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POSSIBILITIES OF FOG COMPUTING FOR TRAFFIC SAFETY IMPROVEMENTS

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Abstract: The main objective of Vehicular Ad Hoc Networks (VANETs) is to improve drivers' safety and traffic efficiency. These networks are considered as a key component of Intelligent Transportation Systems (ITS). Periodic communication of VANET generates a huge volume of data, thus requiring adequate storage and computational resources. Due to high demands in terms of mobility, location awareness and low latency, there is a growing research interest in the role of fog computing in VANETs. Fog computing facilitates the communication, computing and networking close to end terminals. As an integration of fog computing and vehicular networks, the paradigm Vehicular fog computing (VFC) is a promising solution for real-time and location-aware network responses. This paper analyzes the possibilities of VFC and its application in traffic safety improvements. Key characteristics of VFC, the architecture and challenges in vehicular applications are also going to be addressed.

Keywords: VANETs, Fog computing, Cloud computing, Vehicular fog computing

1. INTRODUCTION

Urban vehicular networks are an essential segment of the Intelligent Transportation Systems (ITS). These networks improve traffic safety, support localization and navigation and provide efficient data transmission. Over the years, a prominent trend in the automotive industry was to integrate intelligent devices in vehicles in order to provide a better driving experience (Xiao et al, 2019). Nowadays, vehicles are equipped with on-board computing devices, wireless devices, a rechargeable battery etc. Based on Vehicular Ad Hoc Networks (VANETs), it is possible to inform drivers about potential safety risks for enhancing their awareness of traffic conditions. However, in order to satisfy the communication and computational requirements of traffic management, on-board capacities need to be fully utilized. In addition, the bandwidth of cellular networks is limited and mainly controlled by network operators. Also, the deployment of roadside units (RSUs) is costly. Moreover, the existing computing paradigms are time-consuming and expensive for real-time data transmission in vehicular networks. Therefore, a new platform for traffic management is necessary.

Vehicular cloud computing (VCC), as an integration of vehicular networks and cloud computing, aims at the provisioning of network resources efficiently, so that vehicles represent resource providers and resource customers simultaneously. The ever-increasing demand for provisioning of services, contents and applications in vehicular networks requires more computing resources and real-time feedback. This is an important challenge for resource-limited vehicles and centralized traffic management mechanisms, in particular during high traffic load in urban areas. The performance of such a system is constrained by high latency. To solve these challenges, a new computing paradigm, Vehicular fog computing (VFC), is proposed to better exploit potential computing resources. When vehicles are moving slowly in traffic congestion situations, computing devices in vehicles can form a computing fleet, which refers to the vehicular fog (Tian et al, 2016). The vehicular fog is formed and continuously updated by the following procedure. Vehicles autonomously detect surrounding vehicles connected by vehicle-to-vehicle (V2V) communications. Within the same fog, vehicles can communicate and recognize each other via one-ho, multi-hop V2V or vehicle-to-infrastructure (V2I) communications. Therefore, vehicular fog is an architecture that utilizes numerous cooperative vehicles or edge devices to provide computing and storage resources. The main difference between the cloud computing and the vehicular fog is the proximity to end-users, dense geographical distribution and support for mobility. In general, vehicular fog comprises vehicles that are located closely in a traffic congestion situation. Hence, communication costs tend to be low. These connected vehicles have numerous advantages in vehicular applications, including safety systems, smart traffic lights, shared parking, etc (Kim et al, 2015). Additionally, augmented reality, real-time video analytics, content provisioning and big data analytics can also be provided using fog in a vehicular environment (Yi et al, 2015).

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This paper is organized as follows. After the introductory remarks, section 2 provides key characteristics of vehicular fog computing, including the definition of fog computing, the architecture and the comparison between vehicular fog computing and similar computing paradigms. In section 3, the possible scenarios of vehicular fog computing application for traffic safety improvement are observed. Research challenges and some open issues are presented in section 4. Finally, concluding remarks are provided in section 5.

2. KEY CHARACTERISTICS OF VEHICULAR FOG COMPUTING

Fog computing is a computing paradigm introduced to improve the provisioning of geographically distributed and latency sensitive applications. Cisco (2014) initiated the concept of fog computing in order to extend cloud computing to the edge of a network. Fog refers to as the cloud close to the ground, i.e. From cOre to edGe computing. It is a highly virtualized platform that provides computing, storage and networking services between end users and cloud data centers. According to OpenFog (2017), the main capabilities of fog are the following: security, cognition, agility, latency and efficiency. In general, fog computing provides low latency and location awareness, heterogeneity, end device mobility, wireless access and capacity for processing numerous nodes. Additionally, it supports geographic distribution and real-time applications (Mukherjee et al, 2018). The multitude of geo-distributed devices, including end user devices, routers, switches and access points, are placed at the edge of the network. The major task of fog computing is to use the edge devices in proximity to eliminate data upload/download to/from the core network. Edge devices in fog computing enable access to some of their resources to support the provisioning of requests from their neighboring devices. If the task cannot be provided by the edge device, the core cloud resources will be in charge of further processing.

2.1. Definitions of fog computing

Various researchers and institutions defined fog computing (Naha et al, 2018). According to the definition provided by Vaquero and Rodero-Merino (2014), fog computing is a concept that enables communication between numerous heterogeneous and decentralized devices that cooperate themselves and with the network with the aim of provisioning storage and processing tasks without third party's involvement. These tasks comprise basic network functions or new services and applications. Based on the definition provided by the OpenFog Consortium OpenFog (2017), fog computing can be described as a system-level horizontal architecture that distributes resources and services of computing, storage, control and networking anywhere from cloud to the edge devices. According to IBM (2016), fog computing and edge computing are, in essence, the same computing paradigms, enabling resources and processing of tasks at the edge of the cloud. Fog computing can also be defined as a distributed computing platform where virtualized and non-virtualized end or edge devices perform most of the processing (Naha et al, 2018). The connection with cloud resources is enabled for non-latency-aware applications and long-term storage of useful data. In this case, all devices with computing and storage capacities are referred to as fog devices, while the role of the cloud in a fog computing environment is more precisely described.

2.2. The vehicular fog computing architecture

A high-level architecture of VFC is shown in Figure 1. Such architecture is composed of three layers, the data generation layer, the fog layer and the cloud layer. The data generation layer comprises smart vehicles as an essential segment in a VFC system, due to their real-time computing, sensing, communication and storage capabilities. The data volume generated by the numerous sensing devices in a smart vehicle is estimated to be approximately 25 GB/h in a single day (for example, 20-60 MB/s for cameras, 10 kB/s for radar and 50 kB/s for Global Positioning System (GPS)), according to Huang et al (2017). A smart vehicle can process some of these data itself, in order to support real-time decision making (vehicle-level decisions). Other data are shared and uploaded to the fog nodes for further analysis and used for other purposes, such as traffic and infrastructure planning or monitoring. The fog layer contains fog nodes, i.e. road-side units (RSUs). RSUs are deployed in different locations. They can be easily upgraded to take the role of fog nodes. Hence, fog nodes enable the gathering of the data transmitted from smart vehicles, processing of the data and reporting to the cloud servers. Fog nodes are the connection between smart vehicles in the data gathering layer and cloud servers in a VFC system. Compared to the existing vehicular networks, fog nodes have more functions and provide more diverse services for smart vehicles (navigation, video streaming, smart traffic lights, etc.). In addition, fog nodes process data, store data and support decision making as a fog layer (area-level decisions). Cloud servers form the cloud layer in the VFC architecture. Monitoring and centralized control from a remote location are performed by cloud servers. These servers use the data collected by the fog nodes to perform computationally intensive analytics for optimal decision making. Thus, monitoring and management of road traffic infrastructure are possible to achieve.

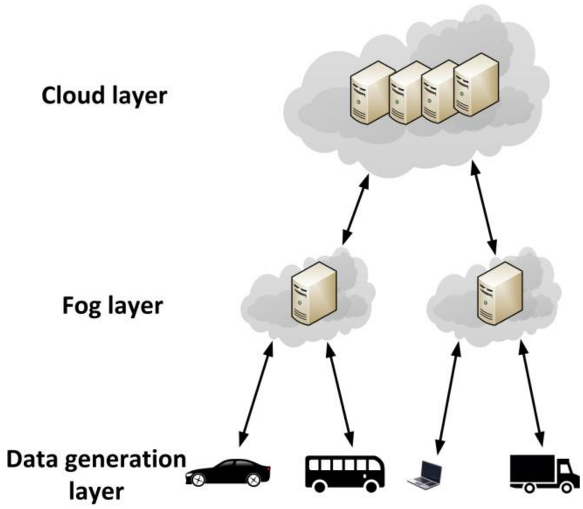

Figure 1. *The architecture of vehicular fog computing*

2.3. Benefits of VFC architecture

If implemented appropriately, the VFC can provide wide-ranging benefits, briefly summarized in Table 1. Fog nodes are seen as the extension of cloud servers from remote locations to the edge of the network, with the aim of provisioning more efficient and effective services. Thus, vehicle-based applications have numerous advantages in terms of response time, communication and storage, which may be of crucial importance in, for example, an adversarial setting. The majority of vehicular applications require real-time response, in particular for traffic control and safety improvements. VCC architecture cannot support low-latency requirements. Due to remote data processing, latency and potential connectivity issues may occur in a VCC system. The average response time for VCC is more than a second, while VFC provides the average response time under 10 ms (Huang et al, 2017). Therefore, fog nodes located in the proximity of vehicles in a VFC system can significantly reduce the response time for vehicular applications.

Table 1. *Typical use-cases of vehicular fog computing*

Application	Service	Description
Traffic control	Smart navigation	Optimal routing for smart vehicles
	Smart traffic lights	Management of traffic lights in each intersection to control traffic flows
Traffic safety	Detection of road conditions	Detection of environmental conditions and adjustments
	Emergency notifications	Broadcasting of emergency warnings to neighboring vehicles
Entertainment	Advertisement	Sharing advertisements of public interest
	Multimedia	Provisioning of multimedia contents for smart vehicles

It is estimated that the data volume, generated and transmitted by vehicles, will have exponential growth in the future (Huang et al, 2017). Despite advancements in communication technologies, the bandwidth requirements to support these data volumes cannot be satisfied by conventional VCC systems. The VFC can alleviate those limitations by pre-processing, aggregating and filtering of the data collected from vehicles.

Due to changes in a vehicular environment, data storage in the remote cloud servers is not convenient. Since vehicular applications are mostly location-aware, the possibility of real-time access to the data stored in decentralized location-aware fog nodes can reduce the necessary storage capacity in the remote cloud servers.

2.4. Comparison between VCC and VFC

The differences between VCC and VFC are summarized in Table 2. Primarily, the VCC has constraints in terms of bandwidth, latency and deployment costs, while the VFC is based on geo-distribution and provides real-time load balancing and local decision making. Furthermore, VFC relies on the cooperation between neighboring vehicles, without the need to send the data to remote cloud servers. Thus, the deployment costs and delays are reduced. In addition, VFC is more robust and provides better responses in critical situations, compared to the VCC. For example, if it is not possible to establish a connection with cloud servers or remote control, the performances of VCC are significantly degraded. However, VFC system can run even in these situations using resources within vehicles. Also, more computational capacity is available and communication delay is reduced in the VFC.

Table 2. *Differences between VCC and VFC*

Characteristics	VCC	VFC
Communication	Bandwidth constrained	Real-time load balancing
Computation capacity	High	Low
Deployment cost	High	Low
Decision making	Centralized	Remote
Geo-distribution	No	Yes
Resource optimization	Global	Local
Reliability	High	Low
Latency	High	Low
Mobility management	Simple	Complex

In general, VCC and VFC are convenient alternatives in the scope of ITS for enabling ubiquitous network access and solving high traffic demands. While VCC supports centralized management of network resources, VFC uses edge devices in order to improve resource utilization. Since VCC and VFC are complementary computing paradigms, their interactions require comprehensive analysis.

3. VEHICLES AS INFRASTRUCTURE IN VFC SYSTEMS

Vehicles in VFC systems can be used as infrastructure, with two possible scenarios: moving vehicles as infrastructure and parked vehicles as infrastructure. These use cases are described below.

3.1. Moving vehicles as infrastructure in VFC systems

In general, there are two types of nodes in vehicular networks: vehicles and RSUs. Vehicular communications, as a segment of ITS, aims at improving traffic safety and efficiency. Participants in ITS can interact through V2V and V2I communications. In V2I communications, the energy consumption of RSUs is the major constraint and has to be considered in order to achieve high reliability and long lifespan of the network (Abraham and Narayanan, 2014). In V2V communications, the distance between vehicles needs to be within the communication range, so that the successful connection can be established. Therefore, network connectivity is one of the most important requirements for efficient data transmission, particularly for V2V communications. Moving vehicles can be used as the infrastructure in a VFC system, which can significantly solve above mentioned challenges in terms of network connectivity. Moving vehicles can be used for continuous data transmission by building up new connections. Due to geo-distribution and local decision making, moving vehicles in a VFC system can collaborate and connect with each other. Some vehicles can take the role of communication hubs. These vehicles can connect neighboring vehicles, i.e. mobile access points. Thus, the fog is formed. Instead of data transmission to cloud servers, a number of tasks can be completed using computational and communication resources locally, which comprises both local decision making and geo-distribution features. Hence, the latency is reduced, as well as costs, with improved efficiency.

In order to employ moving vehicles as infrastructure, it is necessary to determine vehicular speed distribution in space and time domains. Afterwards, the relations between connectivity and mobility in vehicular networks can be defined, in order to assess all the benefits of using moving vehicles as infrastructure.

Slow-moving vehicles can be an important segment of computational infrastructure in VFC systems. Thus, using on-board embedded computation resources, vehicles can be connected via V2V communications. Congested vehicles and also be connected via V2I communications systems with RSUs. In this scenario, the VFC system aggregates computation resources and then reallocates them to satisfy the computation demands of individual vehicles.

3.2. Parked vehicles as infrastructure in VFC systems

The number of parked vehicles (in street parking, off-street parking and interior parking) in an urban area is vast. Compared to the scenario with moving vehicles, locations of parked vehicles are relatively consistent over long periods of time. Therefore, the data transmission from place to place directly in the space domain is not possible. However, using a rechargeable vehicle battery, parked vehicles can establish connections with other parked vehicles, as well as with nearby moving vehicles. Thus, parked vehicles represent a static backbone to improve connectivity. Since parked vehicles are characterized by long-time staying, wide geo-distribution and specific locations, they are very convenient communication nodes in urban areas. These vehicles can compensate the disadvantages of moving vehicles (relatively unbalanced distribution and rapid-changing positions). The number of parked vehicles and the distribution of parking time significantly affect the available capacity and other features of parked vehicles as a segment of communication infrastructure. When parked vehicles in a certain parking lot join VFC, these vehicles form a data center, thus providing the processing of various complex tasks.

4. SCENARIOS OF VFC APPLICATION FOR TRAFFIC SAFETY IMPROVEMENT

VANETs need to respond to many challenging issues including emergency alerts, collision avoidance, cooperative driving, traffic status reports, etc. Since the traditional architecture of VANETs is not able to support the increasing requirements in a vehicular environment, cloud computing and fog computing are considered as convenient paradigms to solve these issues. VANET applications can be broadly categorized into three types: safety applications, convenience applications and commercial applications (Kai et al, 2016). Safety applications comprise notifications for accidents, hazards on the road, slippery or wet road conditions, traffic violation warnings, curve speed warnings, emergency electronics brake light, pre-crash sensing, cooperative forward collision warnings, approaching emergency vehicles, etc. Convenience applications refer to navigation, routing, congestion advice, toll collection, parking and availability information, information on power failure and network breakdown in disaster situations, etc. Due to their on-board batteries and numerous sensors, connected vehicles can help to overcome critical situations. In addition, road and weather conditions can be monitored by sharing the data from on-board vehicle sensors. Commercial applications include sharing the data on vehicle diagnosis, location-based services, advertisements and entertainment, social networking updates, etc (Hartenstein and Laberteaux, 2008; Faezipour et al, 2012; Zaidi and Rajarajan, 2015).

As indicated earlier, fog computing supports applications with low latency requirements (gaming, augmented reality, real-time video stream, etc). A fog-assisted traffic management system provides huge benefits, including reducing road traffic congestion and traffic accidents. Such VFC system contains two subsystems, depending on the area of the activity: subsystem responsible for the local area and subsystem in charge for the global area.

The local traffic control subsystem is in charge of monitoring and managing traffic flows on the local level. The communication range of a fog node can cover several intersections in a specific region. If a vehicle is located within the communication range of a fog node, it is possible to establish a connection with the given fog nod to enable the data transmission to and from the fog node. In particular, the vehicle approaching the communication range of a fog node typically reports its current location, speed, weather conditions and road conditions, until it leaves the specific region.

Based on the data received from neighboring vehicles, the fog node in the local traffic control subsystem can monitor and control the local traffic flow by scheduling the traffic light at each intersection, and this can be performed in two phases. A local intelligent traffic light algorithm is implemented at the fog node in the first phase. Important traffic information, such as road segment occupancy, is determined by each fog node. Afterwards, the intelligent traffic light control algorithm manages the red and green phase proportion for each traffic light. The aim is to provide that phase control is performed in real-time, with low latency. It should be noted that in the case of fast-moving vehicles, the response time for traffic flow control will mainly depend on the speed of these vehicles. Traffic lights should also be updated for vehicles leaving the intersection. In the second phase, the fog node performs pre-processing and aggregation of the received data as the statistical traffic information. During this phase, the reports to cloud servers are also created. It is important to emphasize that the data reported to cloud servers are not the same since each vehicle has a different data format in terms of location and speed. Using the intelligent algorithm, the fog node can integrate the received data as traffic volumes, the number of vehicles, average speed of the vehicles, average waiting time of the vehicles at each intersection, etc. and create the output data to create the report to cloud servers.

The global traffic control subsystem is in charge of control and management of the traffic flows from a wide-range area perspective, typically, a city-wide region. The data sent by fog nodes are gathered at the remote cloud servers, where data analytics is performed. Cloud traffic controlling algorithms comprise a global intelligent traffic light control and a dynamic routing algorithm. The global intelligent traffic light control algorithm is characterized by greater complexity compared to the algorithm performed in the fog nodes. The main goals of this algorithm are to predict and adjust traffic control systems by considering real-time traffic volume, historical traffic records, weather conditions and road conditions. Therefore, the execution of this algorithm at the cloud server is a time-consuming process. However, the response time, in this case, is not critical since the traffic volume and weather conditions on the global level can be considered as stable over a short time period. The outcome of the global intelligent traffic light control algorithm are optimal traffic light policies. These policies are distributed to all fog nodes in the area from the cloud servers. Furthermore, navigation services can be provided by cloud services to improve the control of traffic flows. From a global perspective, a dynamic routing algorithm is also of great importance. Based on the vehicle's current location and destination as the input, the dynamic routing algorithm can calculate the optimal route by predicting and simulating the traffic conditions (Huang et al, 2017).

5. RESEARCH CHALLENGES AND OPEN ISSUES

The VFC-based systems for real-time traffic management are still at an early stage of the development. Efficient integration of parked and moving vehicles is essential for the implementation of the VFC system. Furthermore, accurate traffic mobility and prediction is needed better utilization of vehicles' energy and computing resources. Traffic prediction can be managed by the synergy of the traffic authorities, vehicular fog nodes and vehicles through data sensing, processing and sharing. By tracking the vehicle's position, direction and velocity, vast historical and real-time data can be used to improve mobility prediction. However, network heterogeneity is an important challenge in this context and requires a significant effort to deal with.

VCC and VFC are promising computing paradigms to respond to increasing traffic demands and provide ubiquitous Internet access. Unlike VCC, which provides centralized management of network resources, VFC uses edge computing and storage to reduce latency and improve the utilization of resources. Interaction of VCC and VFC, as segments of ITS, require comprehensive analysis. A fog-to-cloud computing system supports grouping of vehicles in a parking lot and constructing roadside clouds by controlling traffic lights dynamically (Masip-Bruin et al, 2016). Services provided by fog nodes can achieve timely and flexible network responses. However, cooperative uploading and offloading of parked and moving vehicles can be a new form of the shared economy. Pricing of these services can be a further research direction.

Enabling secure communications between vehicles is of great importance for the realization of network service and application. The computation and storage facilities of VCC can be extended by VFC, on the expense of potential security and privacy issues. Current research directions are mainly focused on the security and privacy issues in fog computing regarding the scalability, privacy-preserving authentication and forensics. In order to improve traffic safety and reduce accidents caused by poor road conditions, vehicle-based sensing is needed. Although some models for security assurance and privacy preservation are proposed (Basudan et al, 2017; Ni et al, 2018), unauthentic vehicle connections, heterogeneous road infrastructure and private information of road events are still important challenges for the VFC architecture. Moreover, in situations when computational tasks are performed by different vehicles in VFC, privacy issues must be appropriately managed (Ning et al, 2019).

6. CONCLUSION

This paper presents key characteristics of Vehicular fog computing, a new computing paradigm for VANETs. The VFC attracts a lot of research attention since it supports latency-aware application in a vehicular environment. The architecture of VFC, composed of three layers: the data generation layer, the fog layer and the cloud layer, is described. Advantages of such architecture are indicated in the paper. The VFC extends the computation, communication and storage facilities from remote cloud to the edge of the network. Furthermore, this computing paradigm is a complementary technology to Vehicular cloud computing. The comparison of the key characteristics of VCC and VFC is provided in the paper. Vehicles are an essential segment of VFC systems since moving and parked vehicles can be used as infrastructure, with different features depending on the observed scenario. In terms of traffic safety improvement, VFC is considered as a promising solution for numerous challenges. These applications include sharing notifications for accidents, hazards on the road, slippery or wet road conditions, traffic violation warnings, curve speed warnings, emergency electronics brake light, pre-crash sensing, cooperative forward collision warnings, approaching emergency vehicles, etc. VFC also supports traffic management in local and global level, thus expanding the possibilities of VFC for traffic safety advancement. Since VFC is in an early phase of the development, there are some open issues, mainly concerned by reliability, heterogeneity, privacy and security. These challenges are also presented in the paper.

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