Universiteit Leiden

ICT in Business

Exploratory Research on Implementing Fog Concept in the Connected Vehicles Scenario

Name: **Yulin Luo**

Student-no: **S1473913**

Date: **16/08/2016**

1 st supervisor: **Dr. Neukart Florian**

2nd supervisor: **Dr. Arno Knobbe**

ACKNOWLEDGEMENTS

Without the guidance of my supervisors, support from my girlfriend and family, and assistance of my friends, it would have been impossible for me to write this thesis.

First of all, I would like to thank my first supervisor, Dr. Neukart Florian, for his time, patience, support and guidance during this research. He helped me with identifying the topic and conducting this research step by step. Because of his unconditionally support and encouragement, I'm able to finish this thesis in such a tight time with limited resources. My thanks also goes to my second supervisor, Dr. Arno Knobbe. His constructive suggestions helped me to refine the content of my thesis and provide valuable insight to the thesis. Moreover, both of them use their network to help me find qualified interviewees. I feel grateful for their assistance.

Also, I highly appreciate all the experts who devoted their time and knowledge to do the interviews with me. Their answers provide highly valuable data and insights for my research. Moreover, I'd like to thank Tino de Rijk, Jan Kooiman, and Fei Liu for helping me find interviewees. I really appreciate your help.

Next, I would like to thank all the lecturers, staffs and my classmates in Leiden University. The studying experience here is unforgettable with them. Also, my thanks go to all of my friends in the Netherlands, especially my dear roommates here, Cong Chen and Ting Lu. Their suggestions and encouragement help me a lot in this tough time.

In the end, I want to thank my dear family members and girlfriend for their unconditionally support and love for me. Thank you all for being in my life.

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Connected Vehicles (CV), as an important component of the Internet of Things, are receiving a lot of attention from both academia and the practical world. With the fast development of CV, the traditional way to provide services with remote data centers is no longer appropriate. Many CV services require real-time communication, which significantly influences both quality and safety of services. Also, the increasing data generated by vehicles is huge. It is difficult to transmit all the data to a data center. However, not all the data is required for high-level analysis. To fulfill these requirements, Fog computing has emerged. It brings Cloud computing capacities in proximity to end devices to improve the performance for time-sensitive and data intensive applications. Thus, Fog computing is of potential to be implemented in the CV scenario. Unfortunately, rigorous research about implementing the Fog concept on CV is lacking. What specific CV requirements can be fulfilled by Fog computing is still missing. This research aims to identify Fog capacities, CV requirements, and the links between them. A Fog-based CV pyramid is proposed on the basis of the role of Fog computing in the CV scenario. The matches of capacities and requirements, and the proposed pyramid could assist practitioners to apply Fog computing on CV in the future.

Keywords: Fog computing, Connected Vehicles, Fog capacities, CV requirements, Fog-based CV pyramid.

TABLE OF CONTENTS

Chapter 1 Introduction

With the advent of Big Data era, every single day $2.5 \cdot 10^{30}$ bytes of data are being generated [1]. It is complicated and expensive for most of the companies to maintain a data center. Thus, more and more companies chose to move their data to the Cloud and let the cloud manage and process their data. This pay-as-you-go service uses remote data centers operated by enterprises like Amazon and Microsoft that have solid hardware facilities. In this way, companies are able to only maintain basic IT facilities for their daily operation and put more resources on their core businesses. This service indeed saved money and improved efficiency for enterprises and became popular. However, when it comes to the Internet of Things (IoT), it is not appropriate. The traditional data center provide a bottleneck when meeting certain requirements of IoT services, such as low latency and jitter, mobility, and location awareness. Connected Vehicles (CV) is one of the typical applications suffering from these limitations. In addition, as a single car can generate 15 GB of data per hour, it is impossible to transmit all of it over the air with current technologies.

Therefore, professionals were looking for methods to deal with this situation and the potential of edge networking was explored. In this case, a new paradigm called *Fog computing* was invented as an option to solve this problem. As it was capable of remedying several defects of Cloud, Fog computing received a lot of attention from the CV industry. However, critical research about the implementation of Fog computing on CV scenario is as yet lacking.

1.1 Problem Statement and Research Questions

Fog computing is a novel concept. It is a paradigm that expands the capacity of Cloud computing to the edge of the network [2], which brings several benefits such as low latency and improves the performance of IoT applications. At the same time, there exist similar concepts to Fog computing [3]. Thus, the first thing is to distinguish the concept and features of Fog computing. As Fog computing appears to help IoT applications, its capacities also have to be identified.

Although IoT is still in its infancy, many IoT applications are already embedded in people's daily life. One of the most representative applications is CV. Many vehicle manufacturers invest millions of dollars in the development of connected vehicles and they do make a significant progress on it, like Volkswagen's Car-Net and Toyota's Intelligent Transport System. As Fog computing is capable of increasing the performance of IoT since it works close to end devices, how about applying Fog computing to Connected Vehicles? Some articles, such as [2] [32] [33], say Fog computing is able to help deliver CV services, but it's not a master key. Among all the requirements to successfully implement CV, which can be fulfilled by Fog computing is not clear. Thus, a critical comparison of the Fog computing capacities and requirements of Connected Vehicles needs to be done. Also, the opinions about the implementation from experts in the related field need to be collected.

According to the statement above, the main research question is:

Can Fog computing be implemented on Connected Vehicles?

Sub-questions are as follow:

1. What are the capacities of Fog computing?
2. What are the requirements for successfully implementing Connected Vehicles?
3. Can Fog computing fulfill the requirements of Connected Vehicles?
4. What is the role of Fog computing in Connected Vehicles scenario?
5. How to embed Fog computing into Connected Vehicles scenario?

1.2 Research Contribution

As Fog computing is an emerging concept and hasn't been widely used in CV, this is an exploratory research. The contributions of this study are as follows:

- Refining the concept of Fog computing
- Summarizing the features of Fog computing.
- Identifying capacities of Fog computing and requirements for CV, from both academic and practical perspective.
- Laying out the matches of Fog capacities and CV requirements.
- Identifying the role of Fog computing in CV scenario.
- Recommending a Fog-based CV architecture.

1.3 Thesis Structure

This thesis is organized as follows. In Chapter 2, the research methods being used by the thesis have been introduced, including literature review, Multivocal literature review (MLR), and semi-structured interviews. Chapter 3 illustrates the scientific fundamentals of this research based on the literature review. The result of MLR is presented in Chapter 4, while the analysis and consequence of the interview will be shown in this Chapter 5. Chapter 6 elaborates the role, capacities, and limitation of Fog computing in CV. A Fog-based architecture is proposed as a potential solution to embed Fog computing into CV scenario. Moreover, additional requirements for CV that have been identified during the interviews are introduced. The conclusion is summarized in Chapter 7, which also contains limitations and future work of this research.

Chapter 2 Research Method

The objective of this research is to identify how Fog computing can be exploited/leveraged in terms of CV and the potential architecture can be used to embed the Fog concept into CV. In order to achieve these objectives, three research methods are used.

Starting with a literature review, the goal is to get a deep understanding of the state of art in Internet of Things, CV, and Fog computing. Following by multivocal literature review, the information of Fog definition, capacities and enabling technologies, and CV requirements are collected. Finally, semi-structured interviews with experts working in the two fields (Fog computing and CV) will be conducted, which aim to consolidate Fog capacities and CV requirements.

2.1 Literature Review

The literature review of this research is divided into three parts: IoT, CV, and Fog computing. The literature review on IoT mainly presents its concept, features, architectures, applications and challenges to help readers gain a comprehensive overview of IoT. The next part is about CV. It illustrates the CV definition, characteristics, and potential enabling technologies. The requirements and challenges of providing CV services will also be introduced here. Fog computing will be introduced in the last part, including definition, features, paradigm, and challenges.

2.2 Multivocal Literature Review

As Fog computing is a novel concept and its implementation in CV is at an exploratory stage, academic literature about Fog computing and applying Fog concept on the CV scenario is lacking. Thus, a method called multivocal literature review (MLR), which is “compromised of all accessible writings on a common, often contemporary topic” [4], is chosen to help identify the Fog concept, capacities and enabling technologies, and the requirements of CV.

Google Search Engine is chosen to be the main tool to collect data for MLR of this research. The keywords been used for querying are shown in Figure 1 below.

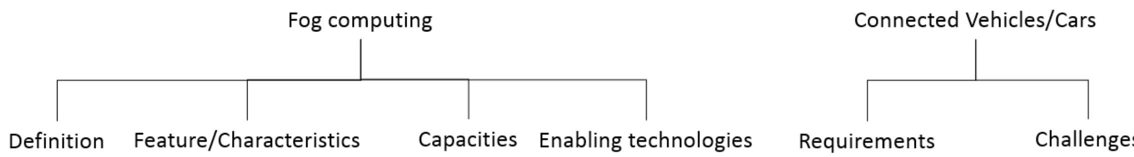

Figure 1: MLR Keywords Map

Since this research aims to match Fog computing capacities and CV requirements, the MLR is divided into three parts: Fog computing, CV and combined. For the first part, keywords are the combination of “Fog computing” and several specific words, “definition”, “feature”, “characteristics”, “capacities”, and “enabling technologies”. The second part uses the combination of “Connected Vehicles” or “Connected Cars”, and “requirements” or “challenges” as the query entry. Last, “Fog computing” and “Connected Vehicles” are used together to do the query.

After using the keywords in Google, the articles with related titles will be read. If its introduction is also relevant, it will be extracted and put in the article lists (Appendix A) to do further reading and take notes. The conclusion of MLR will be presented in Chapter 4.

Nevertheless, [4] also indicates that “reviews of multivocal literature are suggestive and instructive, not definitive or conclusive”. Therefore, the findings of MLR require further validation and are complemented via other methods. In this research, a semi-structured interview method is conducted.

2.3 Semi-structured interview

As discussed in the previous section, merely literature review and MLR is not comprehensive and conclusive. Because as Cooper and Schindler (2008) says “where you are undertaking an exploratory study or a study that includes an exploratory element, it is likely that you will include non-standardized (qualitative) research interviews in your design", semi-structured interview method is selected.

In this method, there will be "a list of themes and questions to be covered, although these may vary from interview to interview" [5]. Due to the fact that it is quite difficult to reach experts having sufficient knowledge in both areas, the target interviewees are divided into two groups: Fog computing and CV. For each area, a specific question list will be prepared before the interview. This is to give a brief overview of what will be asked during the interview and allow them to prepare for the interview. Nevertheless, the questions may be changed and additional questions will be asked during the interview based on the interviewees' background and answers.

The analysis of the interview uses a coding method. "A code in qualitative inquiry is most often a word or short phrase the symbolically assigns a summative, salient, essence-capturing, and/or evocative attribute for a portion of language-based or visual data" [6]. Then codes will be visualized to identify valuable information for this research.

Chapter 3 Scientific Fundamentals

This research is based on three concepts: Internet of Things, Connected Vehicles, and Fog Computing. In section 3.1, the definition, characteristics, architecture, applications, and Challenges for IoT will be presented. Section 3.2 introduces one of the most representative applications of IoT, Connected Vehicles. The overview of the Fog computing will be illustrated by section 3.3. The summary is the last section of this chapter.

3.1 Internet of Things

IoT makes things (physical objects) alive. It aims to connect all the devices, facilities, and services together to make a smart society for human beings. The ideal IoT services can be utilized at any time and any places. Although IoT looks like just entering into normal people's sight in the last ten years, it actually appears much earlier. Based on the years of research, the definition and characteristics of IoT have been identified. Also, different IoT architectures have been presented. Nowadays, IoT applications in multiple fields are already offering services to customers. Nevertheless, quite a lot of challenges still need to be overcome.

3.1.1 Definition and Characteristics

In 1982, Carnegie Mellon University developed the first machine, a coke machine, which was able to connect to the Internet. It can be seen as the start point for the development of IoT. The concept of IoT was first proposed by Kevin Ashton in 1999. He defined IoT as connected objects with radio-frequency identification (RFID) technology which has a unique identity and able to interoperate. At the same time, IoT became popular and got a rapid development. By 2012, ITU's Telecommunication Standardization Sector (ITU-T) published a recommendation which gave definition and classified the characteristics for IoT. It defined IoT as a global infrastructure of the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies (ICT) [7]. With the rapid development of ICT, more and more IoT services and applications came true and were embedded in people's daily work and life.

Now, IoT has been studied and evolved for nearly three decades. The characters of IoT have been sharply clarified. In [7], it illustrates the general features and several high-level requirements for IoT. The characteristics like intelligence have been considered by [8]. Aishwarya Sakaray and V. Bhargv identify some features from a hardware perspective in [9]. Survey [10] lays out the features, which are also challenges for IoT, based on QOS criteria. To sum up, the characteristics of IoT are displayed in Table 1.

Capability	Functionality	Hardware
• Connectivity • Interoperability • Heterogeneity • Dynamic • Scalability • Identifiability	• Intelligence • Sensing • Expressing • Energy • Self-management • Service provisioning • Location awareness • Security and privacy	• Complex • Distributed • Safety

Table 1: Characteristics of IoT

- Capability

In this property, IoT should first be able to connect to the Internet. Objects can be linked to ICT infrastructure in a global platform. Different devices, facilities and services are capable of interoperating with each other. This will force IoT to acquire heterogeneity because they work on different hardware and networks. Also, the information exchanging between objects will be dynamic and real-time. In addition, as the number of the IoT devices will continuously increase, IoT need to be scalable. Moreover, objects must be able to be identified by IoT applications via their unique identifier, which enables IoT applications to provide precise and customized services for its users.

- Functionality

One of the most important features of IoT is Intelligence. The purpose of developing IoT is to make people’s life and work smarter. It must be capable of analyzing and offering suggestions or solutions for its users. That also means it is necessary for IoT applications sensing and expressing via wide distributed sensors, actuators, and user equipment. In order to achieve those capacities, energy support for devices is essential. Also, self-management and service provisioning need to be embedded into IoT to support the performance of IoT. Besides, many IoT services need to obtain user location. So, location awareness is necessary for IoT. Last but not least, since it transformed all the data generated by users in 24/7, the security of IoT network and privacy of users will need serious consideration.

- Hardware

There are a wide variety of devices that will be connected to the Internet and the number will continually grow. What IoT needs to deal with is a very complex system. It’s also a wide distributed system with sensors and devices located everywhere in the world. With the increasing number of objects, the difficulty of managing this system is foreseeable. Moreover, many devices are work closely with users, like phone and healthcare equipment. They must be safe for users.

3.1.2 IoT Architecture

In relatively early published articles, [11] and [12], they proposed a three-layer architecture including application layer, network layer, and perception/device/object layer. While in [7], it adds a support layer to the platform, which is also called service management layer or middleware by [10]. In addition, [10] also raises a new layer, business layer, which is a high-level scope. By comparative and comprehensive analysis, the IoT Architecture is shown in Figure 2.

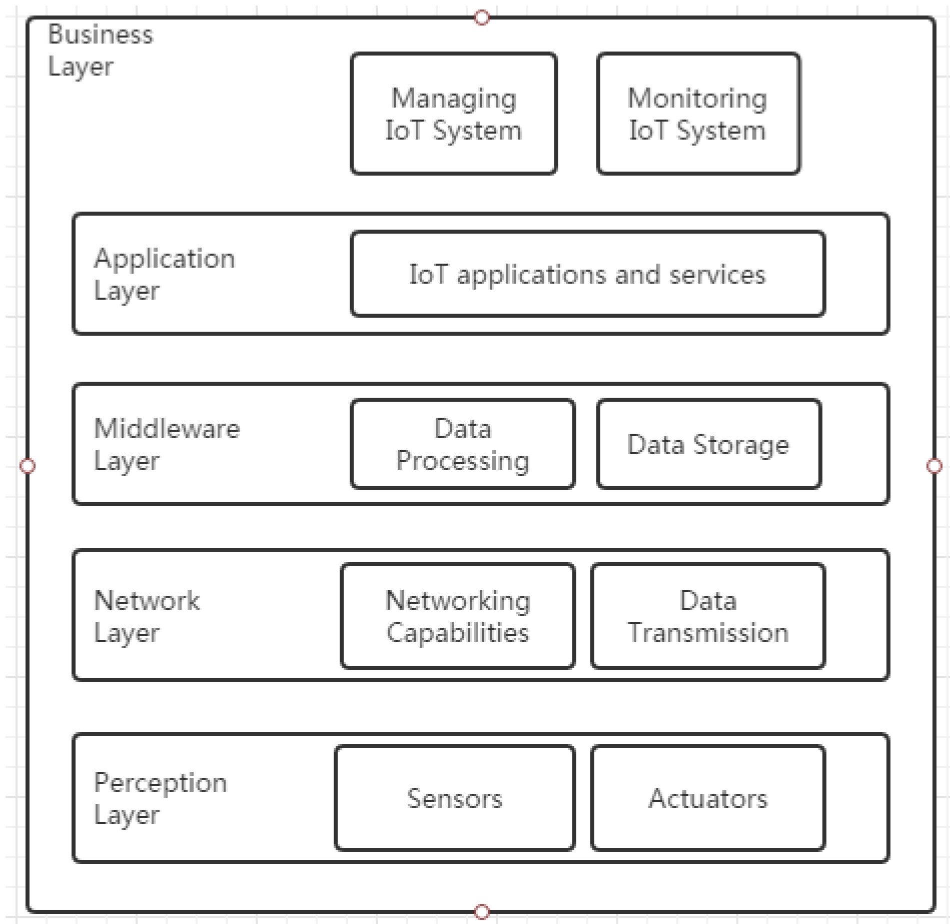

Figure 2: IoT Architecture

- Perception Layer

This layer is the foundation of the whole system. It consists of large amount of sensors and actuators, which enable devices to sense and express. Moreover, user devices are also included in this layer. Then, the data collected by them will be transported to the network layer and the command from higher levels will also be executed in this layer. In addition, functional mechanisms like sleeping and wake-up modes of end devices will be implemented in this layer.

- Networking Layer

The function of this layer is to ensure the connectivity and enable the data transmission between the bottom and higher layers. Network protocols will be applied in this layer. Technologies like RFID, Bluetooth, WiFi and mobile telecommunication and networking security mechanisms will also work in this layer.

- Middleware Layer

This layer will aggregate and process data collected by sensors in the bottom layer. Some data will be sent directly to the corresponding application layer while others will be stored in database/data warehouse and get it ready to support application layer. It will also help IoT applications deal with heterogeneous objects.

- Application Layer

The application layer contains the IoT applications and services. Based on the data delivered by the lower layers, it will response customers' requests and give commands to actuators.

- Business Layer

The Business Layer is responsible for managing and monitoring the operation of the other four layers. It will analyze the data stored in the middle layer and evaluate the performance of applications in the application layer. The report of the analysis will be sent to programmers and specialists to offer them an overall status of the system. Then they are able to fix issues and enhance services. Also, decision makers will use the report to release new services or improve current applications.

3.1.3 IoT Applications

The potential of IoT is enormous. While the possible fields have been identified by specialists and researchers are finite and of which only a few are actually offered to the customers right now. In [13], it groups applications in four domains: Transportation and logistics, healthcare, smart environment, and personal and social. In [14] distributes them from an industry perspective, which includes 15 industries. Those recently published documents and online sources like [15] and [16] use the concept of the smart planet to introduce the applications. Due to their classification, the IoT applications are shown in Figure 3.

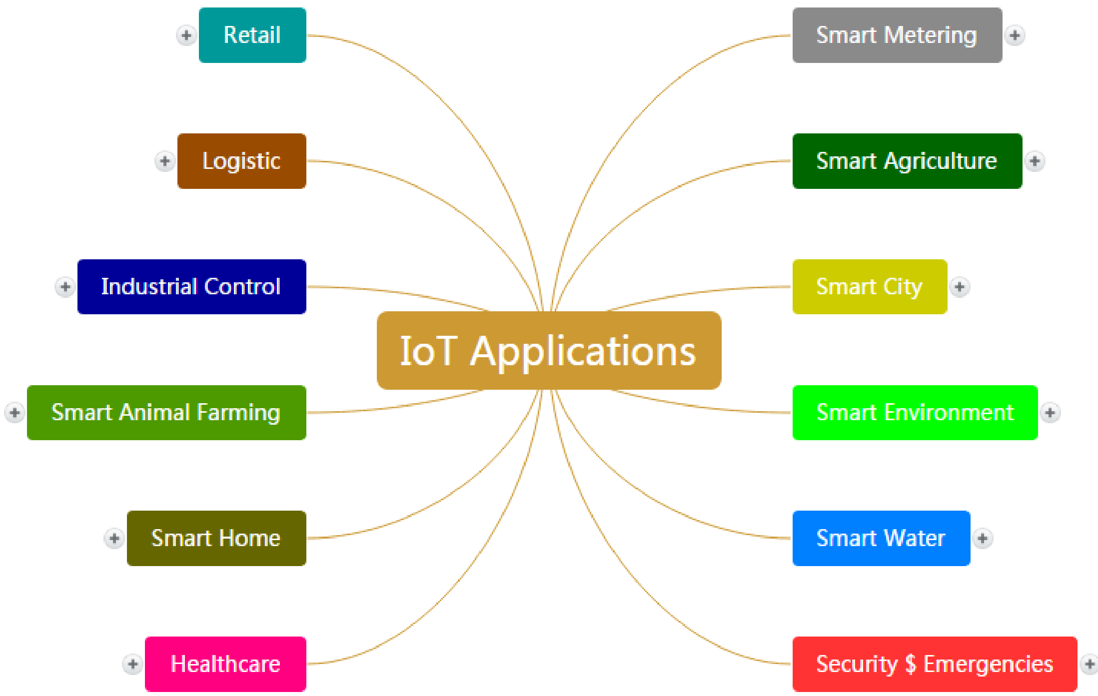

Figure 3: IoT Applications

Applications are divided into 12 classes according to different purposes. As shown in the figure, it covers a wide range of daily life and work. Each field provides several applications to customers, but those applications are only the tip of the iceberg. The version of IoT is extremely wide. Since right now it is still the preliminary stage of the development of IoT and lots of issues and challenges need to be solved. With the technical progress and unified standards, there will be more capacities being explored.

3.1.4 IoT Challenges

IoT is no doubt powerful, while it still faces enormous challenges. In [7] [9] [10] [11] [12] [13] [14] [15], they not only admire its advantages but also point out the challenges and issues it remained. However, the challenges identified by [17] contain the most key problems for IoT. They are divided into 5 categories: security issues, privacy considerations, interoperability/standard issues, regulatory, legal and right issues, and emerging economy and development issues. Each of them contains several sub-issues. Based on this white paper and the other researches, the challenges of IoT are summarized in Table 2.

Issue Categories	Specific Issues
Security issues	• Security platform design • Data confidentiality • Standards and metrics • Balance between cost and security • Maintainability and upgradeability
Privacy considerations	• Data collection and usage • Privacy expectation and preferences • Regulation design
Technical challenges	• Latency and data preprocessing • Ecosystem establishment • Technical expense • Badly designed devices • Standardization • Configuration
Regulatory, legal and right issues	• Data protection (include cross-border) • Civil right and public safety • Data discrimination • IoT liability • Legal action assistant
Emerging economy and development issues	• Infrastructure establishment • Investment • Technical and industrial development • Policy and regulatory coordination

Table 2: IoT Challenges

3.1.4.1 Security issues

Ensuring the security, reliability, and stability of the Internet is crucial for IoT services and applications. The security issues are always the hot topic since the inventing of ICT. The interconnectivity of IoT via network decides that the issues once arise for ICT will also affect IoT. The wide distributed IoT system with increasing devices being connected makes it even more vulnerable for both inside and outside attacks.

- Security platform design. The IoT system consists of multiple stakeholders, including users, service providers, application developers, and infrastructure operators. The design of security platform to effectively improve the security of IoT is complex and difficult. Also, all the stakeholders have to be considered in the platform.
- Data confidentiality. The encryption techniques used to protect data transmission is necessary, but those techniques have to be adapted for IoT. IoT system has a large scale of devices. Some devices change their accessing points regularly. Thus, a strong and fast authentication and access control are required
- Standards and metrics. Both technical and operational standards for IoT should contribute to security. Also, the characteristics of IoT security have to be measured in an appropriate and effective way.
- The balance between cost and security. The performance of security protection relies on the investment on it. The balance point of inputs and outputs need to be considered.
- Maintainability and upgradeability. The maintainability and upgradeability determine the ability to handle emergency situations and new threats. The wide distributed IoT devices will make it difficult to maintain and upgrade security functions.

3.1.4.2 Privacy considerations

The privacy safety significantly influences the trust between users and IoT applications and services. The data collected by IoT system is of big value for both users and service providers. It will also sometimes be shared with third-party companies due to the needs of the services. How to analyze and use the data while not violate users' privacy needs a serious consideration at the service provider's side. In addition, setting regulations to protect the privacy is necessary.

- Data collection and usage. Data collection of IoT applications can be down by both application providers and authorized third parties. It has to be ensured that user privacy won't be violated and illegally used by third parties. Also, service providers should have a strict control of data usage. They need to seriously consider the extent of using the data and the qualified parties that can use the data.
- Privacy expectation and preferences. Different users will have various privacy expectations. Thus, a mechanism is required to allow users to set their individually privacy preferences.
- Regulation design. Regulations used to protect the privacy of users are powerful while difficult to design. Multiple stakeholders of IoT have to be considered.

3.1.4.3 Technical Challenges

With increasing devices connects to the network, the complexity of managing IoT system dramatically rises. In this situation, many technical challenges reveal.

- Latency and data preprocessing. Latency will dramatically impact the performance of time-sensitive IoT applications. It will require high bandwidth and stable transmission. Also, not all the data is needed for high-level analysis. If the data can be pre-processed locally, the performance of IoT applications can be improved and the pressure on data transmission will also be relieved.
- Ecosystem establishment. The ecosystem of IoT should be sustainable and interoperable. Various parts of IoT, such as hardware and software, need to be

continuously improved to meet new challenges and requirements. Moreover, the IoT platform aims to make objects connect with each other regardless of different vendors. Thus, there shouldn’t exist any proprietary ecosystems to restrict data sharing.

- Technical expense. There is no doubt that IoT system needs high-performance hardware and software. High performance requires high expense. The maintenance of the system also cost a lot of money. In fact, resources of companies are limited. Thus, the balance between performance and expense for IoT has to be carefully designed.
- Badly designed devices. IoT devices will interact with each other. Some badly designed devices will threat both users and service providers. For example, if one device has loopholes, malicious attackers can use them to invade the whole system. They can access other user data and application terminals via this device. Also, badly designed devices with defects like low fault tolerance can encumber the performance of IoT system.
- Standards and protocols. Since data transmission works on multiple layers, the protocols and standards applied on different layers and devices have to be well designed. Also, the way to deal with the conflict between newly released techniques and current protocols is a big challenge. Moreover, new IoT applications need to be compatible to exist standards and protocols.
- Configuration. Users of IoT applications may have multiple devices while service providers have to manage thousands or even more devices. A fast and easy tool to set and modify the configuration of those devices is required.

3.1.4.4 Regulatory, legal and right issues

As IoT shapely changes the society, it also creates many new regulatory, legal and right issues [17].

- Data protection. Data collected by IoT devices may be used in other places, sometimes even cross-border. The different data protection law in various regions might be distinct. The different laws in various regions have to be considered.

- Data discrimination. Some personal data will cause discrimination in some scenes. For example, wearable devices will collect users' health data like heart rate and sleeping quality. It might be used by the insurance companies to evaluate users' health status and set fitness levels. The company can choose their customer based on those levels. Although this data benefits the firm, it causes discrimination for customers with negative health data.
- Civil right and public safety. Public safety can be improved by IoT system, while incidents like PRISM indicate that civil right is invaded by multiple entities. In IoT system, more detailed information of users will be collected via ubiquitous sensors, cameras, and devices. Thus, regulations have to be well designed to avoid similar incidents and ensure user data to be used in the right way.
- IoT liability. The liability for IoT is also complicated. If network attack happened, how to identify the liability among device manufacturers, network operator, and application provider is an important issue.

3.1.4.5 Emerging economy and development issues

The global IoT market is predicted to be €1.535 trillion in 2020 from €592 billion in 2014 [18], while for different economies, the development of IoT is at different stages. This leads to several issues.

- Infrastructure establishment. It can be seen that the establishment and renewal of IoT infrastructure will be an urgent issue in the near future, especially in emerging economies.
- Investment. The investment on IoT research and development is not infinite. How to use the limited resource in a right direction to meet market demands will need a serious consideration.
- Technical and industrial development. The overall technological strength and developing level are distinct for different countries. How to balance the development of the IoT technologies in both developing and developed countries should be thought deeply.

- Policy and regulatory coordination. Coordination of policies and regulatory in different regions is necessary. Governments will need to work on protocols together to ensure the interoperability of global IoT system.

3.2 Connected Vehicles

With the maturity of IoT concepts, more and more IoT-based applications and services are developed. One of the most representative applications of IoT is Connected Vehicles (CV). The fast development of ICT technologies like Dedicated Short Range Communications (DSRC) and LTE enables the real implementation of CV. There are several reasons for the development of CV. Nowadays, there are a huge number of cars worldwide and this number is still increasing. The congestion and accidents on the road become a serious problem for both economic and human safety. CV is of high potential to reduce traffic and accidents through its intelligent traffic management and crash avoidance system. The next reason is environmental protection. Automobile exhaust emission is one of the leading factors that cause air pollution for the planet. CV is capable of decreasing fuel consumption via intelligent fuel management system. The vehicle-to-vehicle connection will help them optimize fuel usage. One vehicle can optimize its speed according to surrounded vehicles' driving statuses to avoid unnecessary stops and starts. Also, with the assistance of intelligent traffic management, the automobile exhaust emission will significantly cut down. Last but not least, the demand for onboard Internet services and applications is dramatically increasing. Passengers want to experience high-speed Internet services in the vehicle. Also, they expect to have remote control of their own cars and synchronize their car information with mobile devices. In addition, users need a safety-related application to acquire services like anti-theft and tracking system for their automobiles [19].

It is estimated by Business Insider Intelligence that there will be more than 220 million connected vehicles running on the road. Thus, CV stakeholders like car manufacturers, CV services provider, networking operators, government, and researchers pay a lot of resources for CV. It can be seen that a revolution of the automotive industry is coming.

3.2.1 Definition and Characteristics

Connected Vehicles is a technology that allows vehicles to communicate with each other, road infrastructure, personal mobile devices, and data center (Cloud). With wireless technologies, vehicles like cars, buses, and motorcycles will be able to share real-time information (e.g. speed) with each other[1]. On one hand, CV enables a lot of innovative applications and services to make the driving experience smoother. On the other hand, it will significantly improve the road safety for all the stakeholders, like drivers and pedestrian. According to its definition, several core characteristics can be identified.

- Mobility

Vehicles are highly mobility devices with frequently changing speed and position. Also, vehicles will move not only in the city but also go to the countryside or even extreme locations like mountain area. How to support the mobility in various locations has to be seriously considered.

- Connectivity

Connectivity is the foundation of CV. The connection of CV is a multi-layer communication. The various types of connection will be illustrated in the next section. The ideal pattern of CV would be seamless connectivity.

- Real-time

The interaction among devices, vehicles, infrastructure, and people is real-time. Data is flying in the air as long as the connectivity is enabled. Thus, low latency is an important feature CV needs to acquire. Due to the real-time data transition, it makes many CV services and applications come true.

---

[1] WHAT SHOULD STATES DO NOW? http://www.its.dot.gov/factsheets/pdf/V2I_WhatShouldStatesDo.pdf

- Safety

The most important thing of CV is safety. Since not only vehicles but also pedestrians and bicycles are included in CV scenario, once errors happened to vehicles can cause huge loss. The services provided by CV must be error-free. Also, since vehicles will make decisions or give suggestions based on the data shared by other vehicles, infrastructure or even mobile devices. The data and CV system security has to be guaranteed.

- Geo-distribution

The system of CV is a highly distributed paradigm. Vehicles, devices and infrastructure can be geographically located around the world. It is also because of this feature that makes CV an extremely complex system.

Except those characteristics identified based on the definition, there are also several other requirements for CV.

- Location awareness
- Scalability
- Low latency
- Heterogeneity

Many CV services, like road assistance, require precise location awareness. As the interaction in CV scenario, especially vehicle to vehicle connection, is real-time. The latency should be controlled at a low level. Also, it can be foreseen that the number of connected vehicles will continuously increase. The system of CV has to be scalable. Last but not least. The system of CV consists of multi-layer connections and highly geo-distributed system, which means that it has various software and hardware vendors. Different types of data will be transported via distinct systems. The overall system of CV must acquire heterogeneity.

3.2.2 Vehicle-to-everything (V2X)

In the blueprint of mature CV, vehicles are capable of connecting everything, which can be integrated into the whole IoT landscape. The connection is enabled by both wireless and wired technologies for both inside and outside communications of vehicles. Based on [20], the following content divides the connection of CV into 4 categories: Intra-Vehicle (V2S), Vehicle-to-Vehicle (V2V), Vehicle-to- Infrastructure (V2I), and Vehicle-to-Network (V2N). These four categories show the different connected objects for CV. Each of them has unique enabling technologies and challenges.

3.2.2.1 Intra-Vehicle (V2S)

The intra-vehicle connection can be regard as the communication between vehicles and sensors. Nowadays, there are many sensors on a single vehicle. They assist drivers to monitor vehicle condition, improve vehicle performance, and park vehicles. With the concept of CV, more sensors will be installed to enable a smarter vehicle. It is estimated by MEMS Journal that each vehicle has an average of 60-100 sensors on board today. Since vehicles aim to be smarter, in-vehicle sensors are predicted to reach 200 by 2020. In this situation, the connection within a vehicle will become more complicated. The current approach to solve the connection between Electronic Control Unit (ECU) and sensors is using wired network technologies like Controller Area Network (CAN) or FlexRay [21]. This approach also meets its bottleneck to meet CV requirements, like scalable and updatable. Therefore, wireless technologies become a potential alternative.

There are three basic characters for current onboard sensor network: (1) Sensors are stationary. (2) Sensors are connected to ECU contributing to a simple star topology. (3) No energy constraints for wired connecting sensors [20]. Except these, there are several other features of intra-vehicle connection that also result in the challenges for CV.

- Complexity

With increasing functions needed by vehicles, the sensor network becomes more and more complex. The cable used in traditional wired solution will increase dramatically, which has already composed by several km now. It will add difficulty to maintain and diagnose the system [22]. How to efficiently deal with this situation is a critical challenge for CV.

- Scalability & Updatability

The growing number of connected sensors and applications onboard requires the sensor network to be scalable ad updatable. While a single vehicle has limited space, the requirement for sensor network is harsh. It is difficult for currently wired solutions to achieve those two features.

- Real-time

Several critical in-vehicle functions like auto brake require real-time communication. The latency of data transportation among in-vehicle sensor networks has to be low, which needs the support of enough bandwidth and stable connection. While in wireless sensor network, the interference from both inside and outside of vehicles is not negligible.

- Security

Security is a prominent issue for wireless sensor network. It will be more vulnerable than wired connection since the data are transmitted in the air. How to keep the vehicles from malicious attacks is extremely important to ensure the safety of people in the vehicle.

In order to achieve the requirements of CV and overcome challenges for current intra-vehicle connection, several new wired and wireless technologies have been proposed. The currently used and potential alternative enabling technologies for intra-vehicle communication are summarized in Table 3.

Currently Used	Alternative Technologies
Controller Area Network (CAN)	**Wireless:**

Local Interconnect Network (LIN) Time-Triggered Light Weight Protocol (TTP) Media Oriented System Transport (MOST) Digital Data Bus (D2B) Bluetooth (mainly for mobile devices connection) FlexRay Firewire (IEEE 1394)	Bluetooth (in-vehicle connection) ZigBee WiFi (IEEE 802.11b/p) Ultra-wideband (UWB, IEEE 802.15.3a) 60 GHz millimeter wave (IEEE 802.15.3c) **Wired:** Power Line Communication (PLC) Ethernet (TTEthernet)

Table 3: Summary of Enabling technology for Intra-Vehicle connectivity [3] [4]

The currently used technologies are mainly wired, which will significantly add weight to vehicles. It will also influence the mass and installation cost of vehicles. Moreover, it is difficult to add new functions for wired connection. In order to solve the problem, some specialists develop advanced wired solutions, such as PLC and Ethernet, while others turn to use wireless sensor network. Although WiFi and Bluetooth have already been used for the in-vehicle connection, it is primarily used for infotainment and multimedia applications [22]. V2S connection can also take the advantages of these wireless technologies.

3.2.2.2 Vehicle-to-Vehicle (V2V)

The development of V2V communication dates back to 1994. It was conducted by ISTEA which aimed to establish a safe, predictable and efficient highway system for vehicles [23]. Nowadays, V2V has broader application area and can be used in multiple scenarios. Information generated by automotive electronics like in-vehicle sensors, ECUs, and even infotainment system can be shared with nearby vehicles. In-vehicle experience will become safe, smooth, and interesting.

There are 4 main characters, or requirements, for V2V communication:

- Mobility
- Dynamic
- Scalability & flexibility
- Real-time

Vehicles will move in different scenarios at different speed. Thus, V2V is a high mobility connection, which is much higher than the traditional mobile network. Also, vehicles being connected will change frequently, which leads to a highly dynamic near-field network. So the network should be flexible and scalable. Moreover, the data transmission among vehicles is time-sensitive, which means it is a real-time communication. This real-time communication property leads to the critical consideration of safety as well as the performance of V2V applications. According to its features, several critical challenges for V2V connection appear.

- Stability & Performance

High mobility and dynamic of V2V connection determine that it has a harsh communication environment, especially in the city area with high density of vehicles. The V2V connection will receive considerable signal interference from obstacles like big trucks and buildings. Also, multipath fading, shadowing, and Doppler Effect in high mobility and density of vehicles will lead to a wireless loss. Moreover, V2V requires low latency data transmission, which needs enough bandwidth support.

- Connectivity

V2V connection has to be able to implement independently without the support of road-side infrastructure, cellular base stations or even global positioning system. This will challenge the technologies and protocols being used for the connection between vehicles. This communication will also impact by dynamic changing connected vehicles. How to ensure a fast connection to this scenario is also a puzzle.

- Network security

The security threats can be divided into 3 categories: authenticity, confidentiality, and availability [24]. For each category, there are several different attacks. As V2V network is wireless, it is even more vulnerable, which will obviously influence the safety of people on the road. The malicious attacks happened in such a high mobility scenario may lead to serious accidents and life lost. Thus, security issues will need serious consideration.

- Flexibility

As the number of connected vehicles within a single V2V network will change regularly, the network has to be flexible and efficient to add and release connection for vehicles.

In order to overcome challenges and support the implementation of V2V connection, a wireless network named Vehicular Ad-Hoc Network (VANET) is developed. It is based on the principle of Mobile Ad-Hoc Network (MANET), but VANET can be regard as an independent research field [24]. In VANET, On Board Units (OBU) will be installed in every single vehicle to enable the vehicles to share data with each other [25]. The following content introduces two main enabling wireless technologies for VANET: dedicated short-range communication (DSRC) and dynamic spectrum access (DSA) [20].

- DSRC

DSRC is “a two-way short- and medium- range wireless communications capacity that permits very high data transmission critical in communications-based active safety applications” [26]. IEEE also releases two standard to support Wireless Access in Vehicular Environments (WAVE): IEEE 802.11p and IEEE 1609. The former standard is for PHY and MAC layer and the latter is for higher layers [20]. DSRC has been widely accepted and applied. Several regions like U.S, EU, and Japan have done many experiments for DSRC on-road.

- DSA

DSA is a set of spectrum management techniques that aims to improve communication network performance[2]. It is able to efficiently allocate bandwidth and minimize idle spectral bands or white spaces [27]. Due to the limited spectrum

[2] Dynamic Spectrum Management. https://en.wikipedia.org/wiki/Dynamic_spectrum_management

resource available and the increasing demand on onboard data transmission for DSRC, DSA can act as a complementary technology for DSRC [20].

3.2.2.3 Vehicle-to-Infrastructure (V2I)

Vehicle-to-infrastructure (V2I) communication is the data transmission between vehicles and roadside infrastructures, such as traffic signals, work zones, and toll booths, via wireless technologies[3]. When V2I cooperates with V2V connection, vehicles will be able to acquire the most basic on-road CV benefits. V2I is also the foundation of Intelligent Transportation System (ITS). It plays a significant role in predicting and preventing road accidents. It has several similar features to V2V paradigm: dynamic connection, real-time data transmission, and scalability. Besides, V2I is a widely geo-distributed network and aim to acquire high availability. Based on its features, three main challenges, apart from similar performance and flexibility challenges to V2V, come to light:

- Deployment

How to efficiently deploy V2I equipment is a key problem for this connection. Many aspects have to be critical considered, such as application development cooperation, equipment coverage, budget, and operating and propagation conditions [28]. Also, the deployment should maximally satisfy the availability of V2I connection. In addition, the liability of the infrastructure also needs to be clearly identified.

- Security

V2I has a harsh security environment, including but more issues than V2V scenario. Since V2I has widely distributed equipment, it is easy for adversaries to find an access point to the network. Attacks like impersonation attack and man-in-middle attack will threat on road safety from multiple angles.

- Standards

[3] Vehicle-To-Infrastructure Deployment: What Should States Do Now?
http://www.its.dot.gov/factsheets/pdf/V2I_WhatShouldStatesDo.pdf

As the infrastructure will be provided by multiple vendors, developing technical standards to ensure interoperability is also important.

VANET is also able to support V2I communication. In this system, it is mainly the communication between OBU and Road Side Units (RSU). DSRC can also be used to enable the connection between them. Also, Cellular System is proposed by [28] as a potential technology for V2I connection. Both of two approaches have capacity and coverage limits that should be considered in the deployment stage. While [25] also suggest VANETs can integrate WLAN and cellular system to establish a comprehensive wireless network for V2I communication.

3.2.2.4 Vehicle-to-Network

Previous three connections can still work without the requirements of connecting to the Internet. While for CV paradigm, Internet connectivity is indispensable. With the link to the Internet, vehicles achieve the real sense of being connected. V2N enables many novel applications and services for vehicles like real-time navigation system, city parking services, and vehicle learning. When vehicles connect to the Internet, it can be smarter, safer and more interesting. The functions of V2N seem to be useful and attractive, there are still several issues need to be solved.

- Connectivity.

How to deal with the access point of V2N connection? This could be also linked to V2I and the deployment and coverage of network infrastructure. In addition, services providers should also consider the mechanisms being conducted when vehicles run out of the network coverage.

- Performance.

This is most related to properties such as bandwidth and fault tolerance of the network. As many CV applications like onboard infotainment system require a high speed of download bandwidth and quality of service, the performance of the network will be a key issue for them.

- Security and Privacy.

As said before, security is a common and urgent challenge for all services related to network connection. While privacy issue is another problem for service providers. As data sent to back ends may include sensitive data of the users, how to protect and use this data while doesn't invade data privacy needs a serious consideration.

Current solutions for V2N connectivity can be divided into two categories: brought-in and built-in [20]. Brought-in connectivity uses a technology named MirrorLink and via smartphone network like 3G/4G to connect to the Internet. Built-in system embedded cellular network (e.g. 4G/LTE) to in-vehicle system, like onboard infotainment system, to enable V2N connection. As the capacities of both brought-in and built-in methods are limited and inextensible, two new approaches emerge: WiFi-based and cellular-based connections.

- WiFi-based connectivity

WiFi-based connectivity provides low-cost Internet connection for V2N. This connection is enabled by embedded WiFi device for vehicles via outdoor WiFi hotspots like city WiFi hotspots. The potential protocols can be used to support V2N are 802.11b and 802.11g [29]. However, the deployment of the hotspots, connection establishing time, open WiFi security, frequent disconnection, and protocol drawbacks are still critical issues.

- Cellular-based connectivity

Unlike the coverage of WiFi hotspot, cellular-based connectivity has much better coverage and stability [30]. The low throughput and bandwidth of 3G will be improved by 4G/LTE and the upcoming 5G technology. Nevertheless, the cost of cellular-based connectivity is also higher than WiFi.

Each of the two approaches has their own advantages. In this case, [20] also suggest that V2N connection could have a better performance via a hybrid network to take benefits from both WiFi and Cellular network.

3.3 Fog Computing

In the era of big data, Cloud computing is considered to be a powerful countermeasure to deal with the huge amount of data. It significantly reduces the expense of IT infrastructure for companies and helps Cloud service providers gain the economy of scale. Other benefits like improving the efficiency of managing data, achieving scalability, and pay-as-you-go make it the most popular technology nowadays. However, Cloud computing is imperfect, especially when dealing with IoT applications.

The problems for Cloud computing in IoT scenario can be mainly divided into two aspects. First is the physical distance. One of the most typical features of Cloud is centralization. All the data will be transport to data centers, which can be located in anywhere in the world. In this situation, it will influence the time and stability of data transmission between users and data centers. The long distance will increase the average network latency and jitter [31]. Therefore, traditional Cloud computing is powerless for IoT applications which need fast reactions to the surrounding environment, location awareness, and mobility support. Next problem is the huge volumes of data created by IoT devices and sensors. If all the data will be sent to the Cloud center, it will cause congestion in the network and increase expense on storing and analyzing these data. Yet not all the data are needed by service providers. In this case, to against the deficiency of cloud computing, experts try to find solutions at the edge of network. A new edge computing paradigm, Fog computing, is born.

3.3.1 Overview of Fog Computing

The term Fog computing was first proposed by Cisco in 2011 [32]. The definition was also given by Cisco in 2012. It defined Fog computing as a “highly virtualized platform that provides compute, storage, and networking services between end devices and traditional Cloud computing data center, typically, but not exclusively located at the edge of network” [33]. It is an extension and complement of Cloud computing, which enables data to be preprocessed at the edge of the network. In order to achieve Fog capacity, a large scale of sensors and high geo-distributed Fog servers, which is also called Fog node, are necessary. The data preprocessing at the Fog node make it possible to reduce the response time needed between applications and computing stations. It is capable of improving the performance of latency-sensitive services like Connected Vehicles. However, every coin has two sides. Although Fog computing brings several benefits to IoT, it also results in a quite complicated system.

As Fog computing has such a promising future, the first thing to understand Fog computing is to identify its characters. Nowadays some other edge paradigms are also invented to solve similar problems. They also dim the differences between them. Therefore, the overall features of Fog computing will be presented via the comparison with other two major edge paradigms in the following content.

3.3.2 Similar Edge Paradigms

Several novel edge paradigms have been invented to deal with the deficiency of Cloud computing. There are various forms of edge computing paradigms published in recent 5 years, while three of them receive a lot of concerns and considered to be the most efficient approaches: mobile edge computing, mobile cloud computing, and Fog computing [34]. Although these three paradigms share a lot of common features, they also have different points.

3.3.2.1 Mobile Edge Computing

The first MEC platform which can run applications directly within a mobile base station was launched by Nokia Siemens Networks & IBM in 2013 [35]. After that, in 2014, ETSI’s Industry Specification Group (ISG) gave a definition for MEC in its white paper. It defined MEC as a platform that built an IT service environment and offered cloud-computing capabilities at the edge of the network via Radio Access Network (RAN) to be closed to mobile users [36].

The first version of MEC platform released by ISG can be deployed at LTE base station (eNodeB), 3G Radio Network Controller (RNC) or a combination of multiple Radio Access Technologies (RAT) which includes 3G, LTE and WLAN [36]. Those deployment locations can be both indoor and outdoor. Now, the upcoming mobile technology, 5G, dramatically increases the bandwidth of the network and reduces latency for data transmission, which makes it possible to apply MEC for IoT. As the concept of MEC enables IoT applications to be stored and processed in MEC servers, it pushes IoT services closer to their users. Thus, applications hosted at MEC servers can achieve quick responses to their users as well as location awareness. The Cloud will mainly responsible for comprehensive analysis and historical data storage.

3.3.2.2 Mobile Cloud Computing

The term Mobile Cloud Computing (MCC) was first introduced by Mufajjul Ali in 2009 which focus on centralized Cloud data center managing mobile devices [37]. The concept which we use now defines MCC as “a model for transparent elastic augmentation of mobile device capabilities via ubiquitous wireless access to cloud storage and computing resources, with context-aware dynamic adjusting of offloading in respect to change in operating conditions, while preserving available sensing and interactivity capabilities of mobile devices” [38].

There are two main research areas for MCC. First is the augmented execution for mobile devices. The resource available and computing capacity on mobile devices is limited, especially the battery life. It significantly restricts the deployment and further improvement of IoT applications. MCC aims to enable mobile users to offload part or even all of their tasks to Cloud, using the abundant resources available in cloud data center to process, analyze, and store data for mobile users [39]. It is mainly enabled by using virtualization technology like VM or clone.

Although the offloading service takes the advantage of using powerful Cloud computing for mobile devices, it still cannot reach the requirement of IoT. For applications which have a strict requirement for respond time, like augmented reality, traditional Cloud platforms cannot work well due to the physical distance between users and the Cloud. Thus, another key research area for MCC is to perform computing ability in proximity to users at the edge of the network [34]. There are two architectures for this ability. First one is offering resource-rich server, called Cloudlet, at the Local Area Network (LAN) to provide low latency and high-speed services to mobile devices. The second one is called Ad hoc mobile cloud. It uses idle mobile devices nearby, building a pool to enable them to share resources with each other [39]. One mobile phone can act as a server or several mobile phones can collaborate with each other to handle parallel assignments. This architecture can work without accessing WiFi or Radio technologies. In the future, MCC can combine these two architectures to provide a stable MCC environment for users.

3.3.2.3 Comparison of Edge Paradigms

From the previous description, three paradigms share a lot of similarities:

- Same basic goal.

They share the same goal that is to bring abundant cloud computing capabilities and resources of the data center to the edge of the network.

- Centralized Cloud.

The centric Cloud data center plays a vital role for all three paradigms, which acts as a brain for the whole system. It provides high computing capability and data storage for resource constrained devices and service providers.

- Geographical distribution.

Although they all have a central Cloud data center, the architecture of these paradigms are actually decentralized and highly distributed. There are multiple local servers placed in different regions. A lot of sensors and devices (e.g. phones, cars) appeared in wide geographical locations with high density.

- Mobility.

The targeted customers of these paradigms are mostly mobile devices. The working range of a single local server is limited. As devices (mostly their users) will move from one region to another, it is essential for multiple edge servers collaborating with each other to support mobility. This migration can be done via virtualization technologies.

- Low latency and jitter.

The edge paradigms shorten the distance for user devices. Data processing in close proximity to devices will significantly reduce the latency and jitter for data transportation.

- Complexity.

Because of the geographical distribution, the network for those paradigms is extremely complex.

- Location awareness.

The edge servers with widespread sensors can use a low-level signal to support positioning services. Also, with the advantage of low latency, applications running on these paradigms are able to provide more precise and fast services.

- Scalability.

Due to the fact that the devices connected to networking will jump to 13.5 billion in 2020 [40]. All these three paradigms provide a scalable network architecture for applications.

- Heterogeneity.

As the applications and edge network infrastructures are provided by various entities, edge servers in three paradigms acquire heterogeneity for connecting and processing data transported by user devices.

- Accessibility and availability.

The paradigms aim to provide highly accessible and available connection. Thus, theoretically, the user equipment is able to connect to edge networking via Radio Access technologies at anyplace.

- Enabling application and service ecosystem.

These three paradigms' overall landscape is to build a health and efficient ecosystem for its stakeholders, include Cloud services providers, network infrastructure operators, application and service vendors, and end users.

Indeed, Fog computing, MEC, and MCC share the same goal and offer a set of similar functions and benefits. But there still exist several different points (see Figure 4).

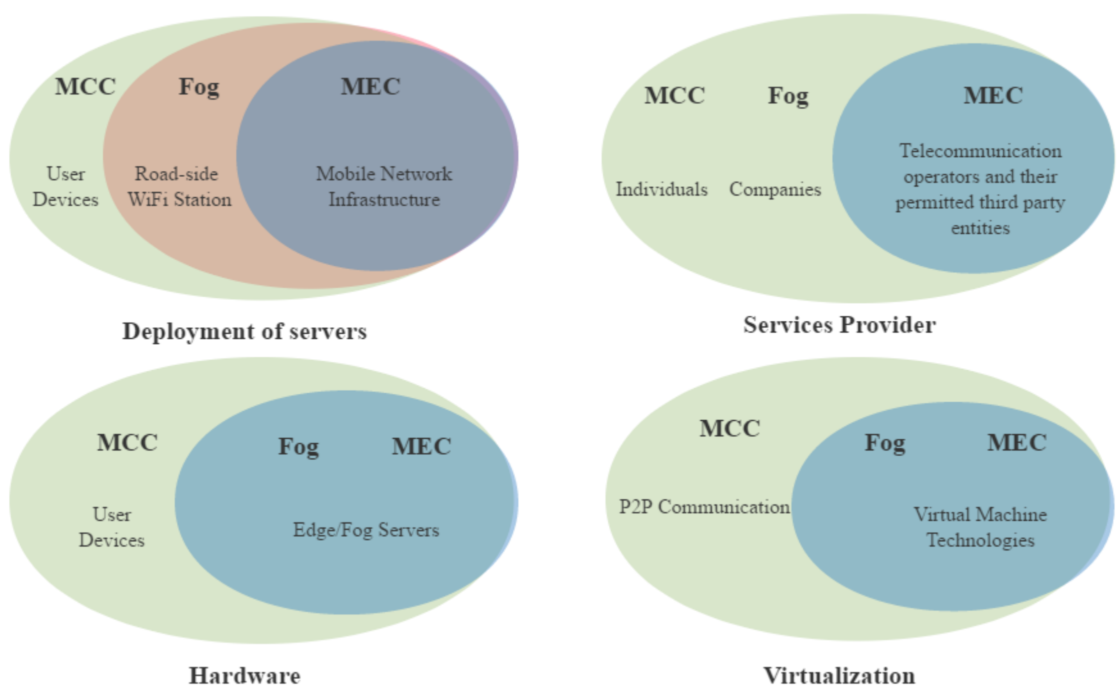

Figure 4: Different points of three paradigms

- Deployment.

MEC mainly deploys the paradigm on mobile network infrastructure, while Fog computing can be presented on broader locations like road-side WiFi station and individual servers. The deployment of MCC is the widest one among others, where user devices themselves could act as an edge server.

- Service provider.

The locations chosen to deploy the paradigm determines the edge service providers. For MEC, telecommunication operators and their permitted third party entities are the only choices. While Fog computing and MCC are able to have multiple providers from companies to individuals.

- Hardware

MEC and Fog computing edge servers are their core computing center. But for MCC, not only edge servers but also user devices can provide computing resources for users.

- Virtualization

All these three platforms are highly distributed systems and various local servers (Fog servers, MEC servers, and Cloudlets) will be physically established in multiple locations. In this case, the implementation of the paradigms is based on Virtual Machine (VM) technologies. It enables applications to share resources and migrate tasks on local servers. The virtualization of servers can also increase the security of the data transmission. ISG suggests that the network infrastructure, where carries MEC services, can also implement services like Network Function Virtualization (NFV) and Software Defined Network (SDN) to improve the performance of MEC [36]. This can also be used by other two platforms. However, the architecture, ad hoc mobile cloud in MCC platform, do not require the virtualization of the infrastructure for peer-to-peer communication.

Similarity	Differentia
• Same basic goal • Centralized Cloud • Geographical distribution • Mobility	• Deployment • Service provider • Hardware • Virtualization

• Low latency and jitter • Complexity • Location awareness • Scalability • Heterogeneity • Accessibility and availability • Enabling the application and service ecosystem	

Table 4: Similarity and Differentia of Three Main Edge Computing Paradigms

The comparison of the three paradigms has been summarized in Table 4. It can be seen that they share a lot of common points. Their differences are mainly caused by the different promoted entities and drivers who inspire the concept (Cisco for Fog computing, ETSL for MEC, and academia for MCC) [41]. As IoT is the main driver for Fog computing, it is considered to be the most suitable edge computing paradigm for IoT applications and service in this research. Also, MEC mainly focuses on the mobile network, while IoT defines broader deployment locations. In addition, current Radio access Technologies like 3G/4G/LTE cannot completely fulfill the requirement of IoT applications, especially in high mobility scenario, CV. Although the upcoming technology, 5G, will be able to improve the performance of MEC, the mature application of 5G still has a long way to go. In the case of MCC, it acquires user devices act as an edge server, which generates additional complexity and security issues for IoT applications. This makes it not the best choice for IoT.

3.3.3 Fog Paradigm

Fog computing plays as a middle layer between Cloud and end users. The general Fog paradigm is a 3-tier architecture (see Figure 5), including Cloud tier, Fog tier, and Smart Object tier. The structure of this paradigm from top to bottom is decentralized. Contrarily, it’s centralized.

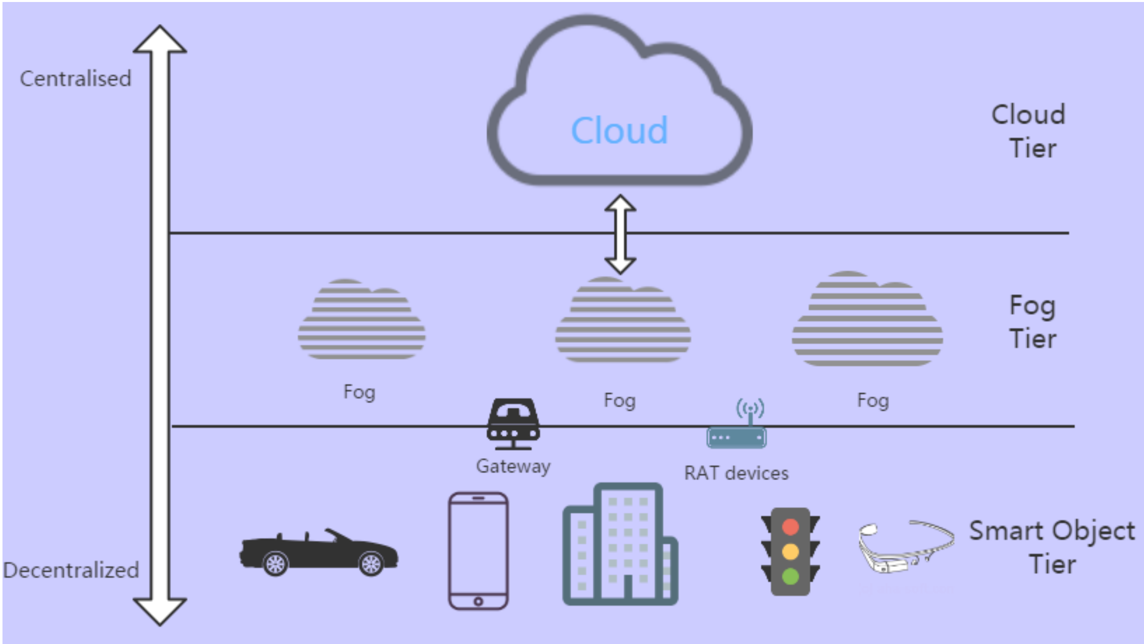

Figure 5: Fog Paradigms

- Cloud Tier

This is the top tier of the paradigm. It contains computing resources and storage capacity, which enables IoT application developer to store and analyze data transported by Fog nodes. It is also responsible for managing, monitoring and coordinating the whole Fog paradigm.

- Fog Tier

This is the middle tier of the paradigm. Wide distributed Fog nodes and the network infrastructure compose this layer. It provides proximal edge computing for the bottom layer. Data collected by user devices and sensors will be preprocessed here. It will discriminate whether to send the data to the Cloud or process the data at Fog node and send result or orders back to user devices or actuators. The virtualization function will also be implemented on this layer.

- Smart Object Tier

The bottom tier is for end users devices and sensors. Network access facilities like gateways, routers, and cellular base stations are also included in this layer. The Radio

Access Technologies (RAT) used by objects can be WiFi, cellular network, Bluetooth, ZigBee and so on.

Those three tiers are the basic tiers of Fog paradigm. Based on this architecture, there might be other specific tiers. In [33], it proposes a 4-tier architecture, which adds a Core Tier between Cloud and Fog. It takes part of the tasks from Cloud tier in Figure 6, which is responsible for managing IP/MPLS, security, Quality of Service (QoS), and multicast. Some researchers [43] recommends a 5-tier architecture. It divides Cloud tier in Figure 6 into three parts: IoT Application tier, Software-Defined Resource Management tier, and Cloud Service and Resources tier. IoT Application tier is the topmost tier which is about the operation and development of applications and services. The tier below IoT Application tier is Software-Defined Resource Management tier, which is responsible for managing the whole networking infrastructure and quality of services. Next to it, is Cloud service and Resources tier. The Cloud resource and its management services are provided by this tier.

3.3.4 Challenges

As Fog computing is a quite novel concept, there are many challenges remained to be conquered. In [33] [36] [42] [43], they all discuss the challenges for Fog concept. To sum up, most challenges can be divided into several aspects below.

- Technical Challenge
  - Computing capacity and storage limitation. Fog computing plays as an extension of Cloud. Its capacity and storage are limited due to the consideration of cost. How to balance performance and cost is a puzzle for Fog computing.
  - Resource management. It can be predicted that there will be billions of end devices connected to Fog network and the number will continuously increase. Since the resource on Fog server is limited, so how to efficiently setup, manage and configure the resource for Fog server is a challenge.

- Programming model. Multiple types of IoT applications will run on or connect to Fog server. As Fog server aim to provide an open source system for programmers, a valid programming model to ease the effort of programmers is necessary.
- Computation offloading. Fog computing supports mobility, especially high mobility scenario, which makes it a high dynamic network. With limited resources on a single server, computation offloading technology is important to ensure the performance and maximize the usage of resources for Fog servers.
- Physical deployment. An efficient deployment of Fog server will improve and maximize the performance of Fog computing and reduce the cost of the infrastructure.
- Energy minimization. Since there will be a large amount of Fog servers deployed in a wide area. The energy consumption is not a negligible issue.

- Security. Network Security is the vital issue for networking service. There is no doubt that security for Fog computing will need a lot of research on it. Advanced technologies like authentication, access control, and intrusion detection will have to be developed to improve the security for Fog networking. In addition, since Fog servers are geographically deployed, they also require physical protection.

- Reliability. The security issues will impact the reliability of using Fog computing. Besides, the recovery capability after failures like reschedule tasks or replication to exploit executing in parallel [45] also influence users' trust of the system.

- Privacy. Since Fog computing paradigm allows third parties to provide Fog server services. The privacy of users has to be protected in an efficient way. The privacy protection will also impact the reliability of users. Nevertheless, regulatory and legal could be considered as a tool to protect user privacy.

- Billing. The purpose of companies provides Fog services is to get benefits from it. Therefore, how to reasonably set price for using Fog services will affect the health of the Fog ecosystem.

3.4 Summary

This Chapter mainly introduces IoT, Connected Vehicles, and Fog computing. Although the development of IoT is still in its preliminary stage, its concept, characters and architecture have been widely accepted. However, there are still many challenges and issues on the way for IoT, which need time and resources to figure out. As one of the most representative applications of IoT, CV is highly recommended to improve road safety and bring smart driving experience. Apart from general features of IoT, it also has unique features such as high mobility and wide geo-distribution. These features make CV implementation quite difficult and complex. According to its special connectivity requirement, its connection has been divided into 4 categories: V2S, V2V, V2I, and V2N. For each specific connection, there are several potential enabling technologies and challenges. In this case, the development of CV still needs a lot of research and supporting technologies to fulfill its implementation. Thus, Fog computing, which is discovered to be able to support IoT applications and services, is of potential to improve the performance of CV. Its features have been identified via the comparison with other two similar paradigms. The general Fog paradigm indicates the role of Fog computing in the IoT architecture. However, Fog computing has just been proposed for 5 years. There are still many challenges which require more researches in this field.

Chapter 4 MLR on Fog Computing and Connected Vehicles

Fog computing is a novel technology which has just been released for 5 years. Academic literature for Fog computing is limited while articles related to the implementation of Fog Computing on CV are even fewer. So materials collected by academic literature review are not comprehensive and complete. Thus, multivocal literature review (MLR) is conducted.

As said in section 2.2, the goal of MLR can be divided into two parts. The first part is to refine the definition of Fog computing, identify its capacities and lay out its enabling technologies. Its result will be illustrated in section 4.1. Section 4.2 will present another part which aims to identify the requirements of CV. All the online materials which have been reviewed can be found in Appendix A. In section 4.3, Fog capacities and CV requirements will be matched to show what can Fog computing do for CV.

4.1 Fog Computing Capacities

Many articles give definitions of Fog computing. Thus, before elaborating the capacities of Fog computing, its concept has to be clearly defined. The features of Fog computing have been identified via the comparison of three similar edge paradigms. Then its capacities can be presented based on the definition and features of Fog computing. The enabling technologies of Fog computing will also be introduced in this section.

4.1.1 Definition

The initial definition of Fog computing is given by [33]. Afterward, the definition was refined by [43] [44] [45]. Also, several online articles and publications also give their definitions respectively to Fog computing. In this case, a critical and comprehensive definition for this paradigm is required. Thus, based on the review of multiple materials, its definition can be refined as below:

Fog computing is a sub-category of edge computing. It is a highly virtualized, widely distributed, and extremely complex computing paradigm. Its Fog servers enable part of central Cloud computing capacities (data processing, analysis, and storage) to work at the edge of network.

4.1.2 Capacities

As there exist several similar concepts for Fog computing, it is necessary to distinguish Fog concept from them. Via the comparison of the similar paradigms in section 3.2 and MLR, the features of Fog computing is shown below:

- Wide geo-distribution
- Complex system
- High scalable
- High accessible and available
- High heterogeneous

According to its concept and features, several capacities can be identified for Fog computing.

- Low latency. As Fog computing works close to end devices, which cuts down the physical distance between users and computing center, it will considerably reduce the latency for real-time data transmission.

- Preprocess data. With the computing capacities at a Fog server, data collected by onboard sensors and cameras can be processed locally before sending it to Cloud/datacenter. For example, road obstacles detected by vehicles will be sent to Fog server and store there. Then, when other vehicles enter this area and connect with this Fog server, they will be instantly informed by the road obstacle detection system on the server about the obstacles in this area. If the obstacles on-road are removed, onboard cameras haven’t detected any obstacles in the position provided by Fog server. The report will be sent to Fog server and the obstacle information stored in the server will be removed. In this case, only those obstacles existing for a long time will be sent to Cloud. Road obstacle detection service provider can analyze that information and give feedback to related road management departments to remind them to fix the obstacles.

- Reduce network traffic. As data will be preprocessed locally, it will minimize the congestion and pressure for the whole network.

- Reduce cost for data transmission. It is expensive for transporting all end devices' data to central Cloud/Datacenter. Since data will be preprocessed at Fog server locally, it will save money for data transmission.

- Location awareness. Working with Cloud means there needs a strong signal for precise location awareness and fast data transportation speed. Instead, Fog allows a low-level signal to determine the location [36].

- Mobility support. Some IoT applications need mobility support of the network, like CV. While Fog paradigm is a wide geo-distributed system. With the cooperation between Fog servers, it is able to support high mobility devices.

- Scalability. As the devices being connected will continuously growing, it needs a scalable system. With traditional devices-Cloud mode, the limited bandwidth will become the bottleneck even Cloud has infinite resources. Since Fog will work locally for devices, it will relieve the pressure for Cloud and bring scalability at the edge of network.

- Heterogeneous architecture. IoT devices are generated by multiple manufacturers. So the network for them has to be heterogeneous. With the virtual technologies applied by Fog computing, it is capable of offering a heterogeneous platform for applications.

4.1.3 Enabling Technologies

After answering the questions of what Fog computing is and what it can do, the remained problem would be how to implement Fog computing in reality. Based on the solution provided by Cisco, the implementation of Fog computing can be divided into 4 parts.

- Connectivity

IoT devices can use routers, switches, and wireless access points to reach Fog servers. The development of Mobile Ad Hoc Network (MANET) will also improve the connectivity for Fog servers. There are multiple wireless access technologies that enable the connection between Fog server and end devices. They can be divided into 3 types: Wide/Metropolitan Area Network (WAN/MAN), Local Area Network, and Personal Network (PN) [44] (see Table 5).

WAN/MAN	Cellular network: 3G/4G/5G, WiMax, HSPA+
LAN	WiFi/802.11
PN	6LoPAN, ZigBee, Bluetooth/Bluetooth LE,

Table 5: Wireless Access Technologies for Fog Computing

- Fog Server: Hardware, Software, and Networking

The computing capacity of a single server depends on its hardware, software, and networking. For hardware, System on Chip (SoC) or traditional computer hardware would be the core of the server. For size-restricted Fog servers, SoC can be used. It consists a set of electronic circuits and integrates all computer components on a single chip. The size of Fog servers and energy consumption can be controlled in a low-level. As every component is integrated into a single chip, it is impossible to just change or update one component like CPU or RAM. For servers requiring high performance and flexibility, traditional computer hardware is a better choice, which new components can be put at any time. Then, virtual machines will be installed on Fog server. Based on virtualization technologies, operation systems, like Cisco IOx and TTTech Fog OS, can be used to manage the Fog server and applications running on it. For Fog networking, Software-defined Network (SDN) and Network function virtualization (NFV) are two proposed techniques to support Fog network.

- Application development and hosting

The development of applications running on Fog server is similar to Cloud application development model. Fog server will act like a mini-Cloud where IoT applications will be hosted. Also, Fog server is an open-source platform. It is able to support multiple development environments and programming languages. In addition, the IoT applications can be developed and enhanced in Cloud and then deploy them to run in the Cloud and in the Fog[4].

- Security

Since Fog server will be deployed in multiple places and transmit data to Cloud and end devices, it will require two perspectives of security: physical security and cyber security. For the former aspect, a strong access control is indispensable. Cisco also suggests using video surveillance cameras to protect Fog server. For cyber security, there exist protection mechanisms for before, during, and after the attack. Before attacks happen, it consists of multiple technologies like Octopus mutual authentication [46] and network access control. During the attack, there are anomaly detection system and intrusion prevention system. Also, an alert system to warn Fog server operators will be conducted. After attacks, a system will collect attack information and provide it to the network operator. Based on the information, experts will be able to analyze attacks, fix loopholes and improve the security of the network.

[4] Cisco Fog Computing Solutions: Unleash the Power of the Internet of Things
https://www.cisco.com/c/dam/en_us/solutions/trends/iot/docs/computing-solutions.pdf

4.2 Connected Vehicles Requirements

The requirements to implement CV can be related to the features and function CV service provider wants to achieve. CV is usually considered to be one of the most typical scenarios for IoT, but this doesn't mean it is same as other IoT applications. Apart from general requirements of IoT applications, CV also has several specific requirements (see Table 6).

General Requirements	Specific/Additional Requirements
• Interoperability • Heterogeneity • Dynamic • Scalability & Updatability • Identifiability • Intelligence • Sensing • Expressing • Energy • Self-management • Service provisioning • Distributed • Safety & Security • Location awareness • Privacy	• Multiple types of connectivity requirements • Real-time support • Mobility support • Flexibility • Data preprocessing

Table 6 Requirements for Connected Vehicles

Since CV is a high mobility scenario, it has several specific requirements to be fulfilled. In this case, traditional methods and techniques been used to support IoT applications may meet bottlenecks in CV. Thus, new approaches have to be developed to fulfill the implementation of CV.

4.3 Matching of Fog Capacities and CV Requirements

Since Fog computing is designed to support IoT services and CV is a representative application of IoT, Fog computing seems to be an ideal tool for CV. In order to understand the benefits of implementing Fog concept on CV, a matching picture of Fog capacities and CV requirements is shown below (Figure 6).

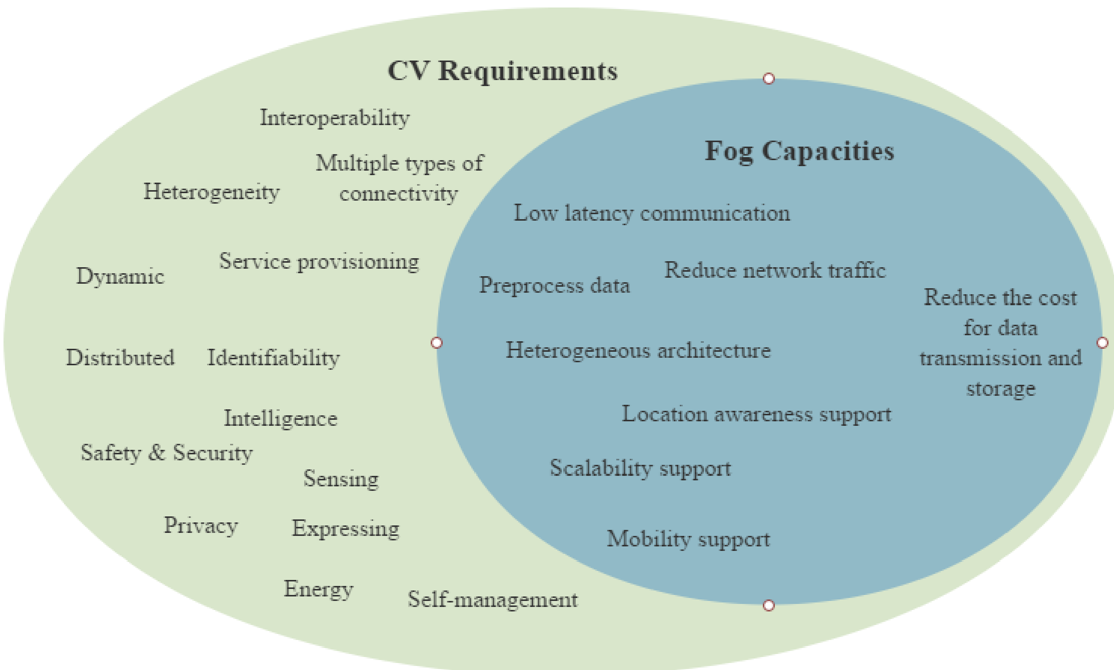

Figure 6: Matching Fog Capacities and Connected Vehicles Requirements

It can be seen from the table that Fog capacities can fulfill CV requirements in six aspects. First, Fog computing can provide low latency communication and reduces network traffic for CV services. These two capabilities can help CV offer real-time services. Second, data collected by sensors in CV can be preprocessed at Fog server. Only valuable data will be sent to Cloud, which will reduce the burden for Cloud and CV service providers. It will benefit real-time communication of CV since the response time is cut down. Third, because sensors, as well as CV hardware, are provided by multiple vendors, it requires the support of a heterogeneous top layer to process its data. Fog computing is a heterogeneous architecture which fits this requirement. Next, vehicles are moving entities in various speed. As Fog servers are widely distributed, it is able to support mobility requirement of CV. Moreover, this will also allow Fog computing to provide precise location awareness with less single level. Since the number of connected vehicles will increase in the future, CV needs to be scalable. While scalability is one of the major advantages of Fog computing. Apart from those requirements, Fog can also reduce the cost of data transmission and storage for CV stakeholders.

4.4 Summary

This chapter summarizes the previous literature review and MLR results of Fog computing and CV. The definition of Fog computing is refined according to different definitions given by academic papers and online materials of Fog computing. Based on its refined definition, features illustrated in section 3.3.2 and MLR, the capacities of Fog computing are identified. Then, via MLR, and the comparison of IoT and CV characters, the requirements to conduct CV services are also presented. Last, the matching of Fog capacities and CV requirements are proceeding. It shows what Fog computing can do for CV. In order to validate the matching level of those two technologies, several interviews with experts in two field, Fog computing and CV, are conducted. The analysis of the interviews will be illustrated in next chapter.

Chapter 5 Interview Analysis

With previous literature review and MLR, the capacities of Fog computing and the requirements for providing CV services are identified and matched. Fog computing is capable of satisfying several requirements of CV. While only based on literature review and MLR is not comprehensive enough. The Fog capacities and CV requirements in practical application field are lacking. In this case, several interviews are conducted to validate and complement those findings.

5.1 Interview Design

With limited time and resource, approaching specialists with abundant experience in both area of Fog computing and CV is difficult. Also, there are not many people having experience in the field of Fog computing. Thus, the targeted interviewees are divided into two groups: Fog computing and CV. Each group has a unique question list.

As explained in Chapter 2, these interviews will be conducted as a semi-structured interview. The sample questions will be listed and sent to interviewees to give them a brief overview of what will be asked. During the interview, the questions may be changed and other questions might be asked based on interviewees' answers and background. There are three ways to do interviews: email, video, and phone call. For the last two ways, interviews will be recorded via iPhone Audio Recorder. After the interview, the audio documents will be transcribed into text format to do further analysis. The first way is sending question list in word format to the interviewee by email. After typing answers, the document will be sent back to me. This may be conducted in one or multiple rounds.

The interview about Fog computing aims to identify its capacities and limitation. The question list for Fog computing has 5 parts (see Table 7).

Stage	Theme	Target

Part 1	Interviewee’s background	Identify the background of the interviewee and also judge the quality of the interview.
Part 2	Drivers for Fog computing	Identify challenges and requirements that drive applying Fog computing.
Part 3	Fog computing definition, features, and capacities	Understand interviewee’s opinion about Fog computing, and its features and capacities.
Part 4	Implementation of Fog computing	Understand interviewee’s opinion about how to implement Fog computing and challenges for the implementation.
Part 5	Implement Fog computing for Connected Vehicles	Identify the potential role of Fog computing in CV scenario and the limitation of Fog computing in this area.

Table 7: Interview Design for Fog Computing

The target for the interview of CV is to identify requirements for providing CV services. The question list has been divided into 4 parts (see Table 8).

Stage	Theme	Target
Part 1	Interviewee’s background	Identify the background of the interviewee and also judge the quality of the interview.
Part 2	The state of art of CV	Identify the current status and challenges for the development of CV.
Part 3	About CV: characteristics, architecture, enabling technologies and requirements	Identify the requirements for successfully implement CV.
Part 4	The implementation of Fog	Understand interviewee’s opinion about

	concept on CV	implement Fog concept on CV.

Table 8: Interview Design for CV

According to the theme of each part, there are several sub-questions. While the sub-questions for each interview are various. The sample question list for the interviews can be found in Appendix C.

After the interview, the audio file will be transcribed into text format. The transcription will be analyzed via a coding method. For example, The sentence "When it comes to "waking up" the car the challenge is that secure communication and booting of ECUs can result in a considerable amount of time. How to tackle that?" could be code as *#challenge_ECU_secure_and_booting*. The coding of the text are conducted in several stages:

1. Coding and labeling the text format.
2. Refining labels.
3. Developing concepts from the labels.
4. Finding relationships between concepts
5. Visualizing concept integration.

After coding, the codes will be divided into different categories to enable further analysis. By analyzing the result of the interview, the capacities of Fog computing and requirements of implementing CV will be consolidated. In addition, the limitation of implementing Fog concept on CV can also be reached.

5.2 Interview Analysis

Invitations of the interview were sent via personal email and social networks like LinkedIn and Facebook. In the end, 2 experts working in the field of Fog computing and 5 experts from CV field were approached for this research. The general information of the interviewees are listed in Appendix B. Due to the confidentiality issues, the name of companies and interviewees are not shown on the list.

5.2.1 Fog Computing Perspective

The interview for Fog computing is conducted as a group interview with two experts from a networking company. One is the project manager of Fog computer production department and the other one is a project manager working in the automotive department. The tool used for the meeting is an internal online meeting system of the company. The labels of this interview are divided into 3 categories: field requirements, Fog capacities, and Fog limitations. The refined labels are shown in Table 9 below.

Field requirements	Fog Capacities	Fog limitations and challenges
#automatic_robot	#real-time_communication	#risk_security
#industry_4.0	#Fog_interface	#risk_complexity
#industrial_automation	#improve_performance_for_higher_constrained_system	#stability
#heterogeneous_system	#integrated_current_control_system	#updatability
#lack_of_data_insight	#less_seperation_automation_pryamid	#balance_of_cost_and_performance
	#facilitate_data_transmission	
	#low_latency	
	#Preprocess_data	
	#Heterogeneity	

Table 9: Labels of the Interview (Fog Computer Producer)

According to the labels, concepts are developed and their relationships to each other are shown in the figure below (see Figure 7).

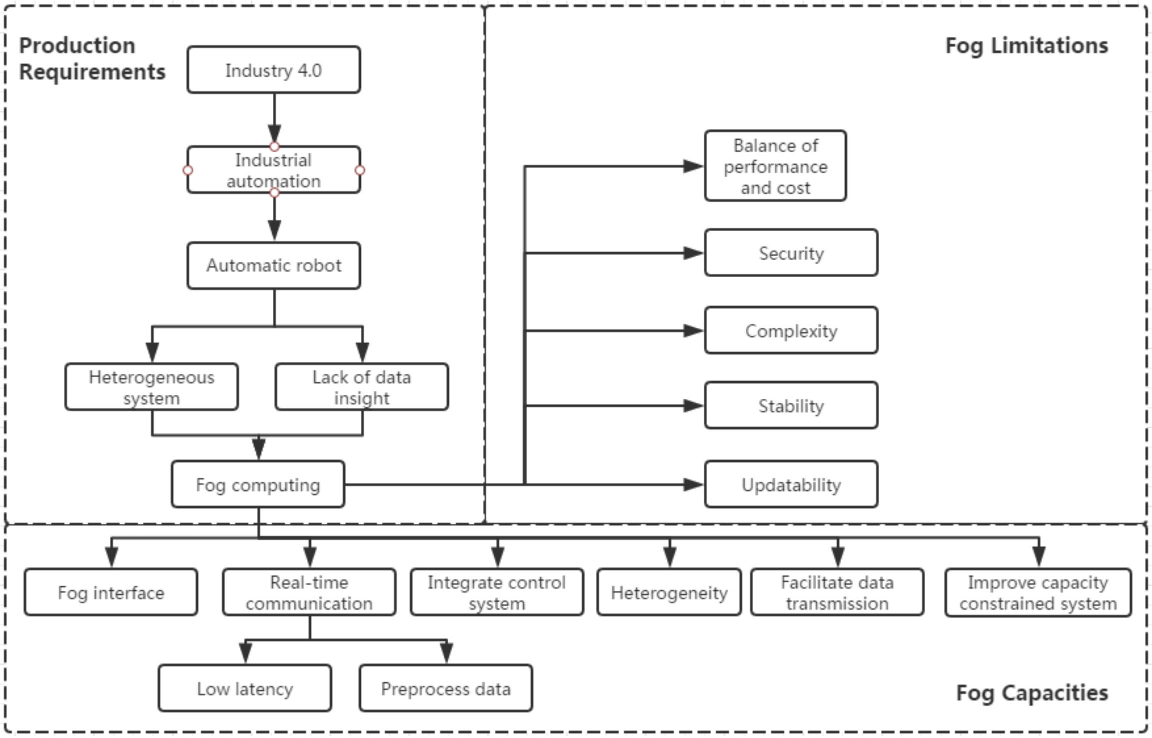

Figure 7: Relationship of the Concepts (Fog Computer Manufacturer)

This company aims to provide safety and reliability of networked computer systems to various manufacturing industries. With the advent of Industry 4.0, a lot of challenges are raising and one of them is industrial automation. The most important component of industrial automation is the automatic robots for production. Systems used to control the production is highly heterogeneous. Also, data collected by sensors in the production lines are all sent to central data center without any data insight. It requires a lot of time and energy to deal with that large amount of data. Thus, Fog computing has emerged as a solution to solve those problems. Fog computing is able to provide low latency and preprocess data for real-time communication. Preprocessing data is also able to provide valuable data for high-level analysis and facilitate data transmission. Next, Fog computing is designed to deal with heterogeneous systems and sources. It will also integrate the local control layer, which currently has multiple systems to manage the production. A single Fog computer interface will also reduce the complexity of managing production activities. Currently, each production management system has its own interface. Production controllers have to operate production activities via multiple interfaces. It increases the complexity to the management. For capacity constrained systems, Fog computing is able to bring Cloud computing capability close to them.

Although Fog computing has such a lot of capacities, it still has several limitations identified by the experts. First, Fog computing brings security risks since everything is being connected, while this limitation has to be overcome to provide Fog services. Although Fog computer reduces the complexity for the control layer, it increases the complexity of Fog computer, which also makes the updates for Fog system become complex. Also, since the current control systems for managing production are mature, Fog computer cannot guarantee the same stability as those systems. Moreover, the balance between performance and cost of Fog computer is another limitation for it.

5.2.2 Connected Vehicles Perspective

CV is a scenario that requires the collaboration of multiple companies. In this case, a total of five interviewees from four different companies working in the field of IoT and CV related areas are approached.

5.2.2.1 Automobile manufacturer

Two interviewees are reached in one famous automotive company. One is an email interview with the CTO of Data Lab. Another one is a phone call interview with project manager in the same department. The labels of two interviews are merged into one table since they are from the same department with similar fundamental knowledge. The refined labels of two interviews are shown in table 10.

Current status of CV	CV requirements	Implementation of Fog Concept on CV
#CV_representative_IoT	#connectivity	#process_data_near_vehicles
#stage_depends_on_different_brand	#real-time	#high_level_anlysis_back_end
#rapid_growth_state	#preprocess_data	#Fog_valuable_for_CV
#indicator_number_of_connected_vehicles	#low_latency	#balance_between_performance_and_cost
#90%_new_cars_connected	#energy_consumption	

#CV_services_increase_rapidly	#safety	
#enormous_sensors_within_single_car	#abusing_security-relevant_features	
#15GB_per_car_per_hour	#hacking_car	
#valueble_information_through_special_gat away_to_back_end	#illegal_invasion_steal_acces s_credentials	
#data_storage_combine_data_center_and_C loud	#digital_ecosystem	
#restricted_data_transmission_and _storage		
#CV_automated_vehicles_different		
#data_enabled_new_services		

Table 10: Labels of Automobile Manufacturer Interview

With the labels of the interviews, the model of the concept can be built (see figure 8).

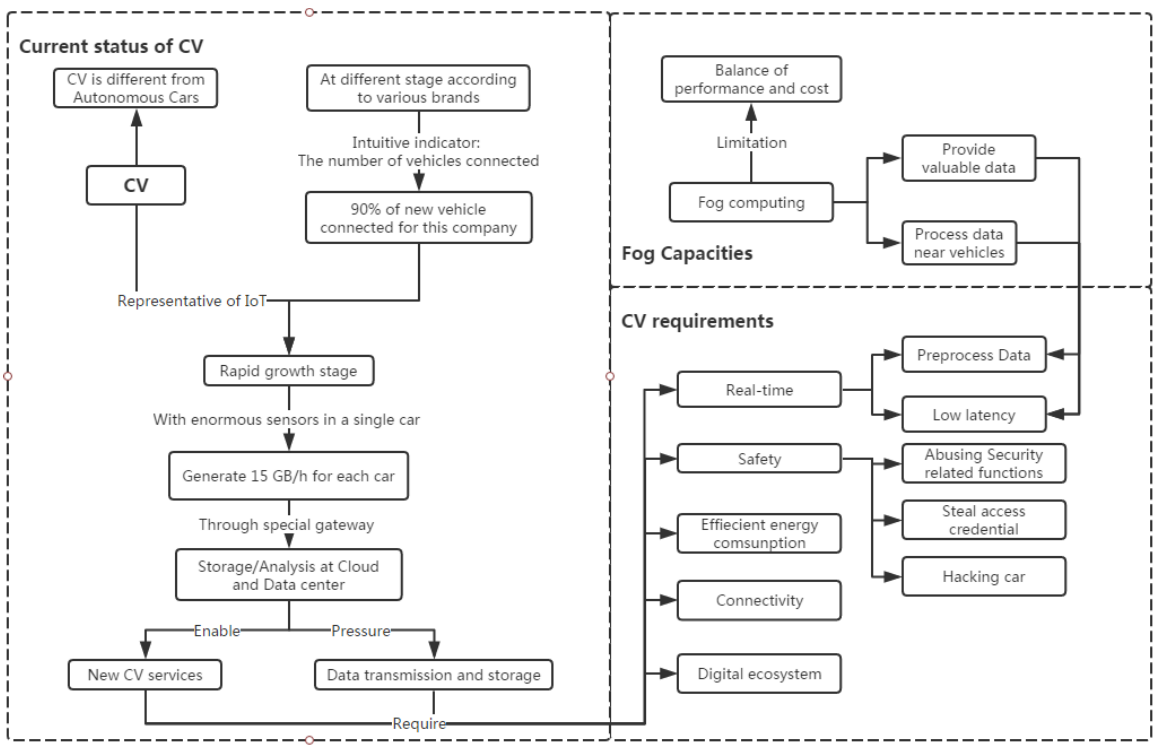

Figure 8: Relationship of the concepts (Automobile Manufacturer)

CV is regarded as one of the most representative applications of IoT. Its current development stage is various from different automotive manufacturers. An intuitive indicator to show its stage for a brand is the number of vehicles been connected. For this company, it has 90% of new vehicles connected, which means this firm is at a rapid growth stage of the development of CV. With enormous sensors installed in a single car, they generate 15 GB data every hour. Now, all of the data are transmitted via a special gateway in the car to the Cloud or Datacenter, where it is stored and analyzed. With this large amount of data, new CV services emerge. Nevertheless, it also brings huge pressures to data transmission, analysis, and storage. Thus, it has several requirements to bring a consolidated CV environment. It mainly has five aspects: real-time, safety, efficient energy consumption, connectivity, and digital ecosystem. As a car producer, this company pays a lot of attention to safety and real-time performance. Abusing security related functions, steal access credential, and hacking car system is the most serious issues needed to be solved. Real-time interaction, which has a significant impact on safety, heavily influences the performance of CV services. If data can be processed near the vehicle, it is able to bring low latency to services and reduce the pressure of data center. Nevertheless, the balance between performance and cost of the Fog server is deemed to be a critical limitation.

5.2.2.2 Network Equipment Provider

This interview is implemented with a specialist working in a well-known network equipment company. This specialist currently works as a solution architect of Intelligent Transport System. The company is currently driving LTE V2X to provide a globally available connection for vehicle connectivity. As the interviewee does not have any experience for Fog computing, the labels for this interview are divided into two categories (see Table 11).

Current status of CV	CV requirements
#CV_automated_vehicles_different	#stakeholders_cooperative
#CV_started_in_the_infotainment	#Functions_interoperability
#fast_growth_stage	#Heterogeneity

#current_stage_is_cooperate_systems	#adjust_existing_vehicles
#new_communication_techonologies_standardized	#standardization_and_liability_for_multiple_vendors
#Cloud_centric_architecture	#connectivity
#data_intensive_trigger_services	#cache_information_if_don't_have_connectivity
#CV_change_business_model_and_value_chain	#real-time
#share_and_store_data	#low_latency
#Involve_multiple_stakeholders	#distributed_data_process_Cloud_and_Local
	#safety
	#data_security
	#privacy
	#trust_management
	#trusted_network
	#back-end_modularity
	#software_test_and_updates
	#legislation

Table 11: Labels for Network Equipment Provider

According to the labels, the concepts has been identified and their relationships are shown in Figure 9 below.

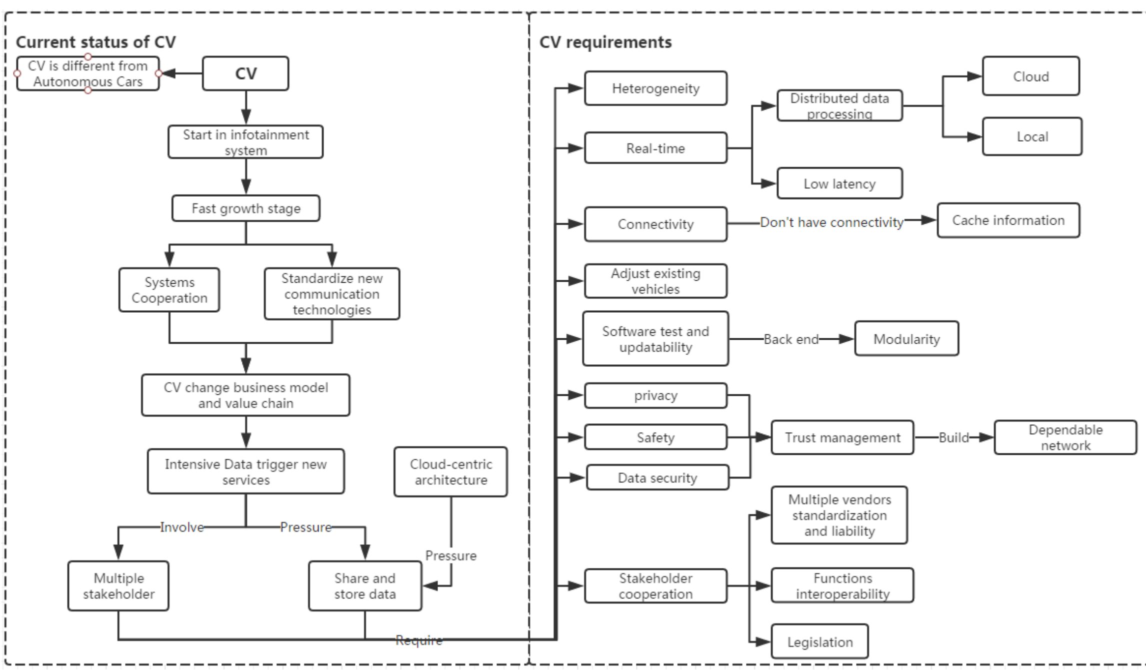

Figure 9: Relationship of the Concepts (Network Equipment Provider)

The initial development of CV started in infotainment system and now it enters into a fast growth stage. Different CV systems are trying to cooperate with each other and new communication technologies are standardizing. As CV is growing, it is able to change the business model and value chain for many industries. The intensive data generated by vehicles will trigger new services. These services will involve multiple stakeholders and put pressure on sharing and storing data. Moreover, the automotive manufacturer cooperating with this firm is still using cloud-centric architecture. This will also bring pressure to data management. In this case, some requirements are raised. First, CV needs the cooperation between stakeholders. A level of standardization for multiple vendors is required. The liability of these vendors should also be clearly identified. Also, the interoperability for various functions will improve the performance of CV and reduce the burden on the network. In addition, the government needs to participant into the CV development, setting rules or even legislating. Requirements for privacy, safety, and data security will heavily influence customers' trust for CV. Conducting a serious trust management to build a dependable network is vital. The software working for CV has to be rigorous tested and able to update. The modular development method at the back end will facilitate software update as well as maintenance. Connectivity is one of the most basic requirements for CV, but mechanisms to deal with the situation when there haven't got any connection to the internet should be developed. Caching critical information in the onboard systems will be one of the solutions. The real-time requirement is key for many CV services. Low latency is the most important attribute for it. Distributed data processing is also proposed by the interviewee to improve real-time performance. As CV contains vehicles, hardware, and software provided by multiple vendors, the systems working for CV should be heterogeneous. In addition, how to adjust existing vehicles that currently can't connect to CV landscape will need a solution.

5.2.2.3 IT Service and Consulting Provider

This interview is conducted with an IT Architect who currently works on IoT solutions in a big IT service and consulting company. Although he is not working in the field of CV, he works in a similar application area, connected shipping, with personal interest for CV. This interview is done via Skype meeting. The labels of this interview categorize same as the first one (see Table 12).

Current status of CV	CV requirements	Fog capacities
#initial_stage	#safety	#edge_scalability
#some_mature_some_have_long_way_to_go	#data_security	#useful_for_sharing_data
#standards_improve	#privacy	#compute_data_locally
#protocol_not_integrated	#trust_management	#compute_locally_enable_fast_and_frequent_communication
#lifecycle_of_vehicles	#data_security_strongly_relate_to_safety	
	#secure_communication_between_vehicles	
	#new_technique_for_validating_data_source_is_required	
	#real-time	
	#low_latency	
	#storage_capacity_both_Cloud_and_local	
	#Scalability	
	#heterogeneous	
	#high_level_layer_requires_key_data	
	#government_participant_regulation_test	
	#well_defined_interface_between_software_and_functions	
	#isolated_functions	

Table 12: Labels of IT Service and Consulting Provider interview

The relationships of the concepts derived from labels are shown below (see Figure 10).

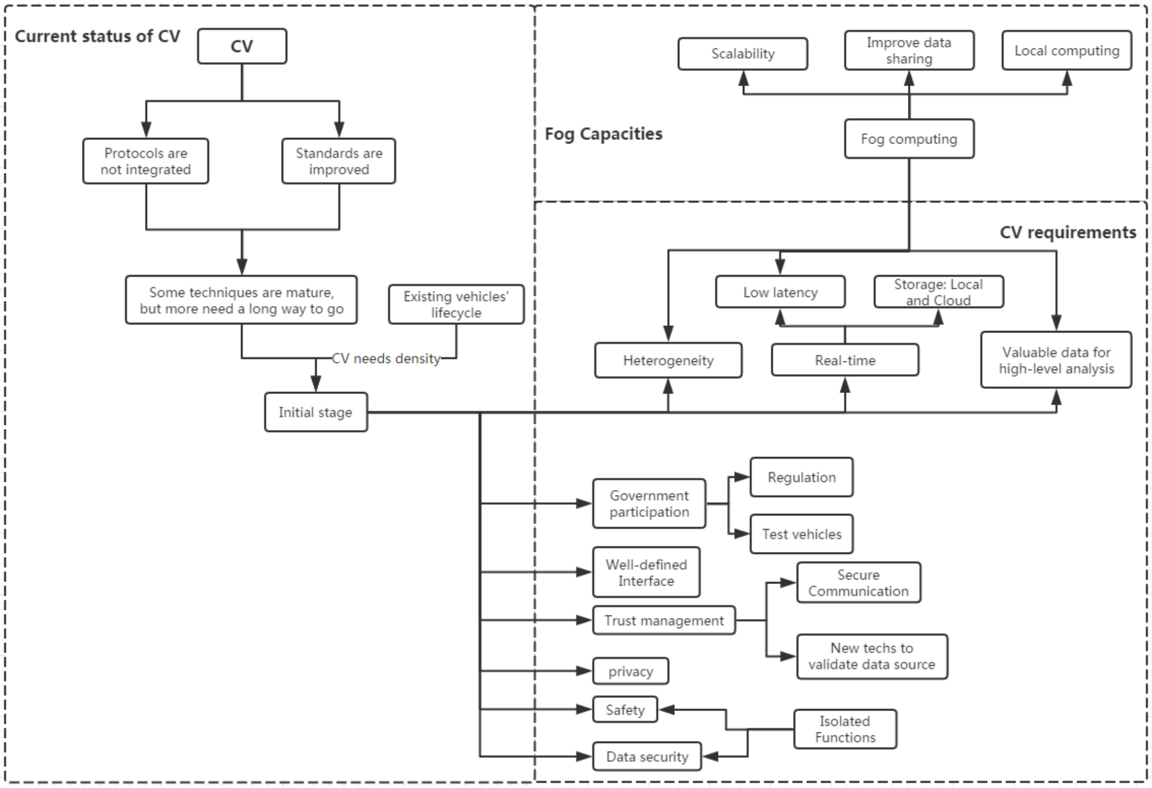

Figure 10: Relationship of the Concepts (IT Service and Consulting Provider)

Currently, CV has made some progress. A lot of standards for CV have been improved, like standards in navigation. Companies also release protocols for CV implementation, while these protocols are not integrated with each other. Moreover, CV needs density, but a lot of cars on the road don’t have connectivity. Their lifecycle will also be a problem for CV environment. Thus, the current development of CV is still at the initial stage and a lot of requirements need to be achieved. Safety, privacy, and data security are considered to be the most important requirement for CV. Data security is strongly related to safety. The interviewee proposes a degree of isolating functions to offer a more secure onboard network. So, if one function has been invaded, the isolated feature will minimize the impact on other functions. Privacy will significantly affect customers’ trust for CV. Therefore, trust management is required. It has to ensure secure communication in CV network. New technologies used to validate data source are also necessary. Moreover, the government also needs to participant into setting regulation and testing vehicles for

CV. For technical part, a well-defined interface between software and functions is needed.

The feedback loop for CV services is important. The requirements of Real-time, heterogeneity, and providing valuable data for high-level analysis are again mentioned by this interviewee. These requirements can be fulfilled by the capacities of Fog computing. Computing locally enables fast and frequent communication. In addition, the interviewee also indicates that computing at the edge will help CV to achieve scalability. Since Fog computing can improve data sharing, Fog computing is able to act as a middle layer for P2P and Vehicle-to-Cloud communication.

5.2.2.4 CV Service Provider

This interview is done with a CEO of a CV service company via WeChat call. He's company has provided CV services for automotive manufacturers for 3 years, which enable him to acquire a lot of experience on CV. The labels of the interview can be found in Table 13 below.

Current status of CV	CV requirements	Fog capacities
#using_autonomous_car_level	#connectivity_for_internet	#fast_response_service_require_local_computing
#locally_clean_data	#Algorithm	#handle_request_from_low_layer_and_transfer_valuable_data_to_up_layer
#TBox_preprocess_data	#Vehicle_manufacturers_and_customer_acceptance	#limitation_Fog_server_deployment
#interval_upload_from_millisecond_to_seconds	#safety	
#using_3G_to_upload_data	#privacy	
#data_analysis_at_back_end_to_provide_service	#data_security	
#use_phone_to_control_onboard_system	#government_participant	
	#standardized_protocol	
	#connected_vehicle_de	

	nsity	
	#existing_vehicles_don't_have_CV_ability	
	#handshake_time_and_vehicle_speed	
	#require_high_density_roadside_infrastructure	
	#signal_coverage	
	#require_precise_location_awareness	
	#protocol_updatability	
	#CV_require_collaborate_of_stakeholders	

Table 13: Labels of CV Service Provider interview

Based on the labels for the interview, concepts are created and their relationships are shown in the Figure below (Figure 11).

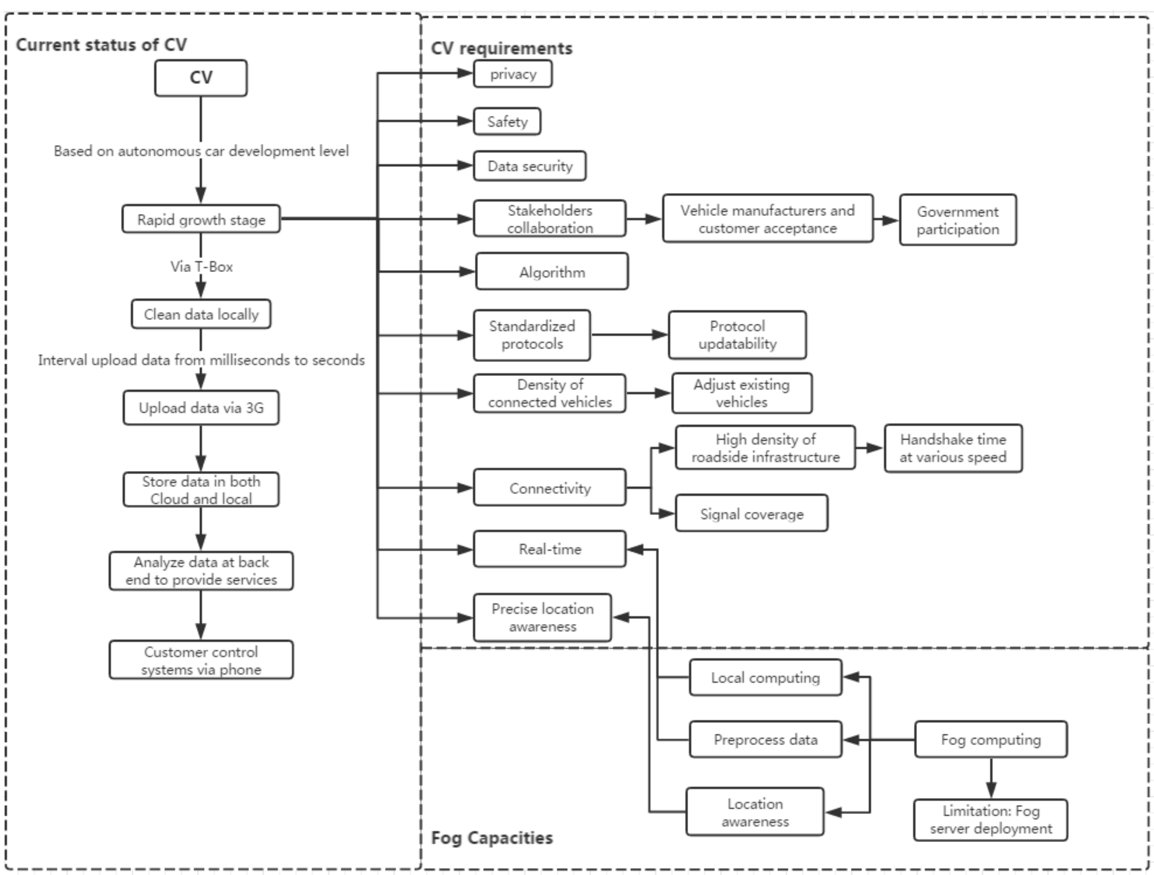

Figure 11: Relationship of the Concepts (CV Service Provider)

The interviewee defines the stage of CV development based on autonomous cars level. In his opinion, CV is at a rapid growth stage. Right now, he mainly uses T-box to clean data generated by the onboard system. The data will be uploaded to Cloud with intervals from milliseconds to seconds via 3G. The intervals will depend on the driving status of the vehicles. The data will be stored both in Cloud and local onboard systems. The uploading data will be analyzed at the back end system in Cloud to provide services. Customers use their smartphone to control the onboard system. The current service loop works like that, but it still has many drawbacks. Also, with the rapid development of the CV, more requirements and opportunities come out. The interviewee also points out that privacy, safety, and data security are extremely important for CV services. Also, stakeholder cooperation is required to ensure the integrity of the services. For this firm, vehicle manufacturer and users acceptance of its services is vital. Moreover, the government is mentioned again as a powerful organization to set regulations. One technical requirement is the algorithms aspect, such as driver assistance algorithm and driving judgment algorithm. They are the main enablers for onboard CV functions. The protocols for connectivity also need to be standardized. These protocols should be able to update since the uncertainty of future. The basic CV services required a degree of density on the road. So, how to adjust existing vehicles to new CV network is an issue. Multiple levels of connectivity are another basic requirement for CV. For WiFi-based connection, the high density of road-side infrastructure is indispensable. The handshake time at various speed would be another problem. For mobile telecommunication technologies, signal coverage is their main issue. Here again, real-time communication is considered as an indispensable requirement for CV. While another requirement identified by the interviewee is precise location awareness.

5.2.3 Result of the Interview

Based on the consequences of each interview, the requirements to acquire a health CV environment can be refined (Table 14).

Requirements from Literature Review and MLR	Additional Requirements from Interviews
• Multiple types of connectivity requirements • Real-time support • Data preprocess • Mobility support • Flexibility support • Geo-distribution support • Interoperability • Heterogeneity • Dynamic • Scalability & Updatability • Identifiability • Intelligence • Sensing • Expressing • Energy • Self-management • Service provisioning • Distributed • Safety & Security • Location awareness • Privacy	• Algorithm improvement • Stakeholder cooperation includes government participation • Trust management • Standardized network protocols • Density of connected vehicles on road • Testable and updatable software • Healthy ecosystem • Well defined interface

Table 14: Refined CV Requirements

For Fog computing capacities, control layers can be integrated to provide a single interface to manage software and improve performance for capacity constrained systems. While only part of the matches shown in section 4.3 have been validated by experts (see Table 15). The rest capacities haven't been considered as strong advantages by them. This shows that CV service providers pay more attention to those five capacities of Fog computing.

Fog Computing Capacities	CV Requirements
• Low latency • Reduce network traffic	• Real-time
• Preprocess data	• Data preprocessing
• Heterogeneous architecture	• Heterogeneity
• Location awareness support	• Location awareness
• Scalability support	• Scalability

Table 15: Validated Matches

5.3 Summary

In this chapter, the matches of Fog capacities and CV requirements have been refined via several interviews. Since CV is a complex scenario, the successful implementation of CV will require multiple industries as well as government's collaboration. However, Fog computing is proven to be a useful component of CV scenario. Data preprocessing at the edge of network improves real-time communication and provides valuable data for high-level analysis. Also, Fog computing can provide a heterogeneous system, location awareness support and scalability support for CV. Nevertheless, through previous reviews and interviews, the implementation of Fog concept on CV also has several limitations that need to be considered. Those limitations will be elaborated in Chapter 6.

Chapter 6 Implementation of Fog concept on Connected Vehicles

In previous three chapters, the benefits of applying Fog computing for CV services have been discussed. Literature and online resources point out that Fog computing can be applied in CV scenario. In fact, none of them presented the exact and specific requirements that can be fulfilled by Fog computing. Thus, in section 4.1.2 and 4.2, the Fog capacities and CV requirements have been identified based on literature review and MLR. There are also several additional requirements coming out during the interviews. CV is an extremely complex application involving the cooperation of multiple stakeholders. As it has so many requirements need to meet, Fog computing is not a master key. Matches between capacities and requirements with both academic and practical perspectives show Fog computing indeed can help achieve some key requirements. The matches have been validated and improved via interviews with experts in Fog computing and CV field. It clearly indicates what Fog computing can do for CV. In order to implement Fog concept on CV, the role of Fog computing in CV scenario has to be clearly defined first. Then, CV architecture embedded with Fog computing need to be created. Although Fog computing is of potential to be applied for CV, its limitations for CV require serious consideration. These three part for integrating Fog computing into CV scenario will be discussed in the following content.

6.1 The role of Fog Computing in Connected Vehicles Scenario

Fog computing aims to bring Cloud-like capacities in proximity to end devices. It plays as an intermediary for the communication between Cloud and end devices, while the exact role of Fog computing in CV scenario and what it can do for CV is unclear before this research. With the refined matches between Fog capacities and CV requirements in section 5.3, its roles can be identified.

- Computing capacity provider.

Although vehicles can communicate directly with each other via near field communication techniques, limited resources in a single vehicle constrain the ability to handle more complex and comprehensive requests. In order to deal with those requests, computing assistant from outside is required. Since many CV services are time-sensitive and strongly impact the safety of users, local computing is the only choice. Thus, with the computing capacity of Fog server, Fog computing is able to fulfill this requirement. With this capacity, Fog computing can provide low latency and network traffic computing, and support real-time communication for CV.

- Data refiner.

Data collected by a single vehicle is already a lot. With the increasing number of sensors onboard as well as connected vehicles, it can be predicted that in the near future, there will be more data generated. Transporting all of the data to Cloud or data center is not wise and feasible. Technical limitations like bandwidth are one hand. The cost to achieve the technical requirements is also expensive. Fog server is capable of refining data locally. It can decide what data should be transmitted directly to Cloud and what data shall be concluded first and then uploaded. It can ensure that only critical data will be sent to Cloud.

- Function supporter

Vehicles are highly mobile devices and many CV services require precise location awareness. Also, as the number of vehicles is increasing, the system working for CV has to be scalable. Fog server is able to communicate directly with vehicles. With virtual technologies, the migration from one server scope to another is enabled. As servers work close to vehicles, Fog can provide precise location awareness with less signal level. Moreover, Fog servers are widely geo-distributed and they can cooperate with each other to help CV achieve scalability.

To sum up, for the lower layer, Fog computing is a computing capacity provider, while for the upper layer, it is a data refiner. For the whole CV paradigm, it acts as a function supporter.

6.2 Fog-based CV Architecture

The role of Fog computing in CV scenario has been identified, while the architecture that embeds Fog computing into CV platform is missing. The next step is to develop the architecture for Fog computing in this area. Based on IoT architecture (section 3.1.2), general Fog paradigm (section 3.3.3), and the Fog-based Industrial Automation pyramid proposed by Nebbiolo[5], the Fog-based CV pyramid is shown below (see Figure 12). This architecture is a novel solution for implementing Fog computing on CV.

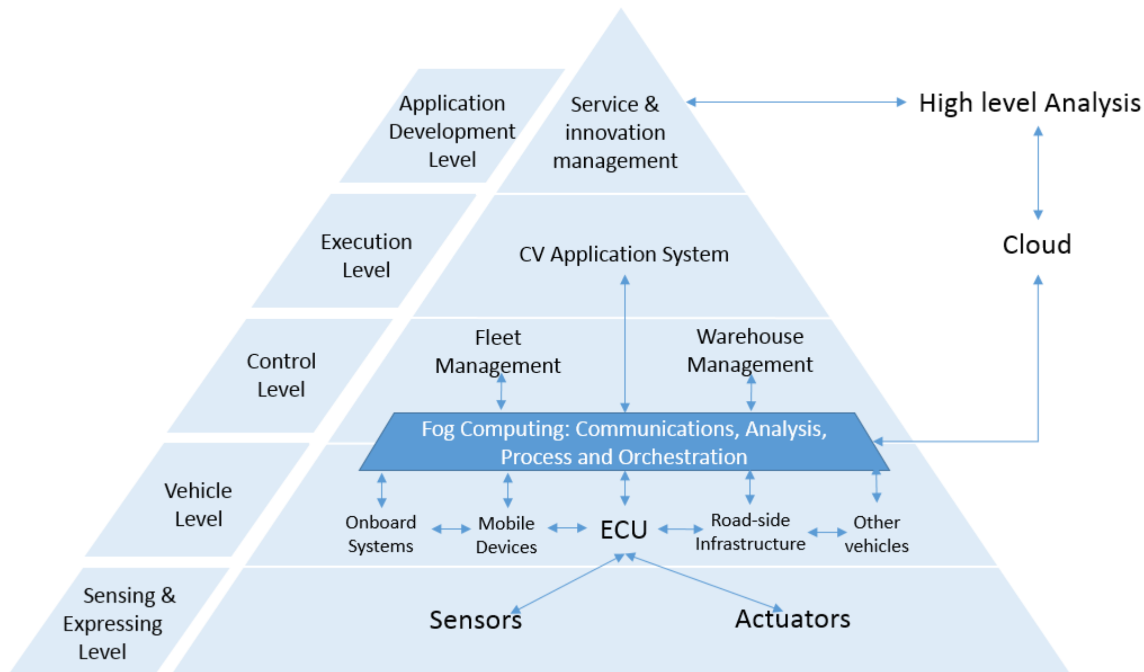

Figure 12: Fog-based CV pyramid

It can be seen from the figure that the pyramid has 5 layers with one intermediary. Each layer has its own components and missions. Different devices, hardware, and software will be deployed on each level.

- Sensing & Expressing Level

[5] Fog-based Industrial Automation pyramid http://www.nebbiolo.tech/

This level is the bottom but fundamental layer of the pyramid which consists of sensors and actuators for the vehicles. Its target is to sense the status of the vehicle and the surroundings and execute the commands from upper layers. They are wired or wireless linked to ECUs to enable the communication with higher levels.

- Vehicle Level

All the CV service-related hardware is included in this layer, such as onboard systems, mobile devices, ECUs, and road-side infrastructure. The V2V connection is also inclusive. They can communicate with each other directly via NFC technologies or use the intermediary Fog computing to connect with remote hardware and vehicles. The communication with upper layers is also done via Fog computing. While the enabling technologies for the connection between Vehicle layer and Fog are wireless technologies like LTE and WiFi.

- Intermediary Fog Computing

Fog computing is an intermediary for the communication between lower two layers and upper three layers. Its main duties are enabling the communication, analyzing data, processing lower layer requests, and orchestrating tasks. It has a direct connection to upper three layers. The communication with top level is done through the connection between Fog and Cloud. Fog computing will preprocess data collected by lower layer and provide valuable data to Application Development Level to enable high-level analysis. In addition, the requests that cannot be dealt with Execution Level will transport to Cloud.

- Control level

The target of this level is to monitor vehicles' status and manage the data storage of Fog server. It mainly consists of two systems, Fleet Management and Warehouse Management. The Fleet Management system has functions such as vehicle tracking, mechanical diagnostics, and driver behavior reporting. It will monitor the status of vehicles and provide diagnostic reports of vehicles to higher levels. Since Fog servers have a certain volume of storage capacity, Warehouse Management function is also needed to manage data stored in Fog server.

- Execution Level

This layer manages CV related applications which have been installed on Fog servers and deals with requests from lower layers, like road obstacle detection system. For requests that can be handled in the Fog server, responses are given by CV Application systems.

- Application Development Level

This level is for high-level analysis, decision-making and innovation of CV services. Since the valuable data provided by Fog computing has been analyzed in the Cloud, CV service providers will be able to improve current services and develop new applications based on the high-level analysis. Moreover, the requests that cannot be solved by lower layer will be processed at this layer with the help of Cloud computing capacities.

6.3 Limitations for applying Fog concept on CV

Although Fog computing is able to benefit CV in several aspects, there are also limitations for applying Fog concept on CV.

- Balance between performance and cost

The performance of Fog server is the main limitation for CV. While the processing power of Fog computing relies heavily on Fog servers. Although it can be tackled by updating the hardware or increasing the density of the server, the cost to improve the performance of Fog computing will rise.

- Complexity

On one hand, Fog computing is no doubt powerful. One the other hand, it is a complex system, no matter within a Fog server or the whole Fog network. This complexity will limit the updatability of Fog computing. The updating process for CV applications is difficult.

- Fog server deployment.

As Fog computing requires geographical distribution, Fog servers will be physically set in multiple places. It is easy to do this in cities. While in places like mountain area, highway, and tunnel, the deployment of Fog server will be quite difficult. Thus, the deployment of Fog servers will significantly impact CV services.

The successful implementation of Fog computing on CV cannot bypass these limitations. How to balance the performance and cost of Fog servers? How to deal with the complexity of Fog computing? How to efficiently deploy Fog servers? The solutions and mechanisms to against these problems have to be carefully designed.

6.4 Additional Requirements for CV

During the literature review and MLR, multiple requirements for CV have been identified (section 4.2). These requirements have already attracted many attentions. Experts are working on potential solutions and technologies to fulfill them. Besides, specialists also point out some additional requirements for CV during the interviews that need to be achieved.

- Algorithm improvement

Algorithms, such as driver assistance algorithm and driving judgment algorithm, are the core of CV services. They heavily influence CV in multiple aspects. First of all, they decide what kind of services can be offered to customers and give logics to CV applications. Then, they are used to process the data generated by vehicles and enable service providers to analyze that data to gain valuable information. Last but not least, they play a vital role in the security protection of CV. It can be seen that there will be more vehicles being connected. New services will be required by customers and existing services need to be improved. Also, the data produced by vehicles will dramatically increase. Moreover, the security situation of CV becomes more and more serious. However, existing algorithms may meet bottlenecks to solve these challenges. Thus, algorithms have to be continuously improved to meet new requirements.

- Stakeholder cooperation includes government participation

CV is a platform that consists of multiple stakeholders, including end users, automotive manufacturers, devices producers, application developers, service providers, infrastructure constructors, networking operators, and governments. It is not a service that is provided by a single automotive company or service provider. All the stakeholders should cooperate with each other to build a safe, effective, and complete CV environment. Since CV is highly related to public safety, it is necessary for governments to take part in the development of CV. The laws and regulations to standardize the CV industry are required. For example, new vehicles have to be able to connect to the network. Automotive manufacturers have to share necessary data. Service providers are required to protect user privacy. Governments can also help to identify the liability of each stakeholder.

- Trust management

CV services rely heavily on the trust of drivers. For example, driving assistant system provides suggestions for drivers. If drivers do not trust the source of the information, this service is actually failed. Also, if the CV applications always crash, users will lose confidence. Moreover, if the data about the drivers is leaked, they will not trust this service. Many factors will influence the trust of users on CV. Thus, the main duties of trust management of CV are ensuring the quality and security of data, protecting user privacy, and guaranteeing the quality of vehicles and applications.

- Standardized network protocols

CV applications can only interact with each other when they follow the same protocols. In CV scenario, vehicles have to be able to communicate with each other, while the applications of CV, as well as the vehicles, are provided by different vendors. In order to enable the communication, the protocols for network need to be standardized.

- Density of connected vehicles on road

Many CV services required a certain density of connected vehicles, such as driving assistant system and vehicle learning system. Thus, more vehicles that can be connected are needed. In this case, automakers or services providers can offer some preferential policies to encourage drivers to change old vehicle to a connectable vehicle.

- Testable and updatable software

The software developed for CV will work for a large number of vehicles in various scenarios. It has to be tested in such a complex situation before providing to users. Also, software needs to be updated to fix bugs, improve performance, and add new functions. However, vehicles will not always connect to the Internet and the way they access the network is also different. Thus, an effective mechanism to update software is required.

- Healthy ecosystem

CV industry has to be scalable and sustainable. Its services, technologies, and secure functions need continuous improvement. As said in previous content, CV industry has a lot of stakeholders. It requires collaboration among diverse entities. Nevertheless, there are competitions between companies. Thus, the competitions have to be controlled in a positive direction. In order to gain a healthy ecosystem, it requires stakeholders to obey the rules voluntarily as well as the supervision of power sectors like governments.

- Well defined interface

The interface is the first step for users to access CV services and for service providers to manage the CV applications. For users, it impacts user experience and even the trust of customers. For service providers, it influences work efficiency of employees. Thus, interfaces for both users and service providers should be well designed.

6.5 Summary

The main novelties of this research are included in this chapter. First, the roles of Fog computing can play in CV scenario have been identified. Fog computing can act three roles for CV: computing capacity provider, Data refiner, and Function supporter. It is able to be an intermediary for data transmission, decision making, and execution of CV services in CV architecture. Second, the Fog-based CV architecture presents how to embed Fog computing into CV architecture. It also suggests several systems and devices that can be used for delivering CV services. Last, several limitations to be tackled to achieve successful implementation are illustrated. Although it is conceptually suitable for CV scenario, its practical application still has a long way to go. In addition, multiple additional requirements for CV have been introduced.

Chapter 7 Conclusion

Nowadays, the development of IoT enters a fast growth stage. More and more techniques have been developed to improve the performance of IoT applications. In this case, a novel paradigm, Fog computing, emerges. As it is designed for assisting IoT applications, Fog computing receives a lot of attention from the application domain. Since CV is one of the most representative applications of IoT, Fog computing has the potential to support CV services. Thus, the exploratory research of implementing Fog concept on CV scenario is valuable for both academia and industry.

This research uses three research methods to answer the research questions. In the literature review stage, the current status of IoT and CV has been introduced. Then, the refined definition, challenges and general paradigm of Fog computing have been illustrated. As there are two concepts similar to Fog computing, the comparison between Fog computing and those two concepts distinguishes it from them and lays out the features of Fog computing. Next, based on the literature review, MLR has been conducted. With the help of those two review methods, the capacities of Fog computing and the requirements to successfully implement CV are summarized. Then, the requirements are matched with capacities. Last, several interviews are used to validate and complement Fog capacities, CV requirements and the matches between them.

In this research, the definition and features of Fog computing have been refined. Also, the capacities of Fog computing and requirements of CV have been identified. The matches between Fog capacities and CV requirements show that Fog computing is capable of helping the implementation of CV in several aspects, but cannot fulfill all of the requirements. This conclusion has been validated and complemented by 5 interviews with 7 specialists. Based on the refined conclusion, the role of Fog computing in CV scenario has been defined. According to its role and capacities, a Fog-based CV architecture has been generated as a possible solution for conducting

Fog computing for CV. Also, multiple additional requirements that have been identified during the interviews are illustrated.

However, as discussed in 6.3, Fog computing is not mature yet. Apart from the challenges remained for Fog computing, there are three additional limitations needed to be considered when implements Fog concept on CV.

7.1 Limitation

This research leaves space for validity concerns. Due to limited time allowed and limited resources available, only one interview in the Fog field and four interviews in the CV field have been done. The data collected for Fog computing and CV is obviously not comprehensive and objective enough. In order to get a better understanding of Fog computing capacities and limitations, more interviews with different companies should be conducted. Also, since CV is an area that requires the collaboration of multiple industries and governments, experts from more industries as well as government officers need to be approached. Moreover, the development of CV is various from companies. Therefore, conducting multiple interviews with different companies in each industry is suggested.

In addition, the Fog-based CV pyramid proposed in section 6.2 is not validated. If combined with interviews or practical experiments for this pyramid, this research would be more convincing.

7.2 Future Work

The future research can start with a more rigorous validation of the Fog capacities and CV requirements. Also, researchers can use the proposed Fog-based pyramid as a start point to test its feasibility and improve it. Currently, little research has been done in this specific field. A lot of topics remained from multiple aspects can be studied.

This research is only an initiation of implementing Fog concept on CV. In the future, practical experiments have to be done to get operation data. An environment with all the stakeholders shall be established to test its feasibility and get it ready for commercial application.

References

[1] Ben Walker (2015). "Evwery Day Big Data Statistic – 2.5 Quintillion Bytes of Data Created Daily". [Online] available: http://www.vcloudnews.com/every-day-big-data-statistics-2-5-quintillion-bytes-of-data-created-daily/

[2] Stojmenovic I, Wen S. The Fog computing paradigm: Scenarios and security issues[C]//Computer Science and Information Systems (FedCSIS), 2014 Federated Conference on. IEEE, 2014: 1-8.

[3] Roman R, Lopez J, Mambo M. Mobile Edge Computing, Fog et al.: A Survey and Analysis of Security Threats and Challenges [J]. arXiv preprint arXiv:1602.00484, 2016.

[4] Ogawa R T, Malen B. Towards rigor in reviews of multivocal literature: Applying the exploratory case study method [J]. Review of Educational Research, 1991, 61(3): 265-286.

[5] Saunders M N K. Research methods for business students, 5/e [M]. Pearson Education India, 2011.

[6] Saldaña J. The coding manual for qualitative researchers [M]. Sage, 2015.

[7] ITU-T Rec Y.4000/Y.2060 "Overview of the Internet of Things" – approved in June 2012.

[8] Carlos Elena-Lenz (2014). "Internet of Things: Six Key Characteristics". [Online] available: https://designmind.frogdesign.com/2014/08/internet-things-six-key-characteristics/

[9] Aishwarya Sakaray, V. Bhargav: Internet of Things: A Review [J]. International Journal of Advanced Research in Computer Science and Software Engineering, March 2016, 6 (3): pp. 16-18.

[10] Al-Fuqaha A, Guizani M, Mohammadi M, et al. Internet of things: A survey on enabling technologies, protocols, and applications [J]. IEEE Communications Surveys & Tutorials, 2015, 17(4): 2347-2376.

[11] Khan R, Khan S U, Zaheer R, et al. Future internet: the internet of things architecture, possible applications and key challenges[C]//Frontiers of Information Technology (FIT), 2012 10th International Conference on. IEEE, 2012: 257-260.

[12] Yang Z, Yue Y, Yang Y, et al. Study and application on the architecture and key technologies for IOT[C]//Multimedia Technology (ICMT), 2011 International Conference on. IEEE, 2011: 747-751.

[13] Atzori L, Iera A, Morabito G. The internet of things: A survey [J]. Computer networks, 2010, 54(15): 2787-2805.

[14] Bandyopadhyay D, Sen J. Internet of things: Applications and challenges in technology and standardization [J]. Wireless Personal Communications, 2011, 58(1): 49-69.

[15] Miorandi D, Sicari S, De Pellegrini F, et al. Internet of things: Vision, applications and research challenges [J]. Ad Hoc Networks, 2012, 10(7): 1497-1516.

[16] 50 Sensor Applications for a Smarter World. n.d. Retrieved May 2015, from http://www.libelium.com/top_50_iot_sensor_applications_ranking/

[17] Karen Rose, Scott Eldridge, Lyman Chapin. Internet Society (Oct. 15, 2015). "The Internet of Things: An Overview". Online available: http://www.internetsociety.org/doc/iot-overview

[18] Steven Norton (Jun 2, 2015). "Internet of Things Market to Reach $1.7 Trillion by 2020: IDC". [Online] Available: http://blogs.wsj.com/cio/2015/06/02/internet-of-things-market-to-reach-1-7-trillion-by-2020-idc/

[19] Ramadan M N, Al-Khedher M A, Al-Kheder S A. Intelligent anti-theft and tracking system for automobiles[J]. International Journal of Machine Learning and Computing, 2012, 2(1): 83.

[20] Lu N, Cheng N, Zhang N, et al. Connected vehicles: Solutions and challenges [J]. IEEE internet of things journal, 2014, 1(4): 289-299.

[21] Tuohy S, Glavin M, Jones E, et al. Next generation wired intra-vehicle networks, a review[C]//Intelligent Vehicles Symposium (IV), 2013 IEEE. IEEE, 2013: 777-782.

[22] D'Orazio L, Visintainer F, Darin M. Sensor networks on the car: State of the art and future challenges[C]//2011 Design, Automation & Test in Europe. IEEE, 2011: 1-6.

[23] Nita Congress (Summer 1994). "The Automated Highway System". [Online] Available:
http://www.fhwa.dot.gov/publications/publicroads/94summer/p94su1.cfm

[24] ur Rehman S, Khan M A, Zia T A, et al. Vehicular Ad-Hoc Networks (VANETs)-An Overview and Challenges[J]. Journal of Wireless Networking and Communications, 2013, 3(3): 29-38.

[25] Singh S. Vehicular Ad Hoc Network (VANET): A Survey [J].International Journal of Advanced Research in Computer Engineering & Technology, June 2016.

[26] DSRC: The Future of Safer Driving. n.d. Retrieved from
http://www.its.dot.gov/factsheets/dsrc_factsheet.htm

[27] Garhwal A, Bhattacharya P P. A survey on dynamic spectrum access techniques for cognitive radio [J]. arXiv preprint arXiv:1201.1964, 2012.

[28] Ott J, Kutscher D. The" Drive-thru" architecture: WLAN-based internet access on the road[C]//Vehicular Technology Conference, 2004. VTC 2004-Spring. 2004

IEEE 59th. IEEE, 2004, 5: 2615-2622. Gozálvez J, Sepulcre M, Bauza R. IEEE 802.11 p vehicle to infrastructure communications in urban environments [J]. IEEE Communications Magazine, 2012, 50(5): 176-183.

[29] Ott J, Kutscher D. The" Drive-thru" architecture: WLAN-based internet access on the road[C]//Vehicular Technology Conference, 2004. VTC 2004-Spring. 2004 IEEE 59th. IEEE, 2004, 5: 2615-2622.

[30] Deshpande P, Hou X, Das S R. Performance comparison of 3G and metro-scale WiFi for vehicular network access[C]//Proceedings of the 10th ACM SIGCOMM conference on Internet measurement. ACM, 2010: 301-307.

[31] Satyanarayanan M. A brief history of cloud offload: A personal journey from odyssey through cyber foraging to cloudlets [J]. GetMobile: Mobile Computing and Communications, 2015, 18(4): 19-23.

[32] Bonomi F. Connected vehicles, the internet of things, and fog computing[C]//The Eighth ACM International Workshop on Vehicular Inter-Networking (VANET), Las Vegas, USA. 2011: 13-15.

[33] Bonomi F, Milito R, Zhu J, et al. Fog computing and its role in the internet of things[C]//Proceedings of the first edition of the MCC workshop on Mobile cloud computing. ACM, 2012: 13-16.

[34] Roman R, Lopez J, Mambo M. Mobile Edge Computing, Fog et al.: A Survey and Analysis of Security Threats and Challenges [J]. arXiv preprint arXiv:1602.00484, 2016.

[35] IBM and Nokia Siemens Networks Announce World's First Mobile Edge Computing Platform. n.d. Retrieved February 25, 2013, from < http://www-03.ibm.com/press/us/en/pressrelease/40490.wss>

[36] Patel M, Naughton B, Chan C, et al. Mobile-edge computing introductory technical white paper[J]. White Paper, Mobile-edge Computing (MEC) industry initiative, 2014.

[37] Ali M. Green cloud on the horizon[C]//IEEE International Conference on Cloud Computing. Springer Berlin Heidelberg, 2009: 451-459.

[38] Kovachev D, Cao Y, Klamma R. Mobile cloud computing: a comparison of application models [J]. arXiv preprint arXiv:1107.4940, 2011.

[39] Liu F, Shu P, Jin H, et al. Gearing resource-poor mobile devices with powerful clouds: architectures, challenges, and applications[J]. IEEE Wireless communications, 2013, 20(3): 14-22.

[40] Says G. 6.4 Billion Connected" Things" Will Be in Use in 2016, Up 30 Percent from 2015[J]. Gartner, Inc, 2015.

[41] Klas G I. Fog Computing and Mobile Edge Cloud Gain Momentum Open Fog Consortium, ETSI MEC and Cloudlets [J]. 2015.

[42] Stojmenovic I, Wen S. The fog computing paradigm: Scenarios and security issues[C]//Computer Science and Information Systems (FedCSIS), 2014 Federated Conference on. IEEE, 2014: 1-8.

[43] Dastjerdi A V, Gupta H, Calheiros R N, et al. Fog Computing: Principals, Architectures, and Applications [J]. arXiv preprint arXiv:1601.02752, 2016.

[44] Vaquero L M, Rodero-Merino L. Finding your way in the fog: Towards a comprehensive definition of fog computing [J]. ACM SIGCOMM Computer Communication Review, 2014, 44(5): 27-32.

[45] Yi S, Li C, Li Q. A survey of fog computing: concepts, applications and issues[C]//Proceedings of the 2015 Workshop on Mobile Big Data. ACM, 2015: 37-42.

[46] Ibrahim M. Octopus: An Edge-Fog Mutual Authentication Scheme [J]. International Journal of Network Security, 2016.

[47] Peng M, Yan S, Zhang K, et al. Fog computing based radio access networks: Issues and challenges [J]. arXiv preprint arXiv:1506.04233, 2015.

Appendix A. Full list of Articles of MLR

Num	Title	Author	URL
1	Fog computing (fog networking)	Margaret Rouse	http://internetofthingsagenda.techtarget.com/definition/fog-computing-fogging
2	Cisco Delivers Vision of Fog Computing to Accelerate Value from Billions of Connected Devices	Cisco	https://newsroom.cisco.com/press-release-content?articleId=1334100
3	Fog computing	Techopedia	https://www.techopedia.com/definition/30255/fog-computing
4	IoT: A Fog Cloud Computing Model	Ahmed Banafa	https://www.bbvaopenmind.com/en/iot-a-fog-cloud-computing-model/
5	Fog Computing: a New IoT Architecture?	Joe McKendrick	http://www.rtinsights.com/what-is-fog-computing-open-consortium/
6	Fog Computing, revs up the Internet of Things	CeBIT	http://www.cebit.de/en/news/latest-news/fog-computing-revs-up-the-internet-of-things.xhtml
7	The IoT needs Fog computing	Angelo Corsaro	http://embedded-computing.com/guest-blogs/the-iot-needs-fog-computing/
8	Fog Computing is Vital for a Successful Internet of Things	Ahmed Banafa	https://datafloq.com/read/fog-computing-vital-successful-internet-of-things/1166
9	Cisco Fog Computing Solutions: Unleash the Power of the Internet of Things	Cisco	https://www.cisco.com/c/dam/en_us/solutions/trends/iot/docs/computing-solutions.pdf
10	The Future of Cloud Computing: Fog Computing and the Internet of Things	Shannon Kempe	http://www.dataversity.net/the-future-of-cloud-computing-fog-computing-and-the-internet-of-things/
11	Fog-computing versus SDN/NFV and Cloud Computing in 5G	Eugen Borcoci	http://www.iaria.org/conferences2016/filesAICT16/DataSys2016_Tutorial_Fog-SDN-NFV_5Gv1.4_EBorcoci.pdf
12	Addressing the Full Attack Continuum: A Security Model for Before, During, and After an attack	Cisco	http://www.cisco.com/c/en/us/products/collateral/security/whitepaper_c11-733368.pdf
13	Fog Computing: From the center to Edge of the Cloud	Ahmed Banafa	https://www.linkedin.com/pulse/20140822065109-246665791-fog-computing-from-the-center-to-the-edge-of-the-cloud
14	For Efficient, Decentralized IoT Computing, the Future May Be in Fog	Jennifer Markert	https://curiousmatic.com/efficient-decentralized-iot-computing-future-may-fog/
15	Fog Computing for Internet of Things Needs Smarter Gateways	Rick Stevenson	http://www.datacenterknowledge.com/archives/2015/04/08/fog-computing-for-internet-of-things-needs-smarter-gateways/

16	IoT, from Cloud to Fog Computing	Maher Abdelshkour	http://blogs.cisco.com/perspectives/iot-from-cloud-to-fog-computing
17	Fog Computing: From the Center to the Edge of the Cloud	Ahmed Banafa	http://ahmedbanafa.blogspot.nl/2014/08/fog-computing-from-center-to-edge-of.html
18	The Future of the Connected Car	Amy-Mae Elliott	http://mashable.com/2011/02/26/connected-car/#_zq6aoCXyuqQ
19	The Connected Vehicle – Next Generation ITS	ITS America	http://www.itsa.org/industryforums/connectedvehicle
20	What's Driving the Connected Car?	SPIRENT	http://www.spirent.com/~/media/White%20Papers/Automotive/Connected_Car_Whitepaper.pdf
21	Connected Car	BROADCOM	http://www.broadcom.com/application/connected_car.php
22	What Should States Do Now?	U.S. Department of Transportation	http://www.its.dot.gov/factsheets/pdf/V2I_WhatShouldStatesDo.pdf
23	Connected Car Study 2015: Racing ahead with autonomous cars and digital innovation	Richard Viereckl, Dietmar Ahlemann, Alex Koster, Sebastian Jursch	http://www.strategyand.pwc.com/reports/connected-car-2015-study
24	Car-to-Car Communication	Will Knight	https://www.technologyreview.com/s/534981/car-to-car-communication/
25	Vehicle-to-x communication	BOSCH	http://products.bosch-mobility-solutions.com/en/de/specials/specials_safety/automated_driving/technology_and_development_1/technological_trends/car_to_x_/car_to_x_communication.html
26	V2V: What are vehicle-to-vehicle communications and how do they work?	Bill Howard	http://www.extremetech.com/extreme/176093-v2v-what-are-vehicle-to-vehicle-communications-and-how-does-it-work
27	Introduction to VANET	Akanksha Upadhyay	http://www.slideshare.net/Akanksha_Upadhyay/vanet0
28	Connected Car Investment Thesis	James Harris	http://www.slideshare.net/JamesHarris21/connected-car-investment-thesis
29	LTE-V: A Cellular-Assisted V2X Communication Technology	Yi Shi	https://www.itu.int/en/ITU-T/extcoop/cits/Documents/ITS%20Events-201507-Beijing/Presentations/S3P2-Yi-Shi.pdf
30	APIs Fueling the Connected Car Opportunity	Scott Morrison	https://www.ca.com/us/register/forms/collateral/apis-fueling-the-connected-car-opportunity.aspx
31	Wireless Tech is Only the Beginning in the Connected Car	Sarah Murry	http://www.broadcom.com/blog/automotive-technology-2/wireless-tech-is-only-the-beginning-in-the-connected-car/

32	5 new technologies for the connected car	Tara Baukus Mello	http://www.bankrate.com/finance/auto/new-technologies-connected-car-3.aspx
33	Connected vehicle: Succeeding with a disruptive technology	Andreas Gissler	https://www.accenture.com/_acnmedia/Accenture/Conversion-Assets/DotCom/Documents/Global/PDF/Dualpub_21/Accenture-digital-Connected-Vehicle.pdf
34	Connected Car Platform	IMS	http://www.intellimec.com/connected-car-vision/

Appendix B. Interviewee Information

Fog Computing	Project Manager	Networking Solution Provider	Fog Computer Production Department	Communication & Electronic Engineering	Internal Online Meeting System
	Project Manager		Automotive Department	Electronic Engineering	
Connected Vehicles	CTO	Automotive Manufacturer	Data Lab		Email
	Project Manager		Data Lab	Computational Linguistics	Phone Call
	Solution Architect	Network Equipment Provider	Intelligent Transport System Department	Computer Science	Skype
	IT Architect	IT Service and Consulting Provider		Software engineering	Skype
	CEO	CV Service Provider			WeChat

Appendix C. Sample Question List

1. Fog Computing Side

Initiate stage. Interviewee's background.

- What is your current position
- What are you currently working on?
- How long have you been working in this field?
- What is your educational background?

Part 1. The challenges encountered during the operation/production phase.

- What are the challenges in your working field?
- How do you deal with those challenges right now (maybe just temporarily)? Or what do you plan to do?

Part 2. Fog computing Definition and features.

- How do you think about the newly emerged platform, Fog computing?
- What is Fog computing in your opinion? (Definition)
- What are the capacities of Fog computing?
- What are the requirements for implementing Fog concept?
- Since there are several similar concepts for edge computing, Fog computing, Mobile edge computing, and mobile cloud computing, what do you think about them? Same? Different?
- What are the limitations and challenges for Fog computing?

Part 3. Implementation of Fog computing

- How to implement Fog computing for you working field?
- What are the requirements of implementing Fog computing?

- How to ensure the connection?
- How about the deployment of Fog server with multiple vendors?
- What is your expectation for Fog computing?

Part 4. Implement Fog computing for Connected Vehicles.

- What do you think about implementing Fog computing for CV?
- What role can Fog computing play in CV in your opinion?
- Implementation of Fog computing for CV:

\- The technology used to access network.

\- How to ensure the connectivity in different places?

\- Since vehicles will move from one Fog server area to another, how to deal with the migration? Also, how do Fog server decide to move one vehicle to next server?

\- Where to distribute Fog server? Different scenarios, like city, countryside, and highway.

- What are the limitations for applying Fog computing in Connected Vehicles scenario?

2. Connected Vehicles Side

Initial stage: Background of the interviewee.

1. What is your current position?
2. What are you currently working on?
3. How long have you been working in the field of Connected Vehicles?
4. What is your educational background?

Part 1. The state of art of Connected Vehicles (CV).

1. What stage is the development of CV in your opinion?
2. How do you evaluate the development of CV right now?
3. Where do you store data generated by vehicles (sensors) for your CV?
4. What are the main challenges encountered in your CV development?

Part 2. About CV: characteristics, architecture, enabling technologies and requirements.

1. What are the characteristics of CV? Or what are the required capacities for implementing CV?
2. What is the most suitable CV architecture in your opinion?
3. I divide the types of connection for CV into 4 (please see below). Do you agree? If not, what is your recommended classification?
   General questions for each type of connection:

(1) What are the main enabling technologies?
(2) What are the main challenges?

- Intra-Vehicle
- Vehicle-to-vehicle (V2V)
- Vehicle-to-roadside infrastructure (V2I)

(3) Where to deploy the road-side equipment for infrastructure in different locations like city, highway, and countryside?
(4) Can the road-side equipment provide by multiple vendors? If it can, how to ensure the cooperation between different vendors?

- Vehicle-to-internet (V2N)

4. If we want to have a real CV, what should we do step by step?
5. What is your expectation of the future of CV?

Part 3. The implementation of Fog concept on CV

Do you know the newly emerged edge paradigms, Fog/edge computing?

- If you do:

(1) How do you evaluate Fog computing? Is it able to help increase the performance of CV?
(2) What role does Fog computing play in CV scenario?
(3) What can Fog computing do for CV?
(4) What are the limitations of implementing Fog computing on CV?

- If not:

(1) How do you think about placing server with computing capacities closed to vehicles to reduce latency, precisely aware location, and preprocess data before sending it to the Cloud/Data Center? Can it help increase the performance of CV?