Towards Cloud-based Vehicular Networks

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ABSTRACT

Following the Internet of Things (IoT) ideology wherein every device is connected, the time has come to evolve the means of transportation and the infrastructure in order to form the Internet of Vehicles (IoV). With the recent emergence of autonomous vehicles, a growing interest in vehicular networking and its potential is seen. Where first the main focus was to inform drivers about potential safety risks, road conditions and traffic information, the view now has expanded to enable Internet access and implement other applications and services. However, many studies have shown that previous designs of Vehicular Networks (VN) cannot handle extensive usage of additional applications. This paper will focus on the integration of Cloud Computing (CC) in Vehicular Networks (VN) forming a new cloud-based resource-efficient vehicular network; a Vehicular Cloud (VC). This will be greatly beneficial for Intelligent Transportation Systems (ITS) now that they can share computation, storage and bandwidth resources supporting the development of new applications. Modern vehicles are equipped with formidable sensors constantly gathering information about the environment. The VC can help to collect all the individual sensor data which is used in vehicular applications and services for improving safety, pollution control and traffic management. We will describe how a VC is beneficial for improving and supporting different types of applications and services within vehicular networks by presenting VC specific examples. Furthermore, we will compare previously proposed approaches regarding the integration of Cloud Computing in VNs and present a general design for Vehicular Cloud Networking (VCN). Lastly, we discuss the remaining challenges and define future research areas regarding cloud-based VNs.

Keywords

Vehicular networks, Vehicle-to-Vehicle (V2V), Vehicle-to-Infrastructure (V2I), Intelligent Transportation Systems (ITS), Vehicular Cloud, cloud computing

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Table 1. List of acronyms

Acronym	Meaning
AUV	Autonomous Vehicle
CC	Cloud Computing
IaaS	Infrastructure as a Service
ICN	Information-Centric Networking
IoT	Internet of Things
IoV	Internet of Vehicles
ITS	Intelligent Transportation System
MANET	Mobile Ad-hoc Network
MCC	Mobile Cloud Computing
NDN	Named Data Networking
PaaS	Platform as a Service
P2P	Peer-to-Peer
RSU	Road Side Unit
SaaS	Software as a Service
V2I	Vehicle to Infrastructure
V2V	Vehicle to Vehicle
VANET	Vehicular Ad-hoc Network
VC	Vehicular Cloud
VCC	Vehicular Cloud Computing
VCN	Vehicular Cloud Networking
VN	Vehicular Network

1. INTRODUCTION

For the past decade, manufacturers have been trying to make means of transportation smarter in order to provide a safer and more pleasant ride. This has resulted in the integration of many advanced sensors and embedded technologies in modern day vehicles, enabling the ability to sense their environment. Recently, with the introduction of autonomous vehicles, a new emerging trend is noticeable. Following the Internet of Things (IoT) [13] ideology wherein every device is connected, the time now has come to interconnect vehicles, creating the Internet of Vehicles (IoV) [11]. In order to form the IoV, Vehicular Networks (VN) are required to offer a medium where vehicles can communicate with each other.

However, designing and implementing such a VN is challenging. Where first the main goal was to implement applications merely for warning the driver about potential safety risks and providing traffic information, a growing interest has arisen in the integration of numerous other applications and services. Although the integration of more applications and services is desirable, it requires much more from the VNs. Already, many studies have shown that currently existing designs of VNs are not able to handle this increase in vehicular applications. This is because of lacking computing power when solely relying on vehicles alone or due to network overload when simply using cellular technologies for data dissemination [17, 20].

Thus, there is the need for a new VN design which tackles these problems, supporting the integration of new applications and services. This research will focus on the integration of Cloud Computing (CC) in VNs forming a new cloud-based resource-efficient vehicular network; a Vehicular Cloud (VC). Modern vehicles are able to warehouse and process vast amounts of and are equipped with formidable sensors constantly gathering information about the environment. The VC enables Intelligent Transportation Systems (ITS) to share computation, storage and bandwidth resources. This makes it possible to develop new advanced applications and services for improving safety, managing traffic and reducing pollution. In this paper, we will elaborate on several of these application scenarios in which CC performs a major role. By reviewing previously proposed approaches, we present a general design for integrating CC in VNs. Furthermore, we discuss the remaining challenges and define future research areas regarding the concept of a VC.

The remainder of the article is organised as follows. Section 2 states the objective of this research and elaborates on the corresponding research questions. Section 3 states the motivation for this research and explains how VNs could benefit from cloud computing in improving and supporting different types of applications and services. Furthermore, this section envisions several promising applications in cloud-based vehicular networks. In Section 4, we focus on the integration of CC in VNs by investigating the existing VN architecture and the architecture of the Internet Cloud. In Section 5, we perform a comparison of existing approaches and solutions, finding their pros and cons. Section 7 states the challenges and identifies future research areas. The conclusion is presented in Section 8.

2. RESEARCH OBJECTIVE

The objective of this research is to answer the question *How can Vehicular Networks benefit from Cloud Computing and Cloud Networking to improve and support different types of applications and services?* In particular, our research addresses the following research questions:

1. How can Cloud Computing be used to support Vehicular Network services and applications?
2. Is the current Cloud Computing platform design well-suited to support Vehicular Networks services?
3. What are the possible approaches for implementing Cloud Computing in Vehicular Networks?

3. MOTIVATION

The main goal of this section is to illustrate the benefit of cloud-based VNs. We touch upon several important scenarios illustrating various aspects in which the VC is greatly beneficial for facilitating unprecedented applications. Furthermore, we provide an insight into the concept of an intelligent infrastructure and the role of autonomous vehicles.

3.1 Time-space relevant applications

Modern vehicles are equipped with advanced sensing capabilities in order to operate more safely and efficiently. Indistinct vehicles can be seen as large sensor nodes producing immense amounts of data. The generated data shows various classifiable properties. Firstly, data has local validity, meaning that certain data is only valid for a specific geographical area. For example, in safety applications, a speed-warning message for a dangerous intersection is only valid for vehicles approaching that specific intersection. Secondly, data has an explicit lifetime, implying that it is only valid within a certain time frame. Traffic information, for instance, may only be valid for a quarter of an hour while roadwork warnings must remain valid as long as the work is completed. Lastly, there is a data property concerning local interest. This property indicates a more commercial purpose for the data like commercial advertisements of local restaurants or businesses. For example, nearby vehicles want to receive safety messages, however, not every vehicle is interested in commercial advertisements. Therefore, local interest regulates the specific needs of subscribers, providing relevant data.

The VC could help provide accurate and resource-efficient dissemination of the data and offer scalability of data storage, computing power and bandwidth. The time-space validity of the data implies that most data should be stored on the vehicles rather than simply uploading it all to the Internet (Cloud). This stimulates the formation of local VCs in which mostly V2V-communication is used for interchanging data, tremendously sparing the utilisation of cellular networks.

3.2 Traffic management

With roads getting increasingly more congested due to a growing number of vehicles on the road, traffic congestion is becoming a serious problem. The VC could be of great benefit in tackling this issue.

Nowadays, nearly every new vehicle is equipped with an on-board navigation system. These systems are already perfectly capable of deciding shortest routes to given destinations. However, with limited traffic information they are not able to give proper detours when facing traffic congestion. In some cases, these systems will offer a detour but still the driver has to decide whether or not this will actually turn out to be a faster way of getting to the destination. In addition, when many vehicles decide to execute the same alternative route, local roads become flooded with traffic, exceeding their capacity which just leads to additional traffic jams.

When relying on a VC, a well-thought routeing plan can be offered. Essentially, ITS will be able to query the plan of each other and estimate the impact on local roads leading to a better throughput of traffic. In addition, by gathering sensor information of vehicles and roadside units (RSU) close to the root of the problem, an accurate assessment of the cause of the congestion and traffic flow can be made such that it can be resolved quickly.

Furthermore, with real-time navigation applications, the computation resources in the cloud can be used for traffic data mining. Vehicles may offer services surpassing their own computing ability. Opposed to traditional navigation systems, only capable of providing static geographic maps, real-time navigation is able to offer dynamic three-dimensional maps and adaptively optimise routes based on traffic data mining. Going even further on this, it becomes able to initially instruct distinct vehicles to execute other travel plans in order to control traffic flow and most optimally use the road network. By cleverly integrating intelligent infrastructure, digital road signs could be used to guide non-intelligent vehicles to their destination, smoothening the transition to the utilisation of AUVs only.

3.3 Collaborative sharing of sensor data

In contemporary VANET designs, an ITS relies merely on its own sensors. However, in a VC it is possible to take it a step further since a VC provides the ability for distinct vehicles to query sensors of neighbouring vehicles subscribed to the cloud, greatly increasing the accuracy of their own gathered data. For instance, sensors of a specific vehicle may notice loss of traction due to slippery road conditions. When successive vehicles can acquire this information by accessing the sensor data of the vehicle ahead, already they could prepare for the upcoming situation by, for example, reducing their speed.

The previous example is just one application using collaborative sharing of sensor data. It demonstrates vehicles collectively gathering sensor information in order to get a more accurate view of the nearby environment. Though, thinking even broader, this feature empowers the development of numerous unique applications. An application called MobEyes was developed where, vehicles use their sensors to record all surrounding events while driving [16]. Now when a car accident occurs, vehicles that witnessed the accident can autonomously report to the police with feeds of the accident to help the investigation. Not only is this beneficial for law enforcement, but insurance-related issues can be solved more easily since the accident can be closely analysed. CarSpeak [15] is another application that grants access to sensors of vehicles in the vicinity. Without knowing who produced what, the application enables autonomous driving using the collectively produced sensor data.

Collaboration in the sharing and processing of sensor data will be one of the strong assets of AUVs. It allows these vehicles to drive with minimal distance from each other, forming a train of vehicles. This concept will expand the capacity of existing roads and provide better throughput.

3.4 Cooperative data exchange

Some vehicular applications may need to download (large) data files from the Internet. For instance, an entertainment application providing on-demand films/series oftentimes requires downloading large files. Although this could be realised by using cellular networks, it is not desirable since the cellular network can be overloaded if every single vehicle utilises it for downloading. There is a need for a solution which more effectively uses the VANET itself instead of congesting cellular networks.

Luckily, the VC makes it possible to cooperatively download and upload data. For example, if a certain vehicle wants to download a large file from the Internet, it could broadcast this in the VC. In the best case, it can occur that another vehicle in the VC happens to have requested the file before and still has it stored. Now, this vehicle can slice the data in multiple chunks and share it via multiple other vehicles as some sort of P2P application. This way, only V2V is utilised for spreading the data. When the vehicle that requested the data received all the chunks, it can reassemble it to build the complete file.

However, it is also very likely that the requested file is not yet present in the VC. Then it needs to be downloaded from the Internet first. Though, with the presence of RSUs, it is preferable to acquire the data through RSUs instead of using cellular communication. Depending on the size of the data, an RSU or multiple RSUs could download it from the Internet. Again, by splitting the data into multiple chunks, for efficiency, an RSU can contact multiple vehicles in the vicinity to download the chunks. Now the original data is scattered over multiple vehicles in a VC. Through V2V communication, each chunk can be delivered to the vehicle that requested the data after which the vehicle can reassemble it again.

So, in this way, cellular networks are spared and downloading becomes much more efficient. Furthermore, if vehicles cache the data chunks, the next time another vehicle demands the data, it will be already present in the VC providing quick access. A framework for secure cooperative data downloading in VANETS is proposed in [14].

3.5 Disaster evacuation management

In cases of predicted disasters, such as hurricanes and tsunamis, massive evacuations are often necessary to make as many people as possible are outside the danger zone before disaster strikes. In such situations, the VC can be very helpful in providing coordinated evacuation routes. Vehicles involved in the evacuation will self-organize into one or several interoperating vehicular clouds that, together with emergency management centres, can provide people that need to evacuate with all the necessary information. For example, the vehicles can indicate their occupants where to find shelter, food, medical attention etc.

Especially AUVs will be extremely helpful in evacuations. They are able to follow collectively decided evacuation routes at high speeds with limited distance from each other. This will stimulate the traffic throughput and prevent large traffic jams and accidents caused by stressed drivers. The VC together with AUVs will be significant assets in improving evacuation management, immensely decreasing the number of possible casualties.

4. TOWARDS THE VEHICULAR CLOUD

In this section, we briefly explain the concept of a Vehicular Cloud. By looking at the VANET architecture and the ordinary Internet Cloud platform, we illustrate how the cloud platform could be integrated into VANETS in order to create a Cloud-based VANET.

4.1 Ordinary VANETs

A VANET basically is a network of moving vehicles (and fixed RSUs) in which multipurpose data is interchanged, originally developed with the general goal of improving safety on the roads [23]. In principal, there is no fixed architecture or topology that a VANET must follow. VANETS are a particular class of MANETS [3] where the main difference is that vehicles do not move randomly as nodes do in MANETs. Normally, vehicles follow fixed paths by using the network of roads and highways.

So the main purpose in VANETS is to establish communication between moving vehicles. Roughly, communication can be arranged in a few ways. V2I is one way in which vehicles contact each other via RSUs. Basically, each RSU functions as a wireless access point to where distinct vehicles can connect. Another possibility is that vehicles directly communicate with each other by setting up a multi-hop ad-hoc network. In this way, there is no need for a third party (RSU) for establishing a communication channel. Furthermore, vehicles could utilise cellular networks (LTE, UMTS) for contacting each other [24]. However, this solution requires a general server to which vehicles can connect. Lastly, there are hybrid solutions which mainly are combinations of the before-mentioned technologies.

4.2 Cloud Computing

The adoption of Cloud Computing initiated when businesses started to realise that instead of investing in their own infrastructure, it oftentimes is economically more interesting to rent infrastructure whenever there is the need [9]. Cloud Computing can be described as [19]:

> *"A model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction."*

Cloud services can be subdivided among three basic delivery models as shown in the following three subsections.

4.2.1 Software as a Service (SaaS)

This model offers consumers (either individual or enterprise) applications running on a cloud infrastructure. The applications are accessible from various client devices through different user interfaces. In this model, the consumer does not manage or control the underlying cloud infrastructure.

4.2.2 Platform as a Service (PaaS)

Instead of installing development tools/software on host computers, this service delivers the development environment as a service to the consumers. Mostly used by enterprises, this service allows them to build their own applications by providing a development platform. Again, the consumer does not manage or control the underlying cloud infrastructure but has control over the deployed applications and possibly configuration settings for the hosting environment.

4.2.3 Infrastructure as a Service (IaaS)

Instead of offering applications or environments, in this model, a consumer is granted access to physical resources. They can rent processing, storage, networks, and other fundamental computing resources on which the consumers then deploy and run arbitrary software (both application and system). Consumers have virtually unlimited resources according to their budget. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, and deployed applications and possibly limited control of select networking components.

4.3 Vehicular Cloud

As explained in Section 3, the Vehicular Cloud is able to revolutionise VANETs by enabling cooperation among vehicles, giving the opportunity to integrate numerous advanced applications and services. In this subsection, we describe how Cloud Computing is applied in VANETs and explain that a new way of networking is needed. Furthermore, we elaborate on the cloud resources and their interoperations. In general, a vehicular cloud can be described as [22]:

> *"A group of largely autonomous vehicles whose corporate computing, sensing, communication and physical resources can be coordinated and dynamically allocated to authorized users."*

4.3.1 Vehicular Cloud Computing

In 2012, Vehicular Cloud Computing was introduced as a way to implement CC in VANETs [10]. VCC is a variant of Mobile Cloud Computing (MCC) [8], based on a conventional cloud computing model. In both the CC and MCC architecture, a physical data centre is in charge of performing the data computation and storage [5]. In VCC, however, the virtual aggregated resources of all participating vehicles combined with RSUs generate the data centre cloud [10]. VCC enables the exploitation of excess computing power and storage. For example, every day, many vehicles are just stationary parked in driveways or parking lots performing no actions whatsoever. In VCC however, these vehicles actually can play a huge role since they are simply underutilised computational resources with vast storage capabilities. With VCC, entire parking lots can function as pop-up data centres, accessible for authorised users and applications. The same holds for traffic jams as instantly a local cloud could be formed to find a quick resolution or schedule alternative routes.

Since it is too costly to upload every content to the Internet cloud and too time-consuming to search and download interesting contents from the Internet cloud, the ability to instantaneously and autonomously form Vehicular Clouds will play an enormous role in the success of Vehicular Cloud Networks [6]. As mentioned earlier, since the contents sensed by vehicles mostly have local relevance they could be best stored on the vehicle(s) itself. In VCC, most queries are interested in the approaching environment. Therefore, vehicles (and RSUs) ahead are the best probes. VCC resolves the queries using a self-organized model of the local environment. That is, vehicles effectively form a cloud within which services are produced, maintained, and consumed.

4.3.2 Information-Centric Networking

For data in vehicular applications the main interested in the content itself, not its origin. This memoryless property of data is characteristic for VANETs. In contrast to browsing the internet where explicit URLs are translated to IP addresses to locate and gather content from a specific server, vehicle applications broadcast their interest for certain information to a local area (the VC) and not to a specific vehicle. Vehicles accept responses regardless of the identity of the content providers. In fact, a vehicle in the vicinity might respond with the data to a request which has, in turn, received the information indirectly through other neighbouring vehicles. In this case, it is not interesting to know the source since only the content is relevant. This property exists considering vehicles are constantly on the move and geographically scattered.In vehicular applications the main interested in the content itself, not its origin. This memoryless property is characteristic for VANETs. In contrast to browsing the internet where explicit URLs are used to gather content, vehicle applications flood query messages to a local area, not to a specific vehicle, accepting responses regardless of the identity of the content providers. In fact, a vehicle in the vicinity might respond which has, in turn, received the information indirectly through other neighbouring vehicles. In this case, it is not interesting to know the source since only the content is relevant. This property exists considering vehicles are constantly on the move and geographically scattered.

Information-Centric Networking (ICN) [1] was initially designed to achieve efficient content distribution on the Internet, yet, it is very useful in (cloud-based) VANETs. ICN focuses on what (content) instead of where (host). By using named data objects instead of IP addresses, ICN ensures the acquisition of relevant data without recognising its origin. An architectural implementation of ICN called Named Data Networking (NDN) [8] has already been extended to vehicular networks [18, 26, 30]. NDN uses two two types of packets for identifying interest and providing data, where the content name of these packets is used for routeing. Vehicles can reply to requested data by reversing the interest path. NDN allows routers on the path to cache content such that requests can be answered more quickly. This way, NDN realises effective content distribution in VCC, essential for proper functioning of vehicular applications and services.

4.3.3 Cloud Resources

A VC is designed such that advanced services and applications can be provided by cooperatively sharing resources amongst cloud members. A VC is momentarily formed by interconnecting vehicles and Road Side Units (RSUs) differing from the conventional Internet cloud which is created and managed by a cloud provider. With VCC and ICN combined, vehicles are able to construct a cloud and control the virtual platform resembling the combined resources of the cloud members. Vehicles are equipped with data storage, sensors, and computing power and store contents generated by their own applications and sensors as well as traditional multimedia files. Data sharing among cloud participants is possible by replying with the content to external search queries. Sensors constantly sense the environment in an autonomous way. They can be read and controlled by external systems via the VC, complying with the IoT model wherein everything is connected.

Resources in the VC are linked plainly via peer-to-peer connections, meaning that vehicles reciprocally negotiate the matter of resource sharing. Performance wise, it could be that one vehicle (or an RSU) in a cloud is appointed to function as a mediator in the process of resource sharing and additional cloud operations.

5. EXISTING APPROACHES

In this section, we discuss previously proposed Cloud-based vehicular networks. Since solutions differ, we try to determine the differences in their approach to integrating the Cloud in VANETs. Furthermore, we will give the main ingredients for designing and implementing a Vehicular Cloud Network to give some sort of general guidelines for a VCN. In the following subsections, we highlight the aspects wherein approaches differ and elaborate on certain fundamental components.

5.1 Envisioned Cloud Resources

The most outstanding difference in the approaches to integrate CC in VANETs is the focus on the type of Cloud resources. For example, in [6], the authors see the underutilised resources in the Vehicular Network to supplement the conventional Internet Cloud while the authors of [10] envision the vehicles to form a self-sufficient Vehicular Cloud. The question here is whether or not the resources in a cloud purely consisting of vehicles collectively posses sufficient processing power and storage to support all related applications. When this is the case, then it would be the most resource-efficient solution since it is making most optimal use of already available resources.

Nevertheless, when it is not possible to solely rely on vehicles alone for accommodating the storage capacity or computing power needed for certain applications, it is still possible to address to the Internet Cloud for performing these more complex tasks. Basically, this creates a hybrid solution by utilising both the Vehicular Cloud and the Internet Cloud where mostly exhausting the Vehicular Cloud in order to make most optimal use of available resources and sparing the use of cellular networks for communication with the Internet Cloud.

5.2 V2I or V2V

Closely related to the previous subsection is the variation seen in V2I and V2V communication. Not surprisingly, when imagining a self-generated VC, most interaction takes place between the vehicles forming the cloud, thus, V2V communication has the main focus. However, when using the Internet Cloud instead of combining vehicles into a spontaneous cloud, naturally, V2I communication would be extensively used for approaching the cloud through RSUs. Hence, the presence of RSUs is more important when envisioning vehicles as an extension to the Internet Cloud since it requires connections to the Internet. It is preferable that RSUs provide this connection since cellular networks will not be able to provide accurate transfer of data, as mentioned earlier.

Then again, when a hybrid solution is implemented, both V2V and V2I communication are needed. Yet, in such a situation, the main focus is still on V2V communication.

5.3 Vehicular Cloud Specific Services

Where in the traditional Internet Cloud Saas, PaaS and IaaS are offered, new additional services are emerging in Vehicular Clouds. In [27], the following services are suggested: Network as a Service (NaaS), Storage as a Service (STaaS), Cooperation as a Service (CaaS), Information as a Service (INaaS), and Entertainment as a Service (ENaaS). In the following subsections, we will briefly explain these services.

5.3.1 Network as a Service (NaaS)

For certain applications in VCs, connection to the Internet is required. Connections can be established through mobile phone networks or other fixed access points (RSUs). Although some cars may have Internet access, not every car has this privilege. When fixed access points are not available, neighbouring vehicles with the ability to access the Internet could provide a connection for the vehicles not capable of doing this. Basically, vehicles agreeing to share this resource can advertise such information among all other vehicles to function as an access point.

This idea to share underutilised connection resources can also be extended to mobile devices (laptops, tablets, mobile phones). These essential resources can be shared on the road by offering Internet access to those who are interested in renting it from others.

5.3.2 Storage as a Service (STaaS)

Since already storage is easily available, meaning the inexpensiveness and compactness of storage, it is expected that vehicles will warehouse multiple terabytes of data. However, in a VC it can still occur that applications on certain vehicles exceed their own storage capabilities and require additional storage space to function properly. Hence, it is desirable that in a VC, vehicles with superfluous storage can account for vehicles needing extra space [2].

Due to the ever-changing topology of a VCN, SaaS is different from offering network access or computing resources. Persistence of data in local VCs is a real obstacle for the implementation of SaaS, especially in p2p applications [22]. Therefore, a technique like replication-based storage needs to be applied, making sure multiple copies of the original file are persistent within the VC on different vehicles. This increases the availability and reliability of data and solves the issue with untrusted storage or with vehicles leaving the VC [4].

5.3.3 Cooperation as a Service (CaaS)

Introduced by [21], CaaS provides several free services without requiring any additional infrastructure, by exploiting the advantages of VCC. In CaaS, a vehicle expresses its interests by subscribing to a certain service or a set of services within the network. By publishing service-specific information in the network, subscribers cooperatively share necessary data regarding the application. By subdividing the network into clusters, CaaS uses Content Based routeing (CBR) for intra-cluster communications and geographical routeing for inter-cluster communications [2].

5.3.4 Information as a Service (INaaS)

For applications in the VC, vehicles often need some sort of information. This can be information regarding traffic, sensor data, emergency situations, accidents etc. In order to guarantee the proper functioning of applications and services, this information needs to be shared constantly. IaaS can be recognised as a term covering the publishing of information in VCNs stimulating safe and efficient driving.

5.3.5 Entertainment as a Service (ENaaS)

With vehicles being able to drive autonomously, it becomes possible to give the passengers (especially the driver) a more comfortable and enjoyable journey by providing onboard entertainment. When considering ENaaS, one can think of live television, films/series on-demand, commercials, web browsing etcetera, all accessible in the vehicle itself.

6. VEHICULAR CLOUD NETWORKING

By analysing many studies and investigating their proposals for implementing VCN, we found a general distinguishment in cloud components within VCN. As described in [29], we subdivide the cloud in VCN into three separable clouds; Vehicular Clouds, Roadside Clouds and the contemporary Internet Cloud. In the following subsections, we will define each of the three cloud components and describe their formation.

6.1 Vehicular Cloud

The Vehicular Cloud is local cloud exclusively formed by vehicles through V2V communication. As stated in [27], a VC is either formed stationary or dynamically. With the former, the VC acts as a normal conventional cloud. This especially happens in static environments like parking lots or garages. As mentioned earlier, these places could act as a spontaneous data centre in which participating vehicles share their onboard resources. On the road, the formation occurs dynamically since vehicles are constantly joining and leaving the local VC.

In the latter case, one vehicle will be selected as a broker (or cloud leader) to negotiate between the vehicles forming the cloud. A VC is a self-maintaining environment in which the cloud leader plays an important role in assigning tasks within the cloud. The authors of [12], present a case study in their paper explaining a VC scenario. They provide a clear overview of the steps taken in VCs regarding the discovery, formation, maintenance and release of the cloud, and indicate the role of the cloud leader within these steps.

However, instead of using a vehicle as cloud leader in dynamic formation, it is also possible to introduce a cloud controller that is responsible for the creation, maintenance, and deletion of a VC [29]. With respect to resource management, this design is similar to a conventional cloud deployment strategy in which cloud resources are scheduled by a controller. Opposed to the situation described above, in this case, a vehicle is not aware of the cloud members and their tasks.

In terms of resource utilisation, the latter solution is able to globally schedule and allocate all resources of a vehicular cloud. It has higher resource utilisation than the first implementation in which a cloud leader is appointed. However, the operations of the cloud controller will need extra computation and connections through either RSUs or cellular communication. Therefore, a self-maintaining vehicle cloud may be more efficient than a VC with a cloud controller due to lower system overhead.

6.2 Roadside Cloud

A roadside cloud is composed of two main parts: RSUs and dedicated local servers. The dedicated local servers virtualise physical resources and act as a potential cloud site. RSUs provide radio interfaces for vehicles to access the cloud. An RSU only has limited radio coverage, therefore, it can only provide access to nearby vehicles, meaning, those located within the radio coverage area of the RSU.

The authors of [29], propose the concept of a roadside cloudlet. A cloudlet is a trusted, resource-rich computer or cluster of computers that is connected to the Internet and is available for use by nearby mobile devices [25]. A roadside cloudlet refers to a small-scale roadside cloud site that offers cloud services to bypassing vehicles. A vehicle can select a nearby roadside cloudlet and customise a transient cloud for use. Here, they call the customised cloud a transient cloud because the cloud can only serve the vehicle for a while. After the vehicle moves out of the radio range of the current serving RSU, the cloud will be deleted and the vehicle will customise a new cloud from the next roadside cloudlet in its moving direction.

6.3 Conventional Internet Cloud

The Internet Cloud, as present today, is still of great benefit when extended to VCN. Compared to a VC or a roadside cloud, the Internet cloud has much more resources. The Internet Cloud is mainly used for complicated computation, massive data storage, and global decision and is accessible through either RSUs, WiFi access points or cellular communication. Opposed to VCs which are spontaneously created, the Internet Cloud is always persistent, thus, able to run applications and services constantly. Furthermore, the Internet Cloud can function as a collecting organ combining all the data gathered in multiple VCs.

There will appear applications which are not directly interesting for vehicles themselves but are intended for municipalities or environmental organisations. For example, road monitoring is of great interest for city councils such that they can proactively react to provide better infrastructure conditions. Such applications oftentimes require the collectively gathered information of vehicles' sensors leading to huge amounts of data. Therefore, the Internet Cloud is better suitable for running these kinds of applications than the VC since it requires data mining on large data sets and the information is not really of common concern among vehicles themselves. Thus, in the situation illustrated here, vehicles (and VCs) function as data providers and the Internet Cloud as the data consumer.

6.4 Proposed VCN Design

Now, after having compared many different approaches, we combine their best aspects and come up with a general design for Vehicular Cloud Networking; the integration of cloud computing in VANETs. Figure 1 visualises the design. We see that the design is a compound of features explained by the previous subsections. As explained in the previous subsections, the VCN design consists of three different cloud types; vehicular clouds, roadside clouds and the internet cloud.

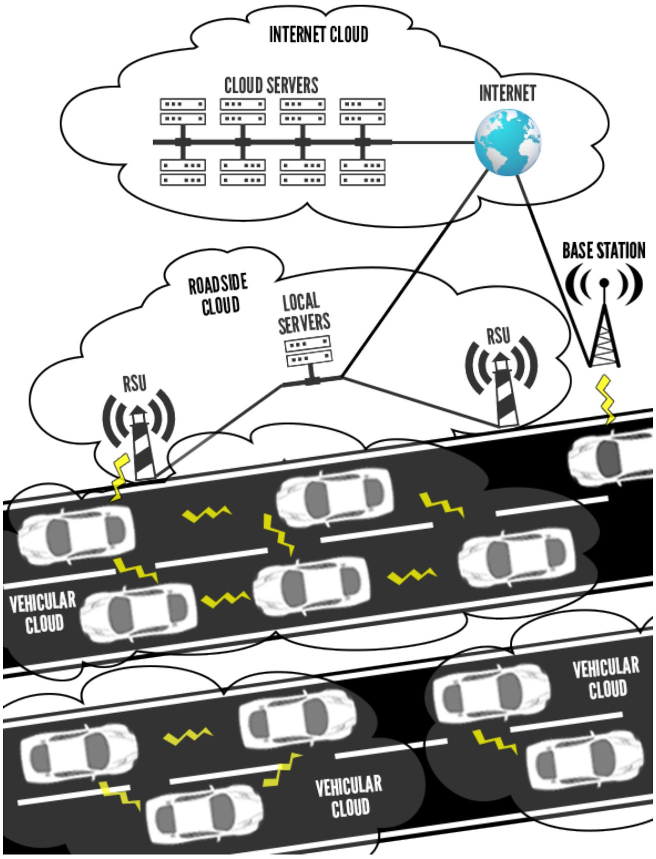

Figure 1. Vehicular Cloud Networking design.

In this design, vehicles cooperatively form their own self-maintaining vehicular clouds. Through roadside clouds, formed by RSUs and their local servers, vehicles are able to connect to the Internet. Furthermore, RSUs can provide vehicles from relevant data regarding their nearby surroundings. As seen in figure 1, the Internet cloud can be reached by connecting to the Internet either through RSUs or via base stations, hence using cellular communication.

The proposed general design has several essential advantages. Firstly, the architecture fully utilises the physical resources in an entire network. This means that the computation and storage resources from vehicles, roadside infrastructures and data centres are all merged into the cloud and, when needed, accessible for all vehicles. Secondly, the hierarchical nature of the design allows vehicles using different communication technologies to access different layers of clouds accordingly. Hence, the architecture is flexible and compatible with heterogeneous wireless communication technologies such as DSRC, LTE, WiFi and CR technologies. Lastly, the VCs and the Roadside Clouds are small-scale local clouds which can be instantaneously and spontaneously formed to provide services quickly.

7. CHALLENGES & FUTURE RESEARCH

The applications discussed in Section 3 require better V2V and V2I collaboration and seamless interaction among the cyber-physical elements in the VCN design. This will allow the system to reach critical and mutually beneficial decisions and effectively manage the highly dynamic nature of computing, communication, sensing and physical resources.

This aim of this research was to provide an understanding of the concept of Vehicular Cloud Networking which still remains an active area of research. In this section, we review the challenges that the concept of VCN still faces. Included are issues indicated by previous papers that, nevertheless, still remain unsolved and need further research. It must be noted that the research challenges are not limited to only these indicated areas.

7.1 Architectural challenges

Architectural challenges involve concerns regarding the formation and structure of VCs and the interactions with physical resources. Hence, it is vital to have an accurate self-maintaining set-up that should be able to cope with the frequently changing habits of a VC. Furthermore, a VC should be capable of handling individual vehicle aspects such as changes in interest or location, resource failure and denial. The following subsections will elaborate on some of these issues.

7.1.1 Adaptive architecture

One of the main characteristics of a VC is the fluctuating number of nodes present in the cloud. Constantly, this directly affects the available computational capabilities and storage resources. This behaviour can endanger the availability of cloud resources and lead to collaboration failures. Therefore, a management system using a cloud subscription mechanism is needed to cope with the dynamically changing connectivity in order to minimise the impact the provision of services and applications.

For instance, when a vehicle leaves the cloud, another vehicle (or a set of vehicles) needs to be selected to account for the services it has provided. Another option could be to combine two VCs in order to provide sufficient resources. As explained in 6.1, this responsibility can be administered by a cloud controller (in the Internet Cloud) or a cloud leader (in the VC). However, for handling frequently varying resource availability on the move, in both cases, the necessary architecture and associated protocols must be developed.

7.1.2 Robust architecture

The fundamental building blocks and structures that compose a VC should be engineered and designed to withstand structural stresses induced by the inherent instability in the operating environment. Research is necessary for the development of architectures enabling vehicle visualisation and migration of virtual vehicles.

7.1.3 Service-oriented network architecture

Contemporary layered network architectures, for example the TCP/IP stack, are not sufficient for supporting ongoing evolving technologies and applications in VNs. Hence, envisioned is the adoption of service-oriented component-based network architectures with intrinsic monitoring and learning capabilities to cope with reusable and extensible applications and resources [7].

7.1.4 Infrastructure failure recovery

In autonomous driving applications, vehicles heavily depend on the infrastructure (e.g., WIFI access points, DSRC RSUs, and LTE) for gathering all the necessary information needed to get a complete overview of their surroundings. In the case of a major infrastructure failure caused by an earthquake, for instance, some of these functions must be taken over by human drivers. However, there is a vital transition period, between when a massive infrastructure failure occurs and when the human takes over of navigation. In this critical period, an AUV should be able to safely guide the transition and prepare its driver. After the disaster, AUVs have lost knowledge of the neighbours beyond the reach of their own sensors. Therefore, it is extraordinarily important that V2V propagation of traffic conditions and important information is still supported in such a situation. This will allow AUVs to make intelligent routeing decisions (to avoid obstacles or blocked roads in case of earthquakes) so that the human drivers can progressively take over with confidence.

7.2 Operational & Policy challenges

7.2.1 *Trust Assurance*

In some situations, in order to be effective at cooperative problem solving, a VC may need to have designated authority to take local action normally requiring a central authority. For instance, when a traffic jam occurs, sometimes rescheduling traffic lights will lead to better traffic throughput. However, this requires a cooperation between the VC and municipal or county authority in order to promote the rapid dissipation of congestion. Hence, the existence of a trust management in VCs can be useful for automated verification of actions.

7.2.2 *Effective Operational Policies*

In order for VCN to operate and interoperate seamlessly, broad participation is needed, requiring local, state or even federal decision makers. Effective operational policies are needed to establish accountability metrics, assessment and intervention strategies, rules and regulations, standardisations and so forth.

7.2.3 *Economic aspects of VCN*

There is a need for the establishment of economic models and metrics to determine reasonable pricing and billing for VCN services. This is particularly difficult since not only corporate cloud providers in the Internet Cloud are present but every participating vehicle in a VC basically provides services by allowing access to its resources.

7.3 Security and privacy

Security and privacy are critical aspects for establishing and maintaining the trust of users in VCs. Privacy measures are required to ensure VC communication and information in an isolated and trustworthy environment, while security procedures are needed to protect against network threats such as man-in-the-middle and Denial-of-Service attacks. Establishing trust relationships between participants in VCN is essential for guaranteeing trustworthy communication and computation.

One of the main security challenges within VCs is verifying the authentication of users and the integrity of messages due to the high mobility of participating nodes. Another important issue is ensuring the confidentiality of sensitive messages. This can be realised by using cryptographic algorithms. Ensuring secure location and localisation are extremely important aspects in VCN since in most vehicular applications accurate location information is crucial. Furthermore, providing data isolation to ensure the security of stored data in the cloud is an important challenge. Lastly, secure data access needs to be implemented to protect stored data in the cloud against unauthorised access. Many of these security issues have been addressed [28], however, research is still required to solve these problems.

8. CONCLUSION

The main goal of this paper was to put forth a novel concept of cloud-based vehicular networks by integrating cloud computing in contemporary VANETs. We explained several interesting application scenarios and proposed a general architecture. The types of clouds and their formation have been identified and discussed. Furthermore, we elaborated on the security and privacy issues VCN is facing. Yet, a number of areas still remain unexplored for researchers including the robust design of the whole VCN system entrenching it to withstand attackers but also provide reliability and stability within the network.

Future research is required to create VCN reference models, protocols, and architectures for addressing evolving trust and privacy issues. Consequently, a collective effort and collaboration among the automotive industry, researchers and the government are needed to surmount these challenges. So, cloud-based vehicular networks can be the next technological shifting paradigm that provides technologically feasible solutions stimulating autonomous and cooperative driving by revolutionising the means of transport.

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