Available online at www.sciencedirect.com
ScienceDirect

April 2016, 23(2): 56–65
www.sciencedirect.com/science/journal/10058885

The Journal of China Universities of Posts and Telecommunications

http://jcupt.bupt.edu.cn

Fog computing for vehicular Ad-hoc networks: paradigms, scenarios, and issues

Kang Kai[1,3] (✉), Wang Cong[1,3], Luo Tao[2,4]

1. School of Software Engineering, Beijing University of Posts and Telecommunications, Beijing 100876, China
2. School of Information and Communication Engineering, Beijing University of Posts and Telecommunications, Beijing 100876, China
3. Key Laboratory of Trustworthy Distributed Computing and Service, Beijing University of Posts Telecommunications, Beijing 100876, China
4. Beijing Key Laboratory of Network System Architecture and Convergence, Beijing University of Posts Telecommunications, Beijing 100876, China

Abstract

Vehicular Ad-hoc networks (VANETs) are kinds of mobile Ad-hoc networks (MANETs), which consist of mobile vehicles with on-board units (OBUs) and roadside units (RSUs). With the rapid development of computation and communication technologies, peripheral or incremental changes in VANETs evolve into a revolution in process. Cloud computing as a solution has been deployed to satisfy vehicles in VANETs which are expected to require resources (such as computing, storage and networking). Recently, with special requirements of mobility, location awareness, and low latency, there has been growing interest in research into the role of fog computing in VANETs. The merging of fog computing with VANETs opens an area of possibilities for applications and services on the edge of the cloud computing. Fog computing deploys highly virtualized computing and communication facilities at the proximity of mobile vehicles in VANET. Mobile vehicles in VANET can also demand services of low-latency and short-distance local connections via fog computing. This paper presents the current state of the research and future perspectives of fog computing in VANETs. Moreover, we discuss the characteristics of fog computing and services based on fog computing platform provided for VANETs. In this paper, some opportunities for challenges and issues are mentioned, related techniques that need to be considered have been discussed in the context of fog computing in VANETs. Finally, we discuss about research directions of potential future work for fog computing in VANETs. Within this article, readers can have a more thorough understanding of fog computing for VANETs and the trends in this domain.

Keywords VANET, fog computing, cloud computing, application, vehicular cloud computing

1 Introduction

It is impressive that the automotive industry has a huge development in recent years. With the improvements in software, hardware and communication technologies, the design and implementation of several types of networks deployed in different environments are upgrading, especially for VANETs [1–3]. VANETs are specific types of MANETs that consist of vehicles with OBUs, RSUs, in which vehicles are seemed as mobile nodes.

A VANET is a set of moving vehicles in a wireless network that apply the information communication technology (ICT) to provide state-of-the-art services of traffic management and transport. Presently, vehicles in VANET are being equipped with embedded sensors, processing and wireless communication capabilities opening a myriad of possibilities for powerful applications, such as vehicle and road safety, traffic efficiency and intelligent transportation systems (ITS) [4]. With the exchange of data among entities in VANETs, it provides safety and comfort for drivers. The true potential of the connected vehicles will be realized only when vehicles are interconnected to each other.

Cloud computing is the hottest technology within recent years. With the development of VANETs, resources as

Received date: 20-11-2015
Corresponding author: Kang Kai, E-mail: onefish@126.com
DOI: 10.1016/S1005-8885(16)60021-3

computing, storage and networking are needed by vehicles much increasingly in different scenarios, a number of solutions based on cloud computing is emerging. According to the requisite and affordability of users, cloud computing platform provides vastly manageable and scalable virtual servers, virtual networks, computing resources, storage resources, and network resources. Moreover, data can be accessed far and wide devoid of the trouble of keeping large storage and computing devices. With cloud computing, large amount of content can be shared and collaborated easily. It offers a solution to process distributed content. Vehicular cloud computing (VCC) is a new concept, which takes advantage of cloud computing to serve the drivers of VANETs with a pay as you go model [4]. But, it cannot meet all the requirements of quality of service (QoS) in VANETs, so that new technologies and architectures are needed.

Fog computing is a paradigm that extends cloud computing and services to the edge of the network. As opposed to the cloud, which is more centralized, fog computing is aimed at services with widely distributed deployments. With one of the attributes localized, low latency communication and more context awareness in fog computing is possible. Similar to cloud, fog provides data, compute, storage, and application services to end-users [5]. Fog computing as a new architecture is a good candidate for VANETs to meet the requirements, such as quick reaction to underlying device, reduce the burden on cloud, analysis real-time data stream with cloud and etc. Any device with computing, storage, and network connectivity can be a fog node, including mobile vehicles and infrastructure by the roads [6]. In VANETs, fog nodes closest to the network edge ingest the data from different types of devices, and developers decide how to use them. Compared with VCC, it is hard to resist the temptation to choose solutions based on fog computing which do better in real-time reaction issues.

The goal of this article is to investigate on the key features of fog computing and identify its main applications for VANETs. The structure of the rest of the paper is organized as follows. Sect. 2 summarizes the related works on fog computing focusing on its concept, features, and making comparison to cloud computing. In Sect. 3, presents applications for VANET based on fog computing and cloud computing. Challenges and issues on fog computing in VANETs are discussed in Sect. 4. And make conclusions in Sect. 5.

2 Fog computing

Fog computing is closely related with the Internet of things (IoT). IoT is generating an unprecedented volume and variety of data. But by the time the data makes its way to the cloud for analysis, the opportunity to act on it might be gone. In Cisco's white paper, intended for IT and operational technology professionals, explains a new model for analyzing and acting on IoT data. It is called either edge computing or fog computing:

1) Analyzes the most time-sensitive data at the network edge, close to where it is generated instead of sending vast amounts of IoT data to the cloud.

2) Acts on IoT data in milliseconds, based on policy.

3) Sends selected data to the cloud for historical analysis and longer-term storage [6].

Next sections, the concept of fog computing will be introduced, state-of-the-art of fog computing will be reviewed, and characterization of fog computing will be presented.

2.1 Concept of fog computing

Stolfo coined the term fog computing where technology is used to protect the real sensitive customer data from disinformation attacks against malicious insiders [7]. Fog computing systems integrate bait information with systems that generate alerts when a decoy is misused. After being embraced by Cisco and other companies, the meaning has been shifted that fog provides data, compute, storage, and application services to end-users, similar to cloud.

Fog computing (also called fog) is described as highly virtualized platform that provides the compute, storage, and networking services between end devices and data centers. Similar to cloud, fog offers data, compute, storage, and application services to customers. Fog computing was first introduced by Bonomi et al. in 2012 [8]. Similar systems typically known as edge computing, such as Cyber Foraging [9], Cloudlets [10]. In Ref. [11], fog computing is defined as 'a scenario where a huge number of heterogeneous (wireless and sometimes autonomous) ubiquitous and decentralized devices communicate and potentially cooperate among them and with the network to perform storage and processing tasks without the intervention of third parties. These tasks can be for supporting basic network functions or new services and applications that run in a sandboxed environment. Users leasing part of their devices to host these services get incentives for doing so.' Although the definition is still debatable, Yi et al. [12] strongly recommender it to differ fog computing from related technologies since anyone of those underlying techniques may offer us a false view on fog computing.

2.2 State of the arts

Bonomi [13] describes the basic architecture for computing, storage and networking for IoT, includes cloud computing and fog computing. The hierarchy between cloud and fog computing is shown in Fig. 1.

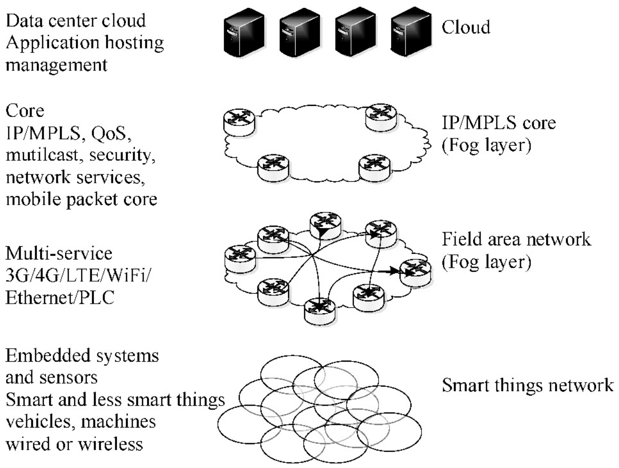


Fig. 1 Fog computing distributed infrastructure for IoT

Bonomi et al. [8] defines the characteristics of fog computing and its role in the IoT, and pay attention to a new dimension that IoT adds to big data and analytics based on massive distributed number of fog node [14]. Bonomi et al. emphasized the fact that the new elements brought in realm of IoT by fog computing is the sensitively to real time response. Fog is appropriate platform deploying various applications which can control critical resources like energy, traffic, healthcare and so forth. After that, Vaquero et al. [11] offer a border and integrative view of the fog. In his work, he summarizes the advances of fog at several levels and presents the definition of the fog. It is an important supplement and improvement of Bonomi's work. Stojmenovic et al. [5,15] elaborate previous scenarios and further expand this concept on smart building and software-defined networking (SDN). Hong et al. [16] proposes mobile fog as a right programming model for developing applications on the fog to achieve the potential benefits of fog computing in terms of efficiency and latency. Mobile fog resolves two main situations:

1) Simplify the development model for large number of distributed heterogeneous devices.

2) Application can use resources in the fog and in the cloud dynamically due to their demands.

Based on mobile fog, Hong et al. [17] propose spatio-temporal analysis application structure for large-scale situation awareness on camera network. Nishio et al. [18] purpose architecture for heterogeneous resource sharing among mobile devices in mobile cloud which refers to some concepts from fog computing. Zhu et al. [19] consider web optimization with fog computing context, using novel manner available at the fog nodes for existing methods, As a result, user's web page rendering performance is improved. Aazam et al. [20] present a model for smart communication to reduce the burden of cloud, which is consist of smart gateway based on fog computing. The fog computing paradigm as a non-trivial extension of the cloud is mentioned and discussed in those works [20–21].

As seen in Fig. 1, fog computing is superimposed onto cloud computing creates a distributed computing architecture for IoT to tackle with data processing and storage services which are needed by distributed embedded systems and sensors, the role of fog computing is like near-end computing proxies between the front-end devices and the far-end servers. But, the details for architecture of fog computing is not described. Reference model for architecture of fog computing is an important topic. Current research works about fog computing do not clarify a unified architecture which makes application development of fog to reinvent the wheel for different scenarios.

This is an ecosystem of industry and academic leaders committed to resolving the challenges surrounding fog and fostering an open architecture for fog computing. As a leader, Cisco is the most crucial and the most important participant to promote the progress of work about fog computing. At current stage, it is specially interested in proposals that focus on fog computing scenarios related to Internet of everything (IoE), sensor networks, data analytics and other data intensive services to demonstrate the advantages of such a new paradigm, to evaluate the trade-offs in both experimental and production deployments and to address potential research problems for those deployments. Customers can develop, manage and run software applications on Cisco IOx framework of networked devices, including hardened routers, switches and IP video cameras. Cisco IOx brings the open source Linux and Cisco IOS network operating system together in a single networked device (initially in routers). The open application environment encourages more developers to bring their own applications and connectivity interfaces at the edge of the network.

2.3 Characterization of fog computing

Fog computing is also known as edge computing, because it extends traditional cloud computing paradigm to the edge. It can be highly virtualized, able to provide computation, storage, and networking services between the end nodes and traditional clouds. Fog computing hosts services at the network edge or even end devices. By doing so, fog reduces service latency, and improves QoS, resulting in superior user-experience. The majority fog characteristics includes: proximity to customers, geographical distribution, and support for mobility. A number of characteristics of fog computing go against your intuition. The different characteristics of fog computing are listing as follows:

1) Edge location, location awareness, and low latency

At the edge of the network, fog computing support endpoints with finest services, reducing in data movement across the network significantly. Fog nodes can ingest data from different types of end devices in local area network, location data in context enables location awareness.

2) Geographical distribution

Fog computing consists of very large number of distributed nodes, as a consequence of the wide geo-distribution, as evidenced in sensor networks in general, and the smart grid in particular. The services and application objective of the fog is widely distributed for example fog will play an important role in delivering high quality streaming to connected vehicles through proxies and access points positioned nearby.

3) Support for mobility

Locator/ID separation protocol (LISP) is a routing and addressing architecture developed by Cisco systems. It provides mobility techniques like decouple host identity to location identity. Using LISP, fog applications can communicate directly with mobile devices. Fog enables administrators to control where users are coming in and how they access the information, supports location-based mobility and improves the performance and quality of services.

4) Real time interactions

Fog computing requires real time interactions for speedy service with low latency, thereby reducing a major block and a point of failure. Important fog applications involve real-time interactions rather than batch processing.

5) Heterogeneity

Fog is a multi-tiered hierarchical organization, and fog nodes are highly dynamic and heterogeneous at different levels of networks hierarchy for low latency and scalability requirements. Fog nodes can be deployed in a wide variety of environments in the form of physical fog node and/or virtual fog node.

6) Interoperability

Fog components must be able to interoperate, wide range of services (like streaming) require the cooperation of different providers. The fog will give rise to new forms of competition and cooperation among providers.

2.4 Comparison to cloud computing

Authors and experts define cloud or cloud computing according to their own understandings and experiences. A number of definitions for cloud computing exists, but there is no single universal upon agreed definition. In this paper, we accepts the most commonly used definition comes from National Institutes of Standard and Technology (NIST). Cloud computing is a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources that can be rapidly provisioned and released with minimal management effort or service providers interaction e.g., networks, servers, storage, applications, and services that can be rapidly provisioned and released with minimal management efforts or service providers interaction [22]. Cloud systems are located within the Internet, which is a large heterogeneous network with numerous speeds, technologies, topologies and types with no central control. Because of the non-homogeneous and loosely controlled nature of the Internet, there are many issues especially quality of service related ones remain unresolved. One such issue that affects the quality of service severely is network latency. Real time applications with which users directly interact with are badly affected by delay and delay jitter caused by latency in networks. In Table 1, the differences between fog computing and cloud computing are summarized in our work, refer to Ref. [23].

Table 1 Comparison of fog computing and cloud computing

Computing	Target user	Connectivity	Features of service	Working environment
Fog computing	Mobile users	Wireless interface, power in the physical proximity and communicate through	Limited localized information services related to specific deployment locations Low latency for real-time applications Support for mobility Less demand for bandwidth Centralized or distributed in local areas Single-hop wireless connection to server at the edge of local network Limited storage and compute power Light-weight data analytics	Outdoor (streets, parklands, etc.) or indoor (restaurants, shopping malls, etc.)
Cloud computing	General Internet users	Faraway from users and communicate through IP networks	Gathering global information High latency for real-time applications Limit to support for mobility Sensitive for bandwidth Centralized and maintained by cloud providers Multiple hops with servers internet connection Ample and scalable storage space and compute power Long-term data analytics	Warehouse-size building with air conditioning systems

Both cloud and fog are concern about compute, storage, and network resources as building blocks. Fog which is working at 'edge of the network' may be a trivial extension of the cloud in our intuition. Three of the major aspects have been compared between fog computing and cloud computing. In the table, the requirements between cloud computing and fog computing is compared. In the requirement of latency, fog computing is much lower than cloud computing. As service of location, cloud computing within the Internet, fog computing at the edge of the local network. In security aspect, fog computing can be defined. Cloud computing does not have the ability of location awareness, but fog computing does. The nodes of fog computing is much more the cloud computing's. In requirement of mobility, cloud computing is limited, but fog computing is supported.

3 Application scenarios for VANETs

Typically the RSU hosts an application that provides services and the OBU is a peer device that uses the services provided. The application may reside in the RSU or in the OBU. The device that hosts the application is called the provider and the device using the application is described as the user. Each vehicle is equipped with an OBU and a set of sensors to collect and process the information then send it as a message to other vehicles or RSUs through the wireless medium. It also carries a single or multiple application unit (AU) that use the applications provided by the provider using OBU connection capabilities. The RSU can also connect to the Internet or to another server which allows AU's from multiple vehicles to connect to the Internet [24–26].

Actually, many challenging issues still need to be addressed with the development of VANETs. It emphasizes on emergency alerts, cooperative driving, traffic status reports, collision avoidance and other applications. Traditional architecture is not suit for its development, makes the opportunities for cloud computing and fog computing.

Many different applications have been proposed for VANETs. With so many vehicles on the roads/highways having so much computing power and sensors, it is obvious and logical to utilize all this data to form an array of scattered sensor networks or highly MANETs. Three types of the applications that have been summarized and recommended for VANETs in researchers' work as follows:

1) Safety applications. Notifications for crashes, hazards on the roads (slippery or wet road conditions), traffic violation warnings, and curve speed warnings, emergency electronics brake light, pre-crash sensing, co-operative forward collision warnings, etc. This could also include generating warning messages that inform drivers of approaching emergency vehicles.

2) Convenience applications. Navigation, personal routing, congestion advice, toll collection, parking availability information and etc. Also, in disaster situations, the critical things are power failure and network breakdown. The connected vehicles can play a very significant role in such situations as they have on-board batteries and many sensors including cameras, etc., thus providing valuable images and SOS calls. The vehicular network can become the emergency communication mechanism. Similarly, road and weather conditions can be monitored by sharing the data from on-board vehicle

sensors.

3) Commercial applications. Vehicle diagnostics exchanges for avoiding possible car problems, location-based services such as advertisements and entertainment, i.e., data/video relay, social networking updates and etc. [27–29].

3.1 Application scenarios of vehicular cloud computing

VANETs applications are not only focused on developing safety services but also non-safety services such as online gaming, multimedia applications and video conferencing, and data streaming is the most important factor of the later. The architecture of VCC relies on three layers: inside-vehicle, communication and cloud. Olariu et al. [30] envisioned the next paradigm shift from conventional VANET to VCC by merging VANET with cloud computing. Based on cloud computing paradigm, vehicles on streets has enabled the exploitation of excess computing power. The concept of VCC was introduced. The definition for the VCC is, a group of largely autonomous vehicles whose corporate computing, sensing, communication and physical resources can be coordinated and dynamically allocated to authorized users. It's the definition from Refs. [31–32].

Application scenarios of VCC have been mentioned in Ref. [4] listed as follows:

An airport as a datacenter.

Parking lot data cloud.

Shopping mall data center.

Dynamic traffic light management.

Optimizing traffic signals.

Self-organized high occupancy vehicle (HOV) lanes.

Managing evacuation.

Road safety message.

Easing frequent congestion.

Managing parking facilities.

Vehicular cloud in developing countries perspective, and etc.

As time pass by, more and more possible implementation scenarios and the applications will be outcome of VCC.

3.2 Application scenarios based on fog computing in VANETs

Currently, this is no definitions of vehicular fog computing networks. In this chapter, we just list the application scenarios based on fog computing in VANETs. Due to the advantages of edge location, fog computing has ability to support applications with low latency requirements. For example, gaming, augmented reality, real time video stream processing based on fog server and fog node. Different from VCC, fog computing is still a first-stage in its development. Applications based on fog computing for VANET not as much as VCC's. As all we known, six of the most familiar application scenarios for fog computing are: connected vehicles (CV), wireless sensor and actuator networks (WSAN), IoT and cyber-physical systems (CPSs), software defined networks (SDN), decentralized smart building control. In this paper, in the domain of vehicular network five application scenarios based on fog computing in VANETs are mentioned.

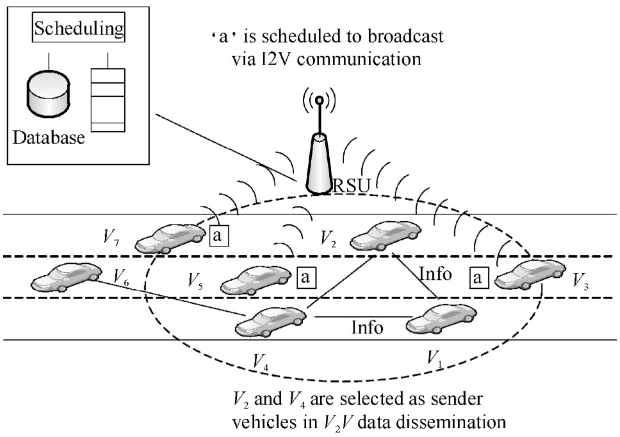
1) Smart traffic lights and connected vehicles

Smart lights serves as fog devices synchronize to send warning signals to the approaching vehicles. The interactions between vehicle and access points are enhanced with WiFi, 3G, road side units and smart traffic lights. A highly distributed collector of traffic data over an extended geographically data. Ensuring an acceptable degree of consistency between the different aggregator points is crucial for the implementation of efficient traffic policies [8].

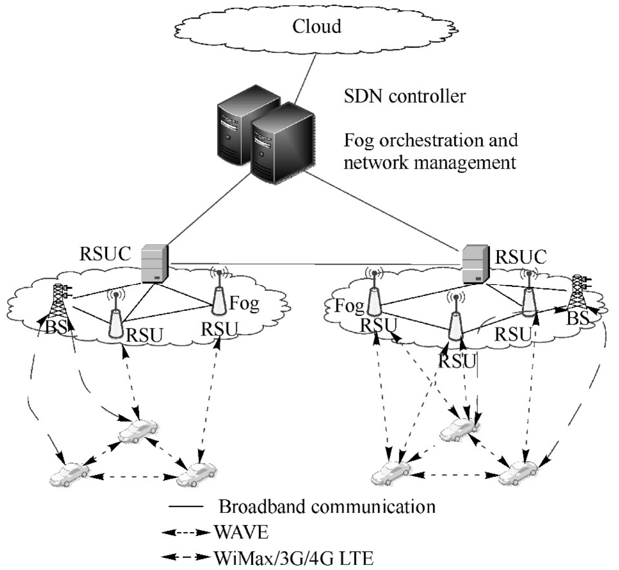
The situation of traffic lights can be changed by vehicles pass by. For example, an ambulance flashing lights can be sensed by video camera automatically. And then, smart street lights interact with the right condition. Neighboring smart lights serving as fog devices coordinate to create green traffic wave and send warning signals to approaching vehicles [5].

2) Software defined networks (SDN)

SDN is a growing computing and networking concept. SDN concept together with fog computing will resolve the main issues in vehicular networks irregular connectivity, collisions and high packet loss rate. SDN supports vehicle to vehicle with vehicle to infrastructure communications and main control. Liu et al. [33] presents the study on scheduling for cooperative data dissemination in a hybrid infrastructure-to-vehicle (I2V) and vehicle-to-vehicle (V2V) communication environment, as shown in Fig. 2(a). It splits control and communication layer, control is done by central server and server decides the communication path for nodes. SDN-based architecture provides flexibility, scalability, programmability and global knowledge while fog computing offers delay-sensitive and location-awareness services which could be satisfy the demands of future VANETs scenarios. In Fig. 2(b), Kim et al. [34] have proposed a new VANET architecture called software-defined networking-based VANET (FSDN VANET) architecture leveraging fog computing which combines two emergent computing and network paradigm SDN and fog computing as a prospective solution.



(a) Data dissemination via the hybrid of I2V and V2V communications



(b) SDN-based VANET architecture leveraging fog computing

Fig. 2 Fog computing in SDN in vehicular networks

3) Parking system

The traffic is really in a mess when the number of vehicles is increasing rapidly. As a consequence, finding a parking space is remarkably difficult and expensive. Kim's study [35] focuses on solving parking problem to relieve the traffic congestion, reduce air pollution and enhance driving effectively in the view of IoT. From this perspective, fog computing and roadside cloud are utilized to find a vacant spot. By utilizing these infrastructures, any parking space at many places can be shared. In his study, he analyzes the matching theory to solve the parking problem. Accordingly, its proposal not only helps drivers finding an ideal available space but also brings the owners of these places profit. Simulation results demonstrate that the proposed approach is a reliable solution for the finding parking slot.

4) Content distribution

Luan et. al. [36] present the application of fog computing as an integrated large-scale network for localized content disseminations. In Fig. 3, content distribution using wireless communications by the fog serves. Assuming that a store installs a fog server at its parking lot with the purpose to distribute the store flyer.

In Fig. 3, in Step 1, the store uploads flyers to the fog server via wireless connections, and the fog server distributes the flyers to vehicles driving through its coverage using wireless communications. With the vehicle moving to different locations, it can further disseminate the cached flyers to other vehicles using wireless communications, as depicted in Step 2. In Step 3, the flyers can also be retrieved and cached at other fog servers deployed at different locations, e.g., bus stop, and further propagated in the network [11].

The fog server deployed nearby the store may be installed and managed by the store owner for the distribution of store flyers. The fog server localized at the bus stop distributes bus information organized by the bus company. So, fog servers distributed installed and managed by different entities to serve their own purposes.

5) Decision support systems

In Roy's [37] work, they proposed novel fog-based intelligent decision support system (DSS) for driver safety and traffic violation monitoring based on the IoT and fog computing. Its conceptual framework could easily be adapted in current scenario and can also become a de facto decision support system model for future hassle-free driving rule violation monitoring system.

The application scenarios mentioned above embody different characteristics of fog computing. All of them are purposed for vehicles in VANET, which are mobile units with the benefits of fog computing characteristics, including mobility-support, geo-distributed, location awareness, low-latency, and real-time interaction. With special relevance to fog components, interoperability is not embodied in above scenarios. SDN scenarios based on fog computing for vehicular network are good examples of heterogeneity. In VANET, application scenarios that have been discussed and deployed based on cloud computing are much more than ones based on fog computing. Through analysis based on literatures, the reasons are as follows:

As a new research area, fog computing is not well known as cloud computing for everyone. Few of researchers take efforts in this direction.

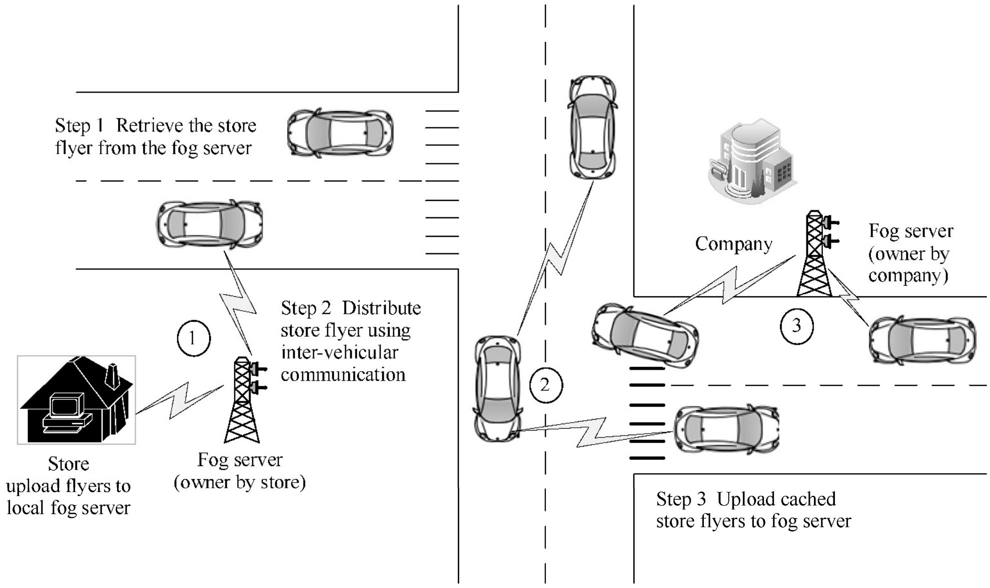


Fig. 3 Fog computing for content distribution in VANETs

Fog computing as extension of cloud computing, its development attaches to the progress of cloud computing. It is impossible to grow up by itself. Parking system, proposed by Kim, is one of fusion of fog computing and cloud computing, figure out an idea to use fog computing.

4 Challenges and issues

In this section, major challenges and potential issues in the context of fog computing for VANET will be identified and discussed. Some of them would be the direction of future work.

Bonomi et al. [8] announce collaboration works to researchers could be considered as guidelines for directions of fog computing, including:

1) Architecture of this massive infrastructure of compute, storage, and networking devices.

2) Orchestration and resource management of the fog nodes.

3) Innovative services and applications to be supported by the fog.

They are crucial challenges and issues in the preliminary research stage for fog computing. To drive industry and academic leadership in fog computing architecture, test-bed development, and a variety of interoperability and composability deliverables that seamlessly leverage cloud and edge architectures to enable end-to-end IoT scenarios, Cisco has formed an organization named 'Open Fog Consortium' was founded on November 19, 2015. The Open Fog Consortium (http://www.openfogconsortium.org/) has been formed to solve some of today's most common challenges, such as high latency on the network, support of end point mobility, loss of connectivity, unpredictable bandwidth bottlenecks and distributed coordination of systems and clients. With an architecture that enables end-user clients or near-user edge devices to carry out computation, communication, control and storage, fog computing can enable rapid innovation, client-centric objectives, pooling of local resources, and real-time processing in cyber-physical systems. The consortium was formed to accelerate the deployment of fog technologies and to provide industry and academic leadership in developing fog computing frameworks and architectures. Cisco has been working for many months with the other founding members—Intel, Microsoft, Dell, ARM, and Princeton University—to form this new industry body. Meanwhile, some existing research works for fog computing concern security, privacy, modeling, QoS and etc. as challenges and issues at this stage. In our opinion, both of the works mentioned above are important, they can promote each other for development of fog computing research area.

Fog computing as technology for the evolution of computing is rapidly growing as demonstrated by the draft H2020 ICT Work Programme for 2016-17 [38] which highlights integration of fog computing with the cloud as a work item under the cloud computing topic (ICT-06-2016). In this context, fog computing for VANETs is an exciting research topic in future. Some of challenges and issues in the realm are discussed, in particular:

1) QoS is an important metric for services which are provided by vehicular fog computing network. In a heterogeneous fog computing network, it is extremely disruptive to traditional networking, developing the architecture a new networking paradigm is the biggest challenge. Yi et al. [12] divides QoS into four aspects: connectivity, reliability, capacity, delay. In this paper, we aim at connectivity and reliability in fog computing for VANETs.

In VANETs, connectivity which is deal with dynamic is crucial for the success of fog computing. Fog nodes are variety of modular compute and storage devices belong to individuals or companies. They are not homogeneous, usually small and ruggedized at the very edge of the local networks. It means fog nodes have different visions of the form factors, common interfaces, and programming environment. Such fog nodes in the vehicular network are highly dynamic and radio/wireless network access is also highly dynamic (such as 3G/4G/WiFi). Embedded system in fog nodes should be support for all the protocols are needed in VANETs environments. To meet task-oriented compute and storage requirements of VANETs, fog nodes in fog computing platform must be operate 7×24 every day of the year. One possible period of fluctuation in the demand will make service out of work, the loss cannot be estimated easily.

Madsen et al. [39] review the reliability requirement of clustering computing, grid computing, cloud and sensor network towards a discussion of reliability of fog computing. Failure detecting and failure recovery methods are the core of reliability, which can be improved through periodical check-pointing to resume after failure, rescheduling of failed tasks or replication to exploit executing in parallel. As a distributed and scalable architecture, how to recognize and repair fog nodes is difficult in fog computing which relies on multiple fog nodes to work together. Especially, in VANETs, check pointing and rescheduling may be not suit the highly dynamic fog computing environment since there will be latency.

2) Security and privacy

To date, there are few works focusing on security and privacy issues in fog computing. Dsouza et al. [40] proposes a policy-based resource access control in fog computing, to support secure collaboration and interoperability between heterogeneous resources. As mentioned above, how to execute policy for distributed fog nodes in VANETs is a big issue.

Fog computing is multi-tenancy, data ingests from VANETs stores and analytics in such a distributed storage service, it make users are concerned about the risk of privacy leakage (data, location or usage). Privacy-preserving techniques in fog computing is not mentioned. In the fog network, privacy-preserving algorithms can be run in between the fog and cloud since computation and storage are sufficient for both sides while those algorithms are usually resource-prohibited at the end devices [12].

5 Conclusions and future work

This article presents fog computing, a frontier concept for VANETs. In this paper, the architecture, several interesting application scenarios, challenge issues of fog computing in VANETs have been identified and discussed. We have outlined the vision and key characteristics of fog computing, a platform to deliver a rich portfolio of new services and applications at the edge of the network. Fog computing supports emerging IoE applications that demand real-time/predictable latency (industrial automation, transportation, networks of sensors and actuators). Thanks to its wide geographical distribution the fog paradigm is well positioned for real time big data and real time analytics. Fog supports densely distributed data collection points, hence adding a fourth axis to the often mentioned big data dimensions (volume, variety, and velocity). The cloud computing and its applications for VANET is mentioned, comparing with fog computing and its applications. As seen, the applications for VCC are much more than those for fog's. We envision the fog computing to be a unifying platform, rich enough to deliver this new breed of emerging services and enable the development of new application scenarios. In order to make the rapid development of fog computing and its applications in VANETs, in my opinion, commercial and entertainment application scenarios should be in first step.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (61271184, 61571065).

References

1. Yang F C, Wang S G, Li J L, et al. An overview of Internet of vehicles. China Communications, 2014, 11(10): 1−15
2. Dua A, Kumar N, Bawa S. A systematic review on routing protocols for vehicular ad hoc networks. Vehicular Communications, 2014, 1(1): 33−52
3. Li J L, Liu Z H, Yang F C. Internet of vehicles: the framework and key technologies. Journal of Beijing University of Posts and Telecommunications, 2014, 37(6): 95−100 (in Chinese)
4. Whaiduzzaman M, Sookhak M, Gani A, et al. A survey on vehicular cloud computing. Journal of Network and Computer Applications, 2014, 40(1): 325−344
5. Stojmenovic I, Wen S. The fog computing paradigm: scenarios and security issues. Proceedings of the 2014 Federated Conference on Computer Science and Information Systems (FedCSIS'14), Sept 7−10, 2014, Warsaw, Poland. Piscataway, NJ, USA: IEEE, 2014: 8p
6. Fog computing and the Internet of things: extend the cloud to where the things are. Waite Paper. San Jose, CA, USA: Cisco, 2015
7. Stolfo S J, Salem M B, Keromytis A D. Fog computing: mitigating insider data theft attacks in the cloud. Proceedings of the 2012 IEEE Symposium on Security and Privacy Workshops (SPW'12), May 24–25, 2012, San Francisco, CA, USA. Piscataway, NJ, USA: IEEE, 2012: 125−128
8. Bonomi F, Milito R, Zhu J, et al. Fog computing and its role in the Internet of things. Proceedings of the ACM Workshop on Mobile Cloud Computing (MCC'12), Aug 17, 2012, Helsinki, Finland. New York, NY, USA: ACM, 2012: 13−16
9. Balan R, Flinn J, Satyanarayanan M, et al. The case for cyber foraging. Proceedings of the 10th ACM SIGOPS European Workshop (EW'02), Jul 1, 2002, Saint-Emilion, France. New York, NY, USA: ACM, 2002: 87−92
10. Satyanarayanan M, Bahl P, Caceres R, et al. The case for VM-based cloudlets in mobile computing. IEEE Pervasive Computing, 2009, 8(4): 14−23
11. Vaquero L M, Rodero-Merino L. Finding your way in the fog: towards a comprehensive definition of fog computing. ACM SIGCOMM Computer Communication Review, 2014, 44(5): 27−32
12. Yi S H, Li C, Li Q. A survey of fog computing: concepts, applications and issues. Proceedings of the 2015 Workshop on Mobile Big Data (MoBiData'15), Jun 22–25, 2015, Hangzhou, China. New York, NY, USA: ACM, 2015: 37−42
13. Bonomi F. Connected vehicles, the Internet of things, and fog computing. Proceedings of the 8th ACM International Workshop on Vehicular Inter-Networking (VANET'11), Sept 19–23, 2011, Las Vegas, NV, USA. New York, NY, USA: ACM, 2011
14. Bonomi F, Milito R, Natarajan P, et al. Fog computing: a platform for internet of things and analytics. In: Bessis N, Dobre C. Big data and Internet of things: A roadmap for smart environments. Berlin, Germany: Springer, 2014: 169−186
15. Stojmenovic I. Fog computing: a cloud to the ground support for smart things and machine-to-machine networks. Proceedings of the 2014 Australasian on Telecommunication Networks and Applications Conference (ATNAC'14), Nov 26–28, 2014, Southbank, Australia. Piscataway, NJ, USA: IEEE, 2014: 117−122
16. Hong K, Lillethun D, Ramachandran U, et al. Mobile fog: a programming model for large-scale applications on the Internet of things. Proceedings of the 2nd ACM SIGCOMM Workshop on Mobile Cloud Computing (MCC'13), Aug 12–16, 2013, Hong Kong, China. New York, NY, USA: ACM, 2013: 15−20
17. Hong K, Lillethun D, Ramachandran U, et al. Opportunistic spatio-temporal event processing for mobile situation awareness. Proceedings of the 7th ACM International Conference on Distributed Event-based Systems (DEBS'13), Jun 29–Jul 3, 2013, Arlington, TX, USA. New York, NY, USA: ACM, 2013: 195−206
18. Nishio T, Shinkuma R, Takahashi T, et al. Service-oriented heterogeneous resource sharing for optimizing service latency in mobile cloud. Proceedings of the 1st International Workshop on Mobile Cloud Computing & Networking (MobileCloud'13), Jul 29, 2013, Bangalore, India. New York, NY, USA: ACM, 2013: 19−26
19. Zhu J, Chan D S, Prabhu M S, et al. Improving web sites performance using edge servers in fog computing architecture. Proceedings of the IEEE 7th International Symposium on Service Oriented System Engineering (SOSE'13), Mar 25–28, 2013, Redwood City, CA, USA. Piscataway, NJ, USA: IEEE, 2013: 320−323
20. Aazam M, Huh E N. Fog computing and smart gateway based communication for cloud of things. Proceedings of the 2014 International Conference on Future Internet of Things and Cloud (FiCloud'14), Aug 27–29, 2014, Barcelona, Spain. Piscataway, NJ, USA: IEEE, 2014: 464−470
21. Firdhous M, Ghazali O, Hassan S. Fog computing: will it be the future of cloud computing? Proceedings of the 3rd International Conference on Informatics & Applications (ICIA'14), Oct 6–8, 2014, Kuala Terengganu, Malaysia. Washington, DC, USA: The Society of Digital Information and Wireless Communications, 2014: 8−15
22. Mell P, Grance T. The NIST definition of cloud computing. Special Publication 800-145. Gaithersburg, MD, USA: Information Technology Laboratory, National Institute of Standards and Technology, 2011
23. Luan T H, Gao L X, Xiang Y, et al. Fog computing: focusing on mobile users at the edge. arXiv:1502.01815v1, 2015
24. Al-Sultan S, Al-Doori M M, Al-Bayatti A H, et al. A comprehensive survey on vehicular ad hoc network. Journal of Network and Computer Applications, 2014, 37(1): 380−392
25. Jiang D, Taliwal V, Meier A, et al. Design of 5.9 GHz DSRC-based vehicular safety communication. IEEE Wireless Communications, 2006, 13 (5): 36−43
26. Moustafa H, Zhang Y. Vehicular networks: techniques, standards, and applications. Boca Raton, FL, USA: Auerbach publications, 2009
27. Hartenstein H, Laberteaux K P. A tutorial survey on vehicular ad hoc networks. IEEE Communications Magazine, 2008, 46(6): 164−171
28. Faezipour M, Nourani M, Saeed A, et al. Progress and challenges in intelligent vehicle area networks. Communications of ACM, 2012, 55(2): 90-100
29. Zaidi K, Rajarajan M. Vehicular Internet: security & privacy challenges and opportunities. Future Internet, 2015, 7(3): 257−275
30. Olariu S, Hristov T, Yan G. The next paradigm shift: from vehicular networks to vehicular clouds. In: Basagni S, Conti M, Giordano S, et al. Mobile ad hoc networking: Cutting edge directions. 2nd ed. Hoboken, NJ, USA: John Wiley & Sons, 2013: 645−700
31. Eltoweissy M, Olariu S, Younis M. Towards autonomous vehicular clouds. In: Ad hoc networks, Berlin, Germany: Springer, 2010: 1−16
32. Basagni S, Conti M, Giordano S, et al. Mobile Ad hoc networking: cutting edge direction, 2nd ed, John Wiley & Sens, 2013
33. Liu K, Ng J K Y, Lee V C S, et al. Cooperative data scheduling in hybrid vehicular ad hoc networks: VANET as a software defined network. IEEE/ACM Transactions on Networking (To be published)
34. Truong N B, Lee G M, Ghamri-Doudane Y. 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 11–15, 2015, Ottawa, Canada. Piscataway, NJ, USA: IEEE, 2015: 1202−1207

To p. 96

10. Alexandre L A, Embrechts M J, Linton J. Benchmarking reservoir computing on time-independent classification tasks. Proceeding of the International Joint Conference on Neural Networks (IJCNN'09), Jun 14–19, 2009, Atlanta, GA, USA. Piscataway, NJ, USA: IEEE, 2009: 89–93
11. Guo J, Lei M, Peng X Y. Echo state networks for static classification with corresponding clusters. Acta Electronica Sinica, 2011, 39(3A): 14–18 (in Chinese)

(Editor: Wang Xuying)

From p. 65

35. Kim O T T, Tri N D, Nguyen V D, et al. A shared parking model in vehicular network using fog and cloud environment. Proceedings of the 17th Asia-Pacific Network Operations and Management Symposium (APNOMS'15), Aug 19–21, 2015, Busan, Republic of Korea. Piscataway, NJ, USA: IEEE, 2015: 321–326
36. Luan T H, Cai L X, Chen J M, et al. VTube: towards the media rich city life with autonomous vehicular content distribution. Proceedings of the 8th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON'11), Jun 27–30, 2011, Salt Lake City, UT, USA. Piscataway, NJ, USA: IEEE, 2011: 359–367
37. Roy S, Bose R, Sarddar D. A fog-based DSS model for driving rule violation monitoring framework on the Internet of things. International Journal of Advanced Science and Technology, 2015, 82: 23–32
38. Draft H2020 ICT work programme for 2016-17. https://ec.europa.eu/programmes/horizon2020/en/draft-work-programmes-2016-17
39. Madsen H, Albeanu G, Burtschy B, et al. Reliability in the utility computing era: towards reliable fog computing. Proceedings of the 20th International Conference on Systems, Signals and Image Processing (IWSSIP'13), Jul 7–9, 2013, Bucharest, Romanian. Piscataway, NJ, USA: IEEE, 2013: 43–46
40. Dsouza C, Ahn G J, Taguinod M. Policy-driven security management for fog computing: preliminary framework and a case study. Proceedings of the IEEE 15th International Conference on Information Reuse and Integration (IRI'14), Aug 13–15, 2014, Redwood City, CA, USA. Piscataway, NJ, USA: IEEE, 2014: 16–23

(Editor: Wang Xuying)

From p. 72

References

1. Yu H, Zou X C, Chen C Y. A super performance bandgap voltage reference with adjustable output for DC-DC converter. The Journal of China Universities of Posts and Telecommunications, 2006, 13(1): 75–78
2. Shih Y C, Otic B P. An inductorless DC-DC converter for energy harvesting with a 1.2 μW bandgap-referenced output controller. IEEE Transactions on Circuits and Systems II: Express Briefs, 2011, 58(12): 832–836
3. Zhang H L, Xiao Z B, Tan X, et al. Low-power sub-1-V compact bandgap reference for passive RFID tags. Electronics Letters, 2015, 51(11): 815–816
4. Widlar R J. New developments in IC voltage regulators. IEEE Journal of Solid-State Circuits, 1971, 6(1): 2–7
5. Brolaw A P. A simple three-terminal IC bandgap reference. IEEE Journal of Solid-State Circuits, 1974, 9(6): 388–393
6. Lee K K, Lande T S, Hafliger P D. A sub-μW bandgap reference circuit with an inherent curvature-compensation property. IEEE Transactions on Circuits and Systems I: Regular Papers, 2015, 62(1): 1–9
7. Ming X, Ma Y Q, Zhou Z K, et al. A high-precision compensated CMOS bandgap voltage reference without resistors. IEEE Transactions on Circuits and Systems II: Express Briefs, 2010, 57(10): 767–771
8. Duan Q Z, Roh J J. A 1.2-V 4.2-ppm/°C high-order curvature-compensated CMOS bandgap reference. IEEE Transactions on Circuits and Systems I: Regular Papers, 2015, 62(3): 662–670
9. Ma B, Yu F Q. A novel 1.2-V 4.5-ppm/°C curvature-compensated CMOS bandgap reference. IEEE Transactions on circuits and systems I: Regular Papers, 2014, 61(4): 1026–1035
10. Ker M D, Chen J S. New curvature-compensation technique for CMOS bandgap reference with sub-1-V operation. IEEE Transactions on circuits and systems II: Express Briefs, 2006, 53(8): 667–671
11. Zhou Z K, Shi Y, Huang Z, et al. A 1.6-V 25-μA 5-ppm/°C curvature-compensated bandgap reference. IEEE Transactions on Circuits and Systems I: Regular Papers, 2012, 59(4): 677-684
12. Leung K N, Mok P K T, Leung C Y. A 2-V 23-μA 5.3-ppm/°C curvature-compensated CMOS bandgap voltage reference. IEEE Journal of Solid-State Circuits, 2003, 38(3): 561–564
13. Andreou C M, Koudounas S, Georgiou J. A novel wide-temperature-range, 3.9 ppm/°C CMOS bandgap reference circuit. IEEE Journal of Solid-State Circuits, 2012, 47(2): 574–581
14. Tham K M, Nagaraj K. A low supply voltage high PSRR voltage reference in CMOS process. IEEE Journal of Solid-State Circuits, 1995, 30(5): 586–590
15. Zhang H Y, Chan P K, Tan M T. A high PSR voltage reference for DC-to-DC converter applications. Proceedings of the 2009 IEEE International Symposium on Circuits and Systems (ISCAS'09), May 24–27, 2009, Taipei, China. Piscataway, NJ, USA: IEEE, 2009: 816–819
16. Dey A, Bhattacharyya T K. A CMOS bandgap reference with high PSRR and improved temperature stability for system-on-chip applications. Proceedings of the 2011 International Conference of Electron Device and Solid-State Circuits (EDSSC'11), Nov 17–18, 2011, Tianjin, China. Piscataway, NJ, USA: IEEE, 2011: 2p
17. Liao L, Lohaus L, Atac A, et al. A low power bandgap voltage reference circuit with PSRR enhancement. Proceedings of the 8th Conference on Ph.D. Research in Microelectronics and Electronics (PRIME'12), Jun 12–15, 2012, Aachen, Germany. Piscataway, NJ, USA: IEEE, 2012: 213–216
18. Mehrmanseh S, Vhidfar M B, Aslanzadeh H A, et al. A 1-volt, high PSRR, CMOS bandgap voltage reference. Proceedings of the 2003 International Symposium on Circuits and Systems (ISCAS'03): Vol 1, May 25–28, 2003, Bangkok, Thailand. Piscataway, NJ, USA: IEEE, 2003: 381–384
19. Francisco K R, Hora J A. Very low bandgap voltage reference with high PSRR enhancement stage implemented in 90 nm CMOS process technology for LDO application. Proceedings of the 2012 IEEE International Conference on Electronics Design, Systems and Applications (ICEDSA'12), Nov 5–6, 2012, Kuala Lumpur, Malaysia. Piscataway, NJ, USA: IEEE, 2012: 216–220
20. Rincon-Mora G A. Voltage references-from diodes to precision high-order bandgap circuits. New York, NY, USA: Wiley, 2002: 16–18
21. Razavi B. Design of analog CMOS integrated circuits. New York, NY, USA: McGraw-Hill, 2001: 27–28

(Editor: Wang Xuying)