Foud: Integrating Fog and Cloud for 5G-Enabled V2G Networks

Ming Tao, Kaoru Ota, and Mianxiong Dong

Abstract

V2G technology is considered a powerful approach enabling renewable energy sources to provide ancillary electrical services, and managing and monitoring power usage in the smart grid. However, owing to the inherent high mobility of EVs, flexible and timely on-demand response services against EV mobility in the V2G system must be provided. Promoted by the advantages of 5G communications, e.g., supporting various connectivity and faster transmission, fogs and clouds are enabled to provide realistic services, and fog computing and cloud computing assisted V2G systems in future 5G mobile networks are expected to be a new paradigm to create a new situation for V2G services. To this end, a fog-based and cloud-based hybrid computing model named "Foud" applied to V2G networks in 5G is proposed. The potential V2G network services provided by Foud are reviewed, and open issues and challenges for future work are also discussed with possible solutions.

Introduction

Enabling renewable energy sources to provide ancillary electrical services through bi-directional communication and energy flows between EVs and the power grid, V2G as a critical network service in the smart grid is considered to be one of the most powerful approaches to manage and monitor power usage [1]. As shown in Fig. 1, to implement the power exchange and the interaction of power-related data, V2G networks employ a two-way communication infrastructure, in which power links are deployed to achieve both battery charging of EVs by consuming power from the power grid, and discharging the stored power of EVs back to the power grid. Various wireless/wired communication technologies are also integrated to support data communications between the V2G system entities (e.g., EVs, local aggregators (LAGs), certification/registration authorities (CAs/RAs), and control centers (CCs)). With such a network architecture, various V2G services can be implemented [2–4], e.g., ancillary services, charging/discharging enabled energy renewable services, security and privacy related preservation services, and so on.

Because EV mobility is one of the unique and inherent characteristics of V2G systems, an EV can perform random or purposeful movement in the V2G network and may work in different modes accordingly. When an EV is connected to a LAG serving as its default access point for power and data communication, the EV is working in home mode. Otherwise, when an EV is temporarily connected to a LAG managed by a different institution, the EV is working in visiting mode [5]. Hence, along with EV mobility, new critical challenges for providing flexible and timely on-demand response V2G services must be addressed [6, 7].

Cloud computing as a new computing model has been considered a challenging research and industrial topic for many years. To achieve reliable, secure, and efficient V2G service responses on-demand within the implemented distributed architecture, integrating cloud computing with the V2G system can improve service management and integration levels by enabling the V2G system entities to focus on more advanced and complicated service applications, and outsource the basic and generic service-oriented applications to the clouds [8]. In [9], by formulating the problem of routing service requests in a cloud environment jointly with the analysis of power in the V2G system, Leon-Garcia *et al*. investigate the opportunities provided by cloud computing to help V2G systems with robustness and load balancing.

Although cloud computing as characterized by powerful computing and storage capacities has been identified as a promising approach that can offer significant benefits for V2G systems, fog computing [10], as a new paradigm that can deliver computing services at the edge of the cloud network and support low-latency and location-aware services, has also been shown to be an alternative approach to ensure the desired levels of V2G services requested by moving EVs. In [11], based on a fog computing platform, Faruque *et al*., present an energy management system prototype for the home and micro-grid levels with customized control-as-services.

Expectably, under the paradigm of cloud computing and fog computing, with the increasing popularity of EVs and rich V2G services, both the number of accessing vehicular terminals and the volume of produced mobile data will experience tremendous growth. However, under the current architecture of mobile networks using the existing communication technologies, e.g., satellite and 3G/4G, both cloud computing and fog computing may not be perfectly suitable for ensuring the desired levels of various performance metrics to any V2G services requested by moving EVs. Fortunately, with the emergence of 5G mobile networks, using the advantages of supporting various connectivity and faster transmission, more realistic services provided by various kinds of clouds and fogs are expected to be enabled [12, 13].

However, to the best of our knowledge, optimizing V2G network services by integrating both cloud computing and fog computing into 5G has

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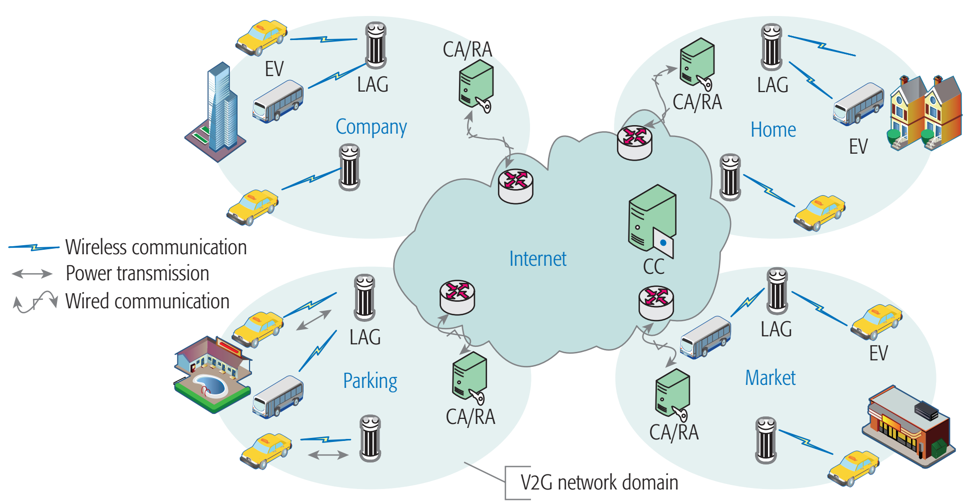

Abbr.	Full name	Function
EV	Electric vehicle	Either power consumer or electricity provider
LAG	Local aggregator	The service access point of power and data communication for EVs
CA/RA	Certification/registration authority	The trusted entity managed by independent institution
CC	Control center	The only entity trusted by all other entities in the entire V2G network environment

FIGURE 1. An illustration of V2G network environment.

been investigated to a much lesser extent. To this end, a new hybrid computing model named "Foud," which makes the fog and cloud available to V2G systems, is proposed, in which two sub-models, permanent cloud and temporary fog, together constitute the infrastructure of Foud. Different from previous proposals, fog computing integrated into Foud is considered a sub-model of temporary fog, owing to the dynamic of mobile computing resources. Additionally, 5G communication technologies are utilized to cope with the issue of the tremendous growth of accessing vehicular terminals and produced mobile data traffic, which is hard to couple with the current architecture of mobile networks using the existing communication technologies.

In this article, the proposal of Foud is first presented, and the potential V2G services supported by Foud are addressed. Subsequently, the effectiveness of Foud is supported by a simulation. Finally, considering the high mobility of EVs and the dynamic of mobile computing resources, open issues and challenges in Foud are discussed with possible solutions.

Proposal of Foud

As shown in Fig. 2, in the context of 5G, by integrating the emerging and advanced technologies of fog computing and cloud computing, a hybrid computing model for V2G networks named Foud is designed.

Architecture of Foud

The architecture of Foud is made up of two sub-models, permanent cloud and temporary fog. In terms of the powerful and stationary computing and storage capacities of the conventional cloud, permanent cloud can make the virtualized computing, storage, and network resources available to the V2G system entities, and mainly provides three distinct types of services, i.e., software-as-a-service (SaaS), platform-as-a-service (PaaS), and infrastructure-as-a-service (IaaS). In temporary fog, the stationary and mobile computing resources provided by the V2G system entities (e.g., LAGs, CAs/RAs, CCs), on-board modules in EVs and even the drivers' devices, which are located at the edge of V2G networks, are temporarily integrated together into a fog to expand the computing capacity. Accordingly, supporting different computing functions (e.g., processing, storage, networking), and integrating 5G communications, Foud could enable the authenticated and authorized end-users in the V2G system to access all available stationary and mobile computing resources in the form of virtualization with significantly reduced costs.

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Inspired by cross-layer design, Foud organizes the involved architecture components into three layers: the user layer, the network layer, and the service layer. The main characteristics and functions of the three layers are described as follows.

User Layer: The user layer is composed of various types of end users and is the lowest level of Foud. In broad terms, the end users consist of all the V2G system entities and the drivers that have the demand to use the services in Foud. Different from the other end users, EVs and drivers have a unique feature in their inherent high mobility. Through communication and computing devices or installed modules, the end users could initiate service requests to the upper layers via service access points (SAPs). Correspondingly, the upper layers will respond to the service requests on demand, and the end users subsequently receive service responses from the upper layers through the SAPs similarly.

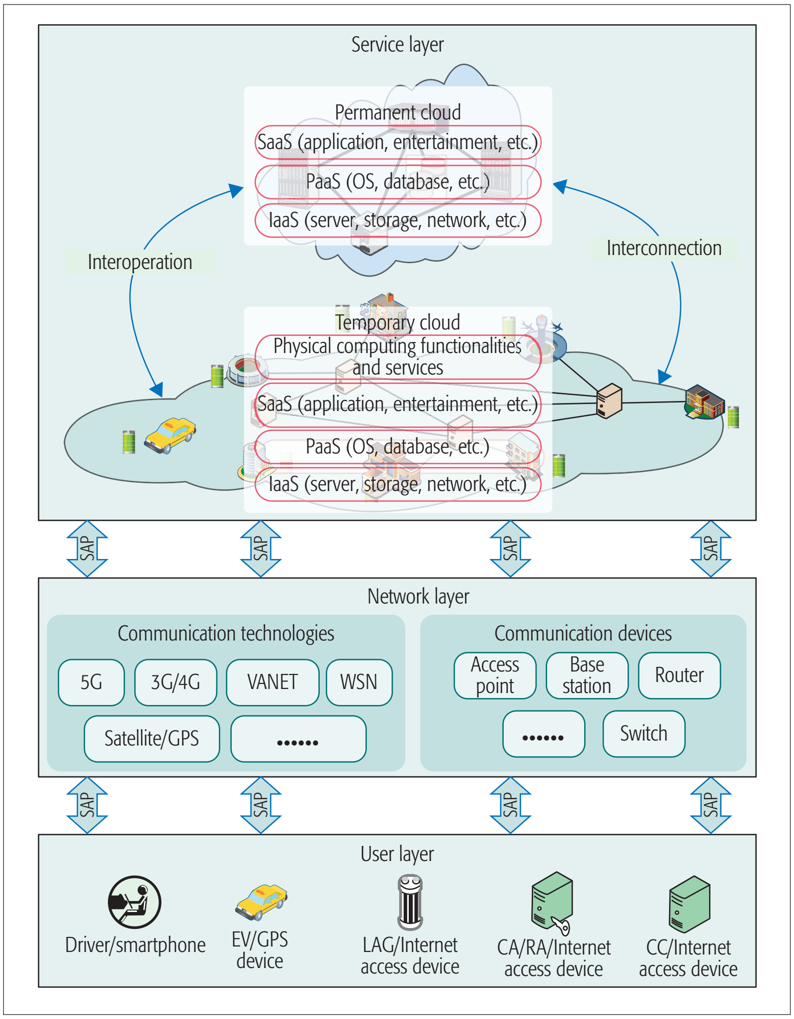

FIGURE 2. Proposed Foud model.

Network Layer: The network layer is made up of a variety of communication devices and technologies, and is designed to implement the interactions between the end users in the user layer and the computing resources. It is also used to enable interactions between the end users, and the interconnection and interoperation between the defined two sub-layers in the service layer. In this layer, 5G communications are the favorites; other current widely used communication technologies, e.g., 3G/4G, satellite, GPS, and so on, are also integrated to form a heterogeneous convergence network. Additionally, the technology of self-defending networks (SDNs) can also be used to shield the heterogeneity of the underlying communication facilities [14].

Service Layer: The service layer consists of two sub-layers: a permanent layer supporting the conventional cloud, and a dynamic layer supporting the temporary fog. By passing the network layer, the service layer, supported by the computing capacities in permanent cloud and the temporary fog, could provide various types of V2G services for the end users located in the user layer through SAPs.

In the permanent cloud layer, the three distinct types of services, SaaS (e.g., application, entertainment, game), PaaS (e.g., OS, database), and IaaS (e.g., server, storage, network), could be provided by various available stationary computing resources organized in the form of virtualization.

In the dynamic layer of the temporary fog, under utilized by the permanent cloud, a mass of computing resources on the edge of V2G networks, e.g., the stationary computing resources provided by LAGs, CAs/RAs, CCs, EVs and drivers in the rest state, and the mobile computing resources provided by EVs and drivers in the moving state, are integrated to form the infrastructure of fog computing. Due to EV and driver mobility, the mobile computing resources provided by them are temporarily connected to the fog; accordingly, this sub-model in Foud is named the temporary fog, which is different from the work in the previous proposals. Additionally, because fog computing is based on the service computing architecture model of para-virtualization, physical computing functionalities and services, and virtualized services in the form of SaaS, PaaS and IaaS, both could be made available to the end-users in the user layer through SAPs.

Interconnection and Interoperation Between Sub-Models

As stated above, the two sub-models, permanent cloud and temporary fog, together make up the architecture model of Foud. The interconnection between the two sub-models can be achieved by a global network consisting of all computing resources in the service layer through the introduced internetworking technologies in the network layer. In addition, to uniformly manage and control the merged network in Foud, different network techniques and protocols must be supported.

Based on the enabled interconnection, the issue of interoperability between the two sub-models could be addressed as well. Through the network, protocol, interface, and security (e.g., certification and authorization) techniques to achieve global control for the V2G system, permanent cloud and temporary fog could fully cooperate and interoperate to perform the joint implementation of V2G services without any additional costs.

Potential V2G Services and Applications

Making full use of the advantages of fog computing, cloud computing, and 5G communications, Foud could facilitate the quick growth of enriched V2G services for the following partial list of applications.

Powerful Computing and Standardized Data Storage: With the powerful computing capacity in permanent cloud and the expanded computing capacity provided by temporary fog, Foud could provide compute-intensive services and applications, e.g., planning the shortest path between power-thirsty EVs and charging stations, and optimizing the deployment of charging stations to provide high quality services with respect to usability, security, and low latency. Additionally, a volume of sensed and aggregated data, e.g., traffic, movement of EVs, battery depletion state, and geographic locations of recharging stations, could be stored in Foud with standardized data formats.

Balanced Power Management Services and Applications: Power management is a major concern in the smart grid. By utilizing the powerful computing and storage capacities in Foud to aggregate and analyze the massive amounts of data information, e.g., the cycles of EV power demand and renewable generation integration, and predicting the power consumption of EVs, Foud could enable balanced power management services and applications via reasonable supply of power and providing flexible on-demand response services for the EVs. In addition, interestingly, because EVs could flexibly act as both energy storage units and energy transporters, balanced power management among different districts also could be achieved through EV mobility.

Resource-Sensitive Services and Applications: With the advantage of the significantly faster transmission performance of 5G communication technologies integrated in Foud, in terms of high bandwidth and low latency, Foud is expected to be available to provide resource-limited end users (e.g., moving EVs) with resource-sensitive services and applications, for example, in-vehicle infotainment, traffic accident notification, collision avoidance, and rescue services needed by power-depleted EVs.

Location-Aware Services and Applications: With the cooperation of the architecture components in Foud, Foud could provide end users with various location-aware services and applications, e.g., help to discover geographic locations and real-time information of available recharging stations based on the EV mobility and battery depletion state to avoid imbalance using the recharging stations and prolonging the waiting time.

Business Services and Applications: Promoted by the benefit of mobile big data delivery using 5G communications, and fog-assisted and cloud-assisted computing, Foud is made to be available to rich business services and applications. For example, using the shared sensed real-time power usage and pricing information, power suppliers could re-design the power grid around the recharging stations, schedule their provisioning around the clock, and implement dynamic pricing during peak-hours and non-peak hours; also, customers could earn lucrative economic benefit from this real-time information.

Simulation and Results

In this section, we set up a simulation using OMNeT++ to qualitatively analyze and evaluate the effectiveness of Foud. In the simulation, using a Quadtree communication structure, we design a prototype that consists of one cloud computing node as the root, four fog computing nodes as leaves, and 500 randomly moving EVs on the road network (an urban area covering 5.0 km × 5.0 km). The entire area is uniformly divided into four parts, each part is managed by a fog node that can directly communicate with the inside EVs, and each deployed randomly moving EV initiates a V2G service request. To ensure the V2G service quality experienced by the EVs, the response time defined as the maximum time interval from submitting the service request to receiving the response is significant for real time. Accordingly, the effectiveness of Foud is measured with respect to the response time of V2G service requests in this work. Additionally, in the simulation, to reflect the advantages of future 5G communication technologies, we consider the test network in two situations: the network without any loads, and the network with loads (512 kb/s), to approximately indicate the transmission performance difference between future 5G communication technologies and existing communication technologies, and observe the differences in the response times in the two different network situations.

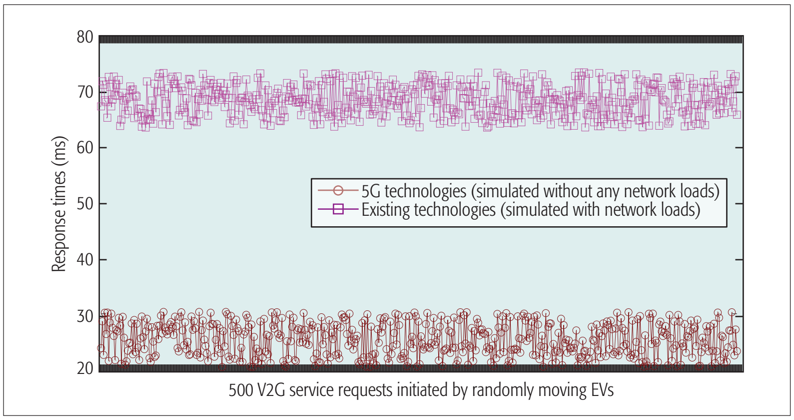

FIGURE 3. The response times in two different network situations.

Average response time (ms)	5G technologies (simulated without any network loads)	25.36
	Existing technologies (simulated with network loads)	68.63
Standard deviation (ms)	5G technologies (simulated without any network loads)	7.88
	Existing technologies (simulated with network loads)	8.92

TABLE 1. Comparisons for the V2G service response times.

The comparison for the response times of V2G service requests initiated by 500 randomly moving EVs in the two different network situations is shown in Fig. 3. Further analysis results of the response times are shown in Table I. From Table I, we can clearly see that, constrained by the current architecture of mobile networks using the existing communication technologies, transmitting a volume of mobile data will cause serious transmission delay that consequently brings about adverse affects on the response times of V2G service requests. In comparison, with the significantly faster transmission performance of 5G communications, the response times of V2G service requests are more acceptable.

Open Issues and Challenges

New architectures and platforms for V2G networks such as Foud must be provably efficient, scalable, secure, and reliable before starting their large-scale deployment. However, existing mechanisms and approaches, such as the mentioned 5G communications, fog computing, and cloud computing, are not yet fully satisfactory in meeting all these requirements at the same time, especially considering EV mobility and dynamic participation of mobile computing resources. There are still significant open issues and challenges that should be addressed in future research work.

Green Foud

Energy efficiency, as one of the major concerns in conventional cloud computing, has been investigated as a challenging academic and industrial topic for many years. In Foud, although the redistribution of energy consumption could be

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achieved by utilizing mobile computing resources in temporary fog, instead of performing the centralized energy consumption in permanent cloud, novel energy-efficient solutions for green Foud by integrating permanent cloud and temporary fog, e.g., reducing the energy consumption caused by under-utilized resources which accounts for abundant actual energy use, still remain critical challenges. Additionally, due to EV mobility, new open issues of using mobile computing resources have arisen as well, e.g., when a mobile computing device leaves its current access network, the maintained mobile communication link will be lost, and excessive transactions of re-searching and re-link routing will cause serious energy consumption. Hence, an efficient mechanism to update the information of mobile communication link loss with reduced energy cost should be investigated.

Cooperative Resource Management in Foud

Due to EV mobility, the computing resources provided by mobile computing devices are integrated into temporary fog in a dynamic manner. Therefore, the performance of V2G services and applications in Foud is seriously influenced by EV mobility. Efficient resource management by dynamically integrating mobile computing resources into temporary fog, and integrating permanent cloud and temporary fog, is an important open issue that also needs to be addressed.

Persistence of Perceived QoS

Foud is expected to be available to various V2G services and applications for end users in terms of ensuring the desired level of quality of service (QoS). However, due to EV mobility and the dynamic participation of mobile computing resources in temporary fog, providing on-demand response services with availability, reliability, scalability, adaptability, and sustainability, performance for moving EVs still remains a critical challenge. Consequently, developing efficient mechanisms to achieve mobility management for EVs, and maintaining service execution conditions by dynamically integrating mobile computing resources without being influenced by the dynamic mobile computing resources, could persistently ensure the desired level of perceived QoS.

Security and Privacy Preservation

V2G networks as highly distributed systems are different from other broadly applied communication systems, especially in which the employed two-way communication infrastructure not only facilitates the functionalities for data and power delivery, but also facilitates cyber-physical attacks. Hence, the problem of security and privacy preservation may be more severe in V2G networks [15]. Although many approaches have been proposed to address this severe problem, these involved open issues, e.g., anonymous mutual authentication, session key establishment, location and identification related privacy preservation, privacy-preserving based charging and discharging, billing and payment, and data publication, still remain the critical challenges in Foud due to the inherent high mobility of EVs and utilizing the mobile computing resources in temporary fog as services. Consequently, taking advantage of the component technologies used in Foud to ensure security and privacy should be investigated in the future.

Conclusion

A new hybrid computing model for V2G networks named Foud is proposed in this article. Foud is made up of two sub-models, permanent cloud and temporary fog, and organizes the involved architecture components into three layers. The user layer is composed of various kinds of end users in the V2G system, and the service layer is divided into two sub-layers: permanent cloud layer and temporary fog layer, providing various kinds of V2G services for the user layer. To ensure the interaction and interconnection between the Foud components, the network layer takes 5G communications as the favorite. Making full use of the advantages of the mentioned advanced technologies, Foud could facilitate the quick growth of enriched V2G services and applications. However, due to the inherent high mobility of EVs and the dynamic participation of mobile computing resources, there are still significant open issues and challenges that should be addressed in the future.

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