VANET-CLOUD: A GENERIC CLOUD COMPUTING MODEL FOR VEHICULAR AD HOC NETWORKS

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ABSTRACT

Cloud computing is a network access model that aims to transparently and ubiquitously share a large number of computing resources. These are leased by a service provider to digital customers, usually through the Internet. Due to the increasing number of traffic accidents and dissatisfaction of road users in vehicular networks, the major focus of current solutions provided by intelligent transportation systems is on improving road safety and ensuring passenger comfort. Cloud computing technologies have the potential to improve road safety and traveling experience in ITSs by providing flexible solutions (i.e., alternative routes, synchronization of traffic lights, etc.) needed by various road safety actors such as police, and disaster and emergency services. In order to improve traffic safety and provide computational services to road users, a new cloud computing model called VANET-Cloud applied to vehicular ad hoc networks is proposed. Various transportation services provided by VANET-Cloud are reviewed, and some future research directions are highlighted, including security and privacy, data aggregation, energy efficiency, interoperability, and resource management.

INTRODUCTION

Cloud computing is a new computing model that makes use of pools of physical computing resources known as data centers. These can be organized on demand into a dynamic logical entity that can grow or shrink over time, usually through the Internet against a leased resource fee. Three categories of digital services can be supplied: software as a service (e.g., applications of emergency management, roadway maintenance, electronic payment and pricing), infrastructure as a service (processing, storage, bandwidth, etc.), and platform as a service (e.g., programing languages, operating systems) [1]. Cloud computing uses virtualization technology in which a cloud physical resource can be carved up into logical or virtual resources as needed.

To ensure the desired levels of latency sensitivity, performance, scalability, reliability, and security to any application that runs in the cloud, a new paradigm was recently proposed called fog computing, in which computing services could be delivered at the edge of the cloud network [2].

In vehicular networks, reduced delay, efficiency, scalability, reliability, and security are very crucial to improve road safety and passenger comfort through intelligent transportation systems (ITS). To support these characteristics, in this article we propose a model called VANET-Cloud that extends the traditional cloud infrastructure consisting of a majority of stationary nodes to the edge of vehicles. Specifically, VANET-Cloud allows onboard computing resources of vehicles to be integrated with the traditional cloud computing environment, which consists only of stationary computational entities. Moreover, this model reaps the benefits of the computing capabilities of vehicles that include processing, storage, as well as sensing to extend traditional cloud computing capabilities with mobile entities. Consequently, more flexible solutions could be provided to help drivers and authorities overcome critical road situations such as finding alternative routes and synchronizing traffic lights to decrease road congestion, managing emergency and traffic incidents, providing commercial vehicle operations, and so on.

Today, these ITS applications are provided by innovative digital services to vehicular customers through well-known vehicular ad hoc networks (VANETs). A VANET is defined as a set of communication nodes consisting of vehicles considered as mobile entities, which move according to a restricted mobility pattern, and fixed entities called roadside units (RSUs), deployed at critical locations such as slippery roads, dangerous intersections, or places well known for hazardous weather conditions [3]. A VANET supports communication among vehicles, called vehicle-to-vehicle communication (V2V), and between vehicles and the RSU infrastructure, known also as vehicle-to-infrastructure communication (V2I), often using Global Positioning System (GPS) devices to determine the location of vehicles [4].

To benefit from a digital service that is often used only once, VANET end users (drivers and passengers) are generally required to buy the required software, a suitable platform, and the appropriate hardware, all of which can be rented

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from innovative vehicular cloud architecture. Unfortunately, a general vehicular cloud model is not yet deployed to serve vehicular customers in terms of their computational needs or to make their onboard computers available to other clients against usage fees. In other words, there is no vehicular cloud architecture offering computing services to drivers and passengers.

To deal with the aforementioned weaknesses, our VANET-Cloud proposal makes the cloud available to vehicular systems and takes advantage of cloud computing resources to better serve VANET end users in terms of providing the lowest cost without the need to buy additional resources. Two sub-models make up the VANET-Cloud architecture. The first sub-model is based on the conventional cloud, which offers cloud services such as software as a service (SaaS), infrastructure as a service (IaaS), and platform as a service (PaaS) to vehicles. The second one consists of vehicles that together form a new temporary cloud. The latter is designed to expand the permanent cloud and aims to increase the computing capacity requested by users.

This article first discusses the various issues that have led to the emergence of cloud-based VANETs, as well as the state-of-the-art solutions proposed recently in this context. Next, the VANET-Cloud model as well as ITS applications that can be supported by this model are described. Finally, various VANET-Cloud challenges that need to be addressed in the future are discussed.

Impact of Cloud Computing on VANET: Issues and Solutions

Cloud computing for vehicular networks has been studied in several recent research efforts [5]. Despite these few attempts at integrating cloud computing with VANETs, there is no general model, to the best of our knowledge, which can be used to design a cloud system for VANETs.

Among the existing works, the authors of [6] proposed a new concept called Vehicular Cloud (VC). VC used underutilized vehicle resources to form a cloud by aggregating vehicular computing resources. The authors considered that VC refers to a group of largely autonomous vehicles the computing, sensing, communication, and physical resources of which can be coordinated and dynamically allocated to end users. It is worth noting that the proposed system did not take advantage of the conventional cloud and was only based on the vehicular resources. In contrast, VC resources cannot always be switched on, and often require the authorization of the vehicle's owner, which can be absent if the vehicle is in steady state (e.g., vehicles in a parking lot).

Mershed and Artil, in [7], addressed the problem of enabling vehicles in a VANET to discover their needed services from mobile cloud servers that are moving nearby. The authors proposed a system called CROWN, which depends on RSUs that act as cloud directories and interfaces. To achieve this, RSUs make available their recorded data to enable vehicles to discover the required cloud services within the area covered by the RSU. Except for the RSU, CROWN system did not consider the onboard computer as a cloud computing entity that can be available to end users.

To provide safety and non-safety services in vehicular applications, the authors of [8] proposed the use of cloud computing services via RSUs. Vehicular cloud for roadside (VCR) scenarios architecture was proposed in [8] to allow vehicles to benefit from private and public vehicular cloud services. The previous efforts of [8] can be considered as help systems for vehicles to access the conventional cloud through RSUs via a cloud gateway in order to find the requested cloud service without using any mobile computing resources.

A pure cloud formed by vehicles has been proposed in [9]. It is a new service paradigm called sensor as a service (SenaaS) for vehicle communication platforms that makes available their components, including vehicle sensors and devices, to third-party vehicle monitoring applications, as cloud computing resources called sensor-cloud service. This proposal lacks the use of the traditional cloud to improve the computing capacity usually requested by vehicles.

Another cloud architecture applied to vehicular networks was proposed in [10], where the authors divided VANET clouds into three major clouds: vehicular clouds (VCs), vehicles using clouds (VuCs), and hybrid clouds (HCs). The VC is subdivided into two categories: a static cloud refers to stationary vehicles providing cloud services, and a dynamic cloud is set up on demand in an ad hoc manner. A VuC allows a VANET to connect to the traditional cloud with RSUs, whereas the HC is a combination of VC and VuC. It is worth mentioning that this proposal requires that in the VC the vehicles should be stationary. Moreover, the vehicles can only interact with the traditional cloud through RSUs, which act as gateways. However, vehicles cannot be connected to the VC if RSUs are not available, as in rural areas.

It is worth mentioning that this proposal requires in the VC that the vehicles should be in a stationary state. Moreover, the vehicles can only interact with the traditional cloud through RSUs only which act as gateways. However, vehicles cannot be connected to the Vehicular Cloud if the RSUs are not available as in rural areas.

The authors of [11] dealt with the cloud security issue for vehicular networks by proposing a new secure provisioning model called vehicle-to-cloud (V2C). V2C is composed of a provisioning infrastructure, which links two levels: the automobile user and the infrastructure provider. To enhance security, in the proposed model the authors integrated three security modules: an authentication module, an authorization and access control policies module, and an assurance module. The authentication module manages identities and authenticates entities in V2C. The authorization and access control policies modules set access control policies for every automobile user. To correlate management actions with the desired requirements, the assurance module is deployed throughout V2C. V2C focuses on the cloud services required by the automobile users and is served via the traditional cloud. However, this approach did not use the computing resources of vehicles to reinforce the functionalities of the vehicular cloud infrastructure.

To deal with the issue of vehicles avoiding obstacles, a cloud-assisted system for autonomous driving was proposed in [12] called

Carcel. Carcel is a system that enables the cloud to collect information from autonomous vehicle sensors as well as from the roadside infrastructure to help vehicles avoid obstacles, such as pedestrians and other vehicles, which may not be directly detected by sensors on the vehicle. Carcel consists of two cloud modules: a request module and a planner module. The first one issues requests for information to the vehicle in order to collect digital information concerning pedestrians and other vehicles that move on the road. The second one aggregates sensor information obtained from various autonomous vehicles and RSUs to detect obstacles. Carcel is a kind of IaaS service used only to solve a particular detection instance of vehicle obstacles.

The authors of [13] proposed a novel vehicular cloud called V-Cloud. V-Cloud dealt with human-related security issues of the car driver. V-Cloud is based on a layered architecture that includes three vehicular network layers: in-car vehicular cyber-physical system (VCPS), V2V, and V2I. The authors proposed that the VCPS layer consists of two types of sensors: a vehicle's internal physical sensors and smartphone embedded sensors. These sensors are responsible for ensuring driver security by incorporating context awareness, healthcare monitoring, and mood detection of the vehicle's driver while driving. We note here that V-Cloud did not take advantage of the computing devices installed onboard vehicles so that they could be used as cloud entities, which can further extend the cloud infrastructure and functionality, and can offer a financial contribution that benefits vehicle owners.

Study	Entity type of vehicular cloud		General/specific purpose of study
	Stationary entity	Mobile entity	
[6] (VC)		x	General computing
[7] (CROWN)	x		General computing
[8] (VC-RS scenarios)	x		General computing
[9] (SenaaS)		x	Sensor cloud
[10] (VC+VuC+HC)	x (only RSU)	x	General computing
[11] (V2C)	x		Security for vehicle network
[12] (Carcel)		x	Detection of vehicle obstacles
[13] (V-Cloud)	x		Car driver security
[14] (GaaS)	x		Access to Internet
[Our proposal] (VANET-Cloud)	x	x	General computing

Table 1. Comparison between cloud computing studies for VANETs.

The authors of [14] addressed the issue of seamless access to the Internet by making use of cloud-based VANETs. In this study, the authors proposed a cloud-supported gateway model, called gateway as a service (GaaS), in order to provide efficient gateway connectivity and enhance the Internet usage experience for vehicular networks. The proposed system consists of four components: gateway, client vehicle, relay vehicle, and cloud server. The gateway is responsible for connecting vehicles to the Internet. This gateway can be stationary in the form of RSUs, or mobile where vehicles themselves play the role of the gateway. The client vehicle is the one that wants to access the Internet and requests GaaS. The relay vehicle helps the client vehicle connect to the gateway if the client vehicle is not within the coverage range of any gateway. The last GaaS model component is the cloud server. It is the service provider in the cloud that provides two special sub-servers, the GaaS registrar and the GaaS dispatcher. The GaaS registrar is responsible for maintaining related information of the gateways, while the GaaS dispatcher dispatches related gateways for the client vehicles. Despite these global functionalities, the proposed model focuses primarily on the Internet connection, and does not take into account the digital resources of vehicles that can contribute to the expansion of the traditional cloud computing environment.

Table 1 compares recently proposed works on vehicular cloud according to two criteria: the first criterion is the infrastructure of the proposed cloud, which can be based on traditional stationary nodes and/or vehicular nodes; the second criterion is the function and purpose of the proposed cloud, which can be for general computing uses (processing, storage, networking, etc.) or for particular purposes such as security.

VANET-Cloud Model Proposal

To leverage cloud computing functionalities, a new vehicular cloud computing model called VANET-Cloud is proposed in this article. This model extends the conventional cloud infrastructure, which consists only of stationary nodes (servers, workstations, etc.), to the edge of vehicles. This extension is achieved by integrating new computing resources (e.g., onboard computers) installed on vehicles. As a result, VANET-Cloud helps vehicular drivers to access computing resources using both mobile and stationary nodes in a virtualized manner with reduced costs. Moreover, our proposed model provides vehicles' computing resources not only to vehicular drivers but also to other users. Based on three layers (i.e., client layer, communication layer, and cloud layer), the model can improve road safety when executing road safety applications. Finally, it can also contribute to different computing functions such as processing, storage, and networking.

VANET-Cloud Architecture

To integrate the various aspects mentioned earlier, we propose a novel cloud computing model called VANET-Cloud. This model is composed of two sub-models: permanent cloud and temporary cloud for VANETs. The permanent VANET-Cloud sub-model reaps the benefits of the conventional cloud — processing, virtual machines, storage, and bandwidth — and makes them available to VANET entities such as vehicles and RSUs. The permanent VANET-Cloud sub-model is extended by adding a temporary VANET-Cloud sub-model that consists of VANET computing resources and passenger devices. Therefore, all available computing resources (i.e., stationary and mobile) are accessible by any end user. Considered as a cross-layer model, VANET-Cloud groups infrastructure components into three layers (as shown in Fig. 1) and is described below.

Client Layer — The client layer is the lowest level of VANET-Cloud and consists of end users. An end user might be a general customer (i.e., not a VANET entity) or a VANET node that requires a VANET-Cloud service. The end user can be characterized by a certain level of mobility in the vehicular environment.

Using communication and computing devices such as smartphone, laptop, onboard computer, and GPS, the end user can establish its service request to adjacent layers through a service access point (SAP). To this end, the client receives its service response sent by the upper layers through SAPs. Locally, the clients can set up their own local network, which can be wired or wireless.

Communication Layer — The purpose of this layer is to ensure the connection between the client located in the lower layer and the VANET-Cloud server (i.e., data center) located in the upper layer via SAPs. This layer consists of several communication devices and networks: Internet gateways, wireless networks such as VANETs, wireless sensor networks, 3G/4G networks, cellular base stations, RSUs, satellite, GPS, private networks, and so on. At this level, all connection technologies (the physical layer, data link layer, medium access control, routing protocols, etc.) are defined and fixed according to the communication device used. The technology choice also depends on the type of client in the lower layer and the data center in the upper layer.

Cloud Layer — The cloud layer refers to the VANET-Cloud data centers, which provide VANET-Cloud services. VANET-Cloud data centers consist of traditional stationary cloud data centers (static VANET-Cloud) and computing devices of VANET entities such as vehicles or passengers belonging to the VANET-Cloud temporarily (dynamic VANET-Cloud). These VANET-Cloud services might be made available to clients through SAPs, by passing the communication layer. VANET-Cloud services available to clients can be divided into three types: SaaS (e.g., application, email, entertainment), IaaS (processing, storage, networks, virtualization, etc.), and PaaS (e.g., database, data warehouse, operating system, web services).

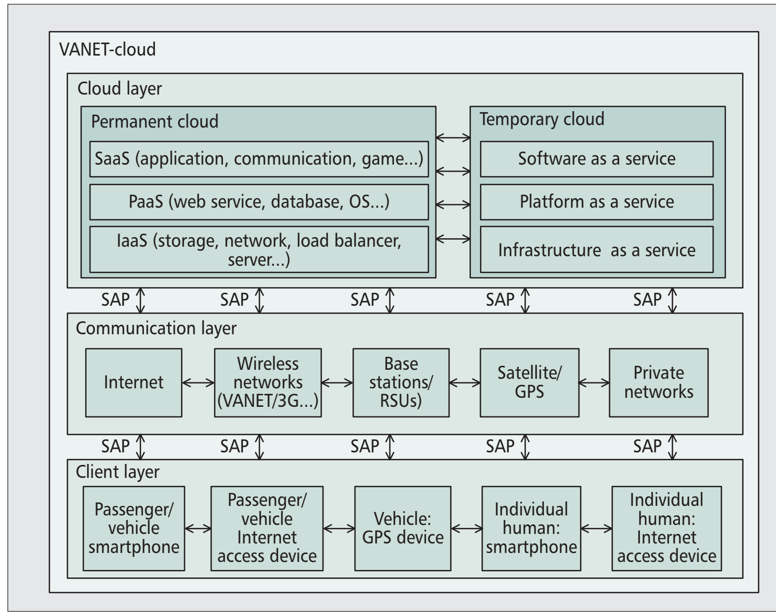

Figure 1. Proposed VANET-Cloud model.

VANET-Cloud Sub-Models of the Cloud Layer

As shown in Fig. 2, the VANET-Cloud layer is composed of a static (permanent) layer and a dynamic (temporary) layer.

Permanent VANET-Cloud Sub-Model — This sub-model consists of stationary and virtualized data centers including the traditional cloud computing infrastructure. These data centers are interconnected through traditional networks, providing several computing functionalities and services to end users who are directly connected to the data center, making VANET-Cloud different from fog computing due to the indirect link between the end user and the data center. Data centers offer various software and applications, running remotely through the Internet via a web browser or some specific program interface.

Platform services such as programming languages and operating systems are also provided to clients. IaaS is also supported by this sub-model. IaaS provides the computing and processing capabilities such as the storage devices, processors, servers, and networking components.

Temporary VANET-Cloud Sub-Model — The temporary VANET-Cloud sub-model consists of a set of mobile and vehicular computing resources such as onboard computer and computing devices of passengers that are not used by traditional cloud computing. These resources (located initially in the vehicular area) are interconnected through the VANET network.

Temporary VANET-Cloud can be stationary or mobile. In the former case, the vehicles, RSUs, and/or passengers can rent their computing resources to other clients while they are in an off state (e.g., cars in parking lots, passengers waiting for a bus). In the latter case, the mobile entities of the temporary VANET-Cloud are

The interconnection between permanent and temporary VANET-Clouds is enabled by a network consisting of all data centers of both VANET-Clouds. Therefore, the provider is responsible for managing and controlling the merged network using different network techniques and protocols.

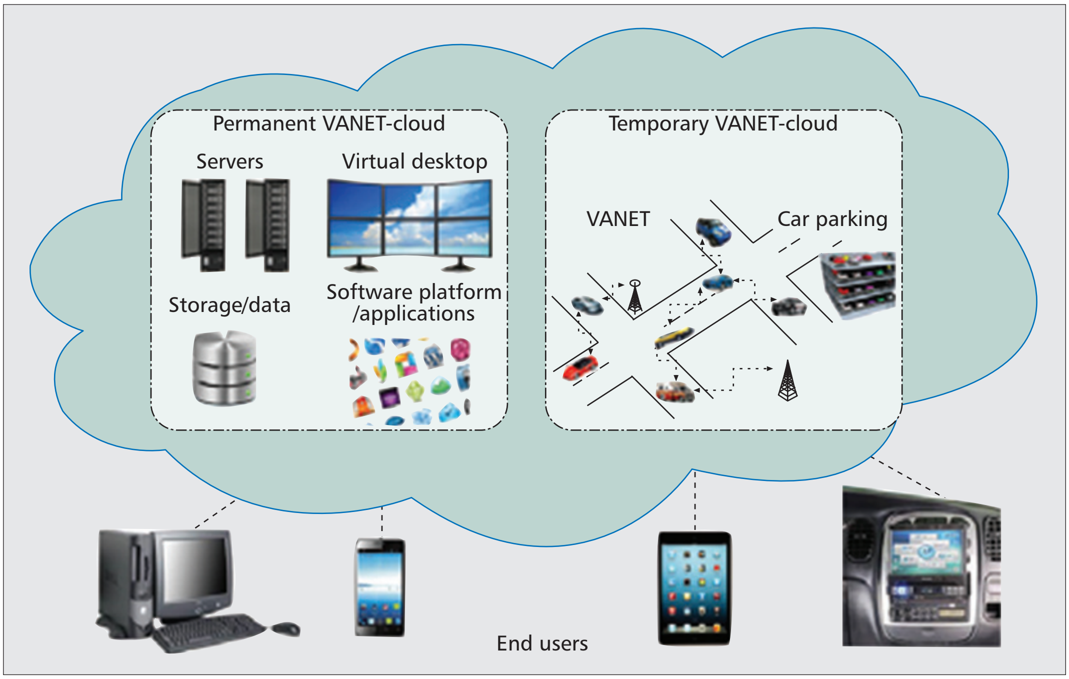

Figure 2. VANET-Cloud sub-models.

vehicles and/or passengers when they move in the vehicular area, which can add sensing information as a new kind of cloud service.

Onboard computers and passengers' mobile devices vary from simple smartphones to internal computers installed inside the vehicles, and made available to a client against a rent price.

Interconnection between Permanent and Temporary VANET-Clouds

Permanent and temporary VANET-Clouds together constitute the proposed VANET-Cloud model as perceived by the client. The interconnection between permanent and temporary VANET-Clouds is enabled by a network consisting of all data centers of both VANET-Clouds. Therefore, the provider is responsible for managing and controlling the merged network using different network techniques and protocols. For example, each node in the temporary VANET-Cloud (i.e., vehicle, RSU, passenger) can access the permanent VANET-Cloud, and each node in the permanent VANET-Cloud can establish a connection with temporary VANET-Cloud nodes leading to a global network controlled by the service provider. As a result, a large and flexible vehicular cloud can be formed to serve many end users.

ITS Applications Supported by VANET-Cloud

VANET-Cloud can support several services of the following applications.

Safety applications in a very large area: Vehicles of VANET-Cloud can provide several safety applications and information to other vehicle drivers concerning collision notification and avoidance, crash prevention and safety, traffic incident management, and so on. These safety applications could provide information about a larger vehicular environment compared to information provided by traditional VANETs or by the traditional cloud.

Vehicular software and applications: VANET-Cloud components (i.e., vehicles and data centers) offer to end users various vehicular software and applications that help to discover geographic positions and real-time information concerning car parking places and availability, full station, service station, hotels, and so on.

Web services and applications: VANET-Cloud allows services over the Internet to be made available from the business's web server for clients. In contrast to classical web service providers, web services (i.e., email, meeting organization, appointments) are advertised over a large computing capacity provided by VANET-Cloud which is much faster and cheaper using the vehicles' onboard computers.

Processing and cloud backup: Using data centers and vehicles' computing resources, VANET-Cloud can be used for compute-intensive applications such as the shortest path problem or other NP-hard problems encountered often in vehicular areas. Therefore, computational complexity in terms of computational time can be reduced or overcome compared to the use of traditional computing resources alone. VANET-Cloud also ensures data storage in data centers using standard data formats.

Business and research applications: On one hand, e-commerce is easier using VANET-Cloud over traditional VANETs because the cloud approach is based on digital buying services that are rarely available in VANETs. Vehicular providers (e.g., drivers, passenger) can provide commercial applications against a usage fee. On the other hand, through the use of a large number of vehicular onboard computers, VANET-Cloud ensures an efficient computing platform that could be used to conduct academic and experimental studies.

VANET-Cloud Challenges

Cloud computing for VANETs is still in the early stages of development. Consequently, there are serious challenges and issues that should be addressed, as follows.

Security and privacy issues in the vehicular cloud: As a distributed system, the major challenges for the vehicular cloud are security and privacy. In such a system, users input their data and run their applications at data centers managed by other people. The problem becomes even more challenging when temporary VANET-Cloud onboard computers are considered as servers. Consequently, security and privacy issues should focus on ensuring data integrity, controlling data access, preventing data loss, protecting the confidential data of users, and so on.

Sensing and aggregation data: In the VANET context, cloud computing faces an important challenge, which is the sensing and aggregation of data as a service. This kind of service can be provided by the temporary VANET-Cloud using sensors of vehicles and digital equipment vehicular passengers. New research solutions are required to efficiently sense and aggregate various types of sensor data, including traffic data, drivers' health information, information about the environment (disasters, fire, etc.), movements of vehicles and citizens on roads, and so on. The sensed data can be processed to yield results that can help to cope with critical or undesirable situations.

Green VANET-Cloud: Another major issue in VANET-Cloud is the improvement of energy efficiency. Cloud data centers consume an important amount of energy each year [15]. VANET-Cloud providers can contribute to reduce energy cost in data centers using alternative servers such as onboard computers located in vehicles. The use of mobile computing resources can also ensure the redistribution of the energy consumed because these vehicles are self-powered and help to minimize the energy consumption of data centers of the entire cloud compared to the energy consumption when using only centralized data centers. To achieve this result, researchers need to investigate energy-efficient solutions by combining permanent and temporary servers.

Communication and coordination between VANET-Cloud sub-models: Continuous and preferred communication within permanent and temporary sub-models, in addition to the communication and coordination between these two sub-models, are also VANET-Cloud challenges. Vehicles have limited lifetime in the network of the cloud, and require a strategy to ensure continuous and efficient communication between VANET nodes as VANET-Cloud entities. We also need to develop new communication protocols that perform data exchange within or between VANET-Cloud components.

Interoperability and standardization: Since VANET-Cloud is based on diverse stationary and mobile computing resources such as data centers or onboard computers, many steps should be taken to address the interoperability challenge to allow these different entities to work together. Furthermore, standardization can be seen as a good solution to address the interoperability issue so that a consensus can be reached among the VANET-Cloud players (i.e., developers, vehicle manufacturers, etc). As a result, interoperability issues (heterogeneous operating system, application programming interface, etc.) among VANET-Cloud devices and software will not cause any additional cost for the client or for the provider.

Quality of the Provided Services: VANET-Cloud aims to provide different services requested by the client with a certain level of quality, known as service level agreements (SLAs). Consequently, the provider is responsible for guaranteeing the availability, reliability, and performance of the cloud resources. SLAs are highly constrained in the VANET-Cloud environment because an important part of the cloud is non-permanent, especially when vehicles move and change the vehicular network topology. The definition of the SLA specification and SLA evaluation throughout the service execution should be investigated in the future.

VANET-Cloud resource allocation and sharing: Resource allocation and sharing are important issues that also need to be addressed, particularly for mobile cloud entities such as vehicles and passenger devices. This mobility can affect the performance of VANET-Cloud applications. An optimal dynamic combination of mobile computing resources can improve the offered service. In such cases, a reserved resource should be ready to be used with a reduced response time.

Resource allocation and sharing are important issues that also need to be addressed, particularly for mobile cloud entities such as vehicles and passenger devices. This mobility can affect the performance of VANET-Cloud applications. An optimal dynamic combination of mobile computing resources can improve the offered service.

Conclusion

In this article, we have proposed a new cloud computing model for VANET called VANET-Cloud. Our proposal is based on two sub-models: permanent and temporary clouds. The VANET-Cloud model consists of three layers. The client layer is formed by different cloud end users. The cloud layer is based on stationary data centers and mobile ones such as vehicular resources. To ensure communication between the client layer and the cloud layer, a third communication layer is proposed.

The proposal provides digital services such as software, computational infrastructures, and platforms to VANET users at a reduced cost. It can also improve road safety by sensing, gathering, and forwarding traffic data from and to vehicles and RSUs to take the appropriate action in undesirable traffic situations such as accidents or congestion. In addition, the proposed model can help vehicles' drivers to satisfy their computing needs (e.g., the execution of safety and non-safety applications, accessing the Internet) while driving. Furthermore, this model provides additional revenues to vehicles' drivers by allocating their onboard computing resources.

VANET-Cloud can support various services, especially road safety services allowing road actors to cope with undesirable road situations such as accidents and collisions. VANET-Cloud

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can also provide several computational services (processing, storage, web services, bandwidth, and others) to end users. Finally, this article has shown that maintaining security and privacy, interoperability, and standardization will become major challenges of VANET-Cloud that should be addressed in the future.

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