTING

Layer	*Devices*	*Function*
End-user layer	Mobile phones, laptops and sensor nodes	Produce and consume content; Spot fog nodes; Return the result
Access network layer	Wireless network devices and a small number of wired networks devices	Send the end user's task to the fog node based on a predetermined rule
Fog layer	Fog edge node, foglet and fog server	Compute, storage and communicate
Core network layer	Core network devices	Send tasks that exceed the computing or storage capabilities of the fog layer to the cloud data center
Cloud layer	Cloud server	Data backup and processing tasks of big data

b) System Architecture: The system of fog computing can be divided into several parts: hardware control, protocol abstraction, hardware platform foundation, resources, node security, node management and hardware virtualization [4].

Hardware such as sensors or software-based devices connects a single fog node to thousands of such devices. Protocol abstraction helps fog nodes communicate with devices using different protocols, which enhances interoperability between fog nodes and multi-vendor devices. Hardware platform foundation is the basic operating environment and module components provided for hardware. The resource layer includes network, accelerator, computing and storage. Node security is critical to the security of the whole system, including all levels of fog node components from hardware to software. Node management is the management of high-level nodes to low-level nodes. The implement of the fog platform can be realized by the virtualization of hardware processors.

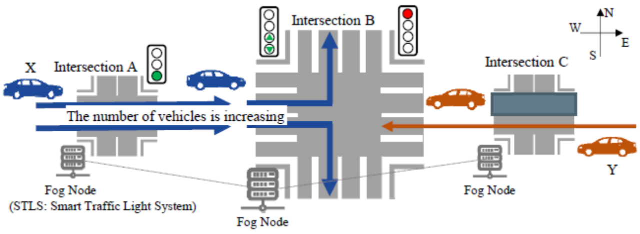

Fig. 1. A scenario of a fog-based smart traffic light system in IoV [5]

c) Basic Scenario and Model of Fog Computing for IoV: Fog computing has demonstrated its superiority in dealing with problems of high mobility and distributed computing, such as traffic congestion and real-time transportation management. Figure 1 illustrates a basic scenario where fog computing is used in smart traffic light systems for IoV [5]. Each traffic light system can coordinate with each other, such as changing the length of red-light time, by analyzing traffic conditions received from sensors on vehicles and roadside routers. Traffic light systems at every intersection constitute the network of fog nodes via wireless transmission technology such as 5G and Wi-Fi. To minimize latency, each fog node collects data streams from the environment in its proximity. As is illustrated in Fig. 1, the number of vehicles from A to B is supposed to be increasing, while that is less from C to B. Under this circumstance, the fog nodes at intersection A, B and C will cooperate to adjust the management plan, extending green-lights in east direction and red-lights in west direction. Without uploading the data streams to the cloud server, local fog nodes can solve the problem based on their computing resources, which reduces the delay of decisions.

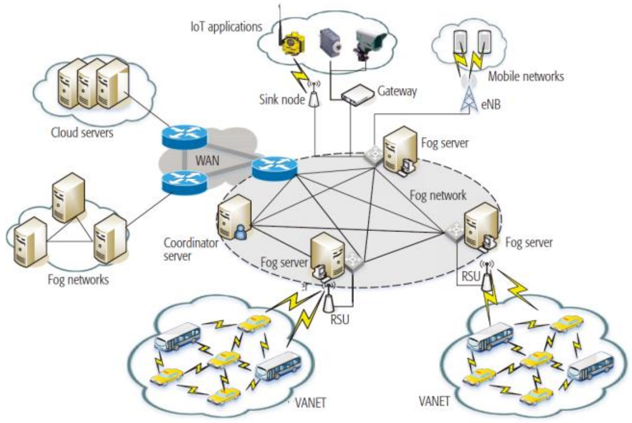

Fig. 2. Proposed fog-based architecture for IoV [6]

Fig. 2 shows a basic model of fog-based IoV. It contains two layers: the fog layer and the edge layer [11]. The fog layer is the combination of fog servers distributed in different locations and connected with cloud servers through routers in the Wide Area Network (WAN). The edge layer consists of many units of ad hoc networks, such as Vehicle ad hoc network (VANET), mobile networks and some IoT applications. Information and instruction are transferred by roadside units (RSUs) from fog devices to mobile terminals.

Based on fog computing, the fog layer in IoV has two different modes: the coupling mode (CRF) and the decoupling mode (DRF) [6]. RSUs are set in the same location with fog devices in CRF mode, while RSUs and fog devices are equipped in different locations. Both modes represent two alternative integration methods for interactive devices. A fog server is only responsible for events that it subscribes in a certain range of the surrounding environment. It means that perhaps all fog nodes could be requested, but only those subscribing in a certain rage can actually accept the request and receive the information.

III. INTERNET OF VEHICLES BASED ON FOG COMPUTING

A. VANET

Vehicle ad hoc network (VANET) is an opening network that encourages moving vehicles equipped with wireless interface to connect to fixed roadside wireless routers [7]. With the increasing number of vehicles, the range of VANET is growing larger and larger, containing numerous mobile nodes that move at high speed and communicate with each other. As the new era of VANET, the IoV supports the service for a city or even a whole country.

In IoV systems, the real-time GPS, various sensors in autonomous cars and smart traffic light systems and intelligent transportation management are required to communicate and deploy the resources intelligently and reasonably. According to limited computation capacity and resources, computing tasks are uploaded to centralized cloud servers, and the results are transferred back to users after data-processing. There are still some flaws in centralized cloud servers for resources management in IoV. The centralized computing model could not support highly dynamic management and interactive environment in IoV because of service provision and constrained rate of transmission. In addition, latency is unavoidable on account of flooding forwarding information base [8] and transmission through WAN, which becomes the bottleneck of autonomous driving in VANET. Moreover, VANET is a heterogeneous network, which cannot be supported by a centralized cloud [9].

The root cause of such problems lies in the contradiction between constrained resources and real-time local management. Therefore, a new paradigm in VANET called Vehicular Fog Computing (VFC) has been proposed, which accelerates computing and storage by transferring traditional vehicular cloud services to edge fog nodes. Vehicular Fog Service (VFS) solves such problems by providing greater safety on the road and many applications with less latency, such as intelligent traffic management and autonomous driving.

The number of vehicles grows by millions annually. Some researches show that most vehicles remain parked up to 95% time in a day, which is a great waste of resources. These parked cars can be changed into fog nodes and provide computing services for surrounding vehicles on the road. The On-board Units (OBUs) of future vehicles not only establish communication between vehicles and RSUs, but also provide services for information storage and processing. The OBUs in parked cars can be deployed as network access points (NAP) and computational servers.

Reference [10] evaluating the average end-to-end latency and TCP throughout performance in VFC facilities. The study illustrates that the average delay and throughout performance remain at a stable level although the number of background connections varies from 30 to 100. In addition, the results of the simulation show that the performance of VFC facilities holds on to a high level when the number of TCP flows increases.

B. Big Data in Fog-based IoV

IoV is a heterogeneous network consisting of VANETs, roadside IoT, mobile networks, and cellular mobile networks [6]. This could cause the failure of data processing and high latency when converting supported data format in IoV services based on cloud computing. Fog computing successfully offloads computing tasks to local fog nodes, and solves the problem of high latency in big data and invalid heterogeneous network services.

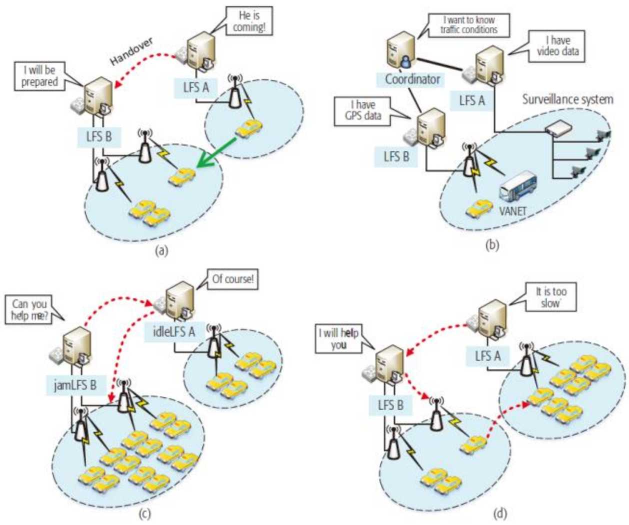

Fig. 3. Cooperative Fog Computing Scenario

For the synergistic cooperation of Local Fog Servers (LFSs), Wenyu Zhang introduces four types of cooperative model between two adjacent nodes [11]. As discussed in Section 2, a fog server is only responsible for events happening in a certain range of it, which is called a topic-based publish/subscribe model. The Mobility Support and Service Migration (MSSM) mechanism can coordinate different LFSs when users travel between them. As shown in Fig. 3a, when a vehicle travels from LFS A to LFS B, LFS A will send a message to LFS B before the vehicle leaves its subscribing range so that LFS B could be prepared in advance and maintain uninterrupted service. The second type of LFS cooperation is Multi-Source Data Acquisition (MSDA). The dynamic data processed in fog nodes can involve many fields, such as GPS, spectrum, temperature, road situation, etc., while the computing capacity of a single fog node is limited. The MSDA is to collect data from different LFSs that are in charge of the relevant information around them. Fig. 3b illustrates an example that a coordinator acquires the traffic conditions of the whole city. LFS A set by the road has the data of GPS, while LFS B set at a crossroads has the data of surveillance systems. The coordinator sends a message to both LFSs and receives data of GPS and surveillance systems respectively. By MSDA, the width and depth of data can be enlarged and the management can be more efficient. The third type of LFS cooperation is Distributed Computation and Storage. It is common sense that the vehicles are distributed unevenly in the city, thus the workloads of LFSs are unbalanced. In this model, distributed computation and storage are applied to migrate service from jammed LFSs to idle LFSs. For example, in Fig. 3c, LFS A's workload is very low, while LFS B works under heavy stress of resources. Then LFS B will request help and allocate some workloads to LFS B. The fourth type is Multi-Path Data Transmission. It is a huge burden for IoV that it has to support millions of mobile ends and sensors. If shared by millions of devices, the wireless channel between LFSs and mobile devices can cause network congestion. Fig. 3d gives us an example that the downloading rate from LFS A is too slow because it is shared by too many vehicles. In this case, LFS B can build a multi-path route from LFS B to the VANET and transmit data to the user bypassing the congested channel of LFS A. Similarly, it also works in data transmission between LFSs and the Cloud.

In pursuit of low latency and high mobility in the IoV environment, researchers start to pay more attention to real-time big data processing. A multi-dimension layered architecture based on fog computing, named as the Real-time Intelligent Transportation System (RITS) big data analysis, was proposed in [12], including the intelligent computing dimension, the real-time big data dimension, and the IoV dimension.

The intelligent computing dimension in RITS big data is the lowest dimension and divided into four layers, low fog computing layer, intermediate fog computing layer, high fog computing layer and cloud computing layer. The low fog computing layer consists of electronic devices that can process data locally, such as vehicles and ITS smart devices. The component can directly perform fast and simple data processing. The intermediate layer fog computing layer consists of fog nodes located at the edge of the network with more resources, such as RSUs and Routers. Different from the low layer, this layer can process more complex data by receiving data from the lower layer. Besides, thanks to being close to users, the response of real-time applications is fast. The high fog computing layer consists of the Internet WAN components, which provides fog computing facilities. As the width and depth of data keep growing, it brings a slight latency in this layer. But it still accelerates the computing based on streams. The cloud computing layer provides centralized processing on massive data with artificial intelligence. The core task of this dimension is to decide which data should be sent to the upper layer with no perceivable delay.

The middle dimension in RITS big data is the real-time big data analytics dimension, which provides real-time data processing in the IoV environment. This dimension can be divided into three layers based on the lambda architecture for generic real-time big data processing [13]. The top layer is the batch layer, which has unlimited storage and computational capacity by utilizing cloud computing facilities. Due to the high latency in cloud computing, this layer is not responsible for real-time services but for answering the queries of real-time applications. The second layer is the speed layer. Data in this layer is processed in near real-time fashion by dividing computing projects into parallel and distributed tasks. The fog clusters and nodes in the lower dimension are utilized. Data analytics are allocated to different fog computing layers considering the resource capacity. Compared to the batch layer, this layer focuses on the small and latest data sets rather than considering the historical data. The bottom layer is the serving layer, which mainly utilizes resources in low and intermediate fog computer layer. The amount of data saved in this layer is relatively small and the stream data can be processed quickly.

The highest dimension, the IoV dimension, represents the structure and events in IoV and consists of six layers: perception layer, infrastructure network layer, artificial intelligence layer, communication layer, application layer and business layer. These layers implement the technical and economical functions of real-time big data in each part of the IoV, from data acquisition to transmission, then to calculation and feedback.

It is also important to note that RITS big data requires reliable data transmission and a high degree of coordination between dimensions and layers.

C. Security

Communication and data security play an extremely important role in IoV, of which it is significant to ensure that the information transferred and received by the intelligent terminal during highly mobile interaction is not leaked. When the application of the Internet gets deeper, local services, such as intelligent transportation management and autonomous driving, will increasingly involve users' personal information and privacy like itinerary within a few days, home address, and even private key in communication. It remains a problem how to guarantee that data transmitted from the local terminal is not tampered with maliciously and how to use it efficiently.

The present security mechanisms of cloud computing still focus on the encryption key [14]. However, the cloud server approves users to get access to the database from anywhere and at any time, which expose the encryption key in an opening environment. In addition, clouding computing security mechanism does not consider the verification of users' identities, which increases the risk of privacy and data theft.

Mhidi Bousselham introduced a new security mechanism and offensive decoy technology (DT) based on fog computing system. The local fog server can detect external intrusion by analysis of user behavior profile (UBP). For example, a port attempts multiple logins into account. Then the fog server will create decoy documents that contain disinformation to protect users' privacy.

Mohammad Wazid proposed a secure authentic key management protocol in fog-based IoV, which assure the communication authentication in vehicle-to-vehicle (V2V), vehicle-to-roadside unit (infrastructure) (V2I), vehicle-to-fog server (V2F), roadside unit-to-fog server (R2F), and cloud server-to-fog server [15]. Despite considering the authentic key management, it is still vulnerable to be attacked by vehicle impersonation, RSU impersonation and fog server impersonation due to heterogeneity and high mobility of IoV [16]. In addition, fog computing system also faces problems, such as node capture/device tampering, boundary inspection and signal jamming. Therefore, there is still a long way to go to improve the security mechanism of IoV.

IV. Challenges and Future Work

A. Implementing Fog Computing in IoV Environment

VANET is actually a mobile ad hoc network with frequent interruption, high mobility and low contact rates, which has an impact on vehicles' downloading information when access to the Internet. Due to the limited number of access points in the initial stage of the deployment of IoV and large amounts of vehicles and data requests beyond the capacity of fog nodes, it is necessary to make RSUs evenly distributed. In addition, the solutions for link failure and packet loss should be proposed when the vehicle enters the overlapping coverage area of RSUs and switches to the next RSU.

B. Big Data in Fog-based IoV

As is introduced in Section 3, the scenario of fog computing is variable and hardly predictable, which requires the big-data performing system to make decisions under uncertainty conditions. However, the boundary conditions are not always accurate and available in present cooperative fog computing systems. Therefore, it is essential to find an appropriate denote and assessment of uncertainty. In addition, due to the heterogeneity of IoV network, a new data presentation and processing model that accommodates heterogeneous or new types of data needs to be proposed [12].

C. Security and Privacy

Security threats and privacy theft cannot be fully excluded by existing security protocols in fog-based IoV. Developing new technologies and security mechanisms with various protocols is a top priority to ensure IoV security. However, current security mainly depends on the bit-level encryption technology and different levels of security protocols, which adopt patching and hanging design ideas. It is necessary to develop endogenous security standards during the construction of communication networks. The 6th generation mobile networks (6G) is proposed with endogenous security network protocols and networking mechanisms to achieve authentic identity, control security, reliable communication, and data trust, which will be the inevitable choice of the future fog-based IoV communication technology.

V. Conclusion

Fog computing has been presented for the application of the Internet of Vehicles. In this paper, we propose three aspects of fog computing that can be applied to IoV environment, which include vehicle ad hoc network, big data processing, and security. While the application of fog computing is promising, there are still some challenges as we discuss in this study, which can be new directions in the following research.

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