Abstract: Vehicular Cloud Computing (VCC) adapts from the fact that Vehicular Nodes can use their on-board Computational power, Storage and Communicational resources to interact with the Cyber-Physical elements possible in ways as never before. Through this survey we identify Vehicular Cloud Computing as an essential stepping stone towards visualizing the Internet of Vehicles (IoV) ecosystem to integrate Mobile Adhoc Networks, Wireless Sensor Networks, Mobile Computing and Cloud Computing. We provide an in-depth classification on the state of the art of Vehicular Cloud computing by drawing a relationship between the existing domains and Internet of Vehicles through a review of the works carried recently in literature. We compare and contrast Vehicular Cloud Computing with other similar fields to gain a better insight of the subject. Finally we present the open issues and challenges that need the utmost attention in realizing tomorrow’s cyber-physical systems.

Keywords: Internet of Things; Internet of Vehicles; Vehicular Cloud Computing; Mobile Cloud Computing; Vehicular Ad hoc Networks; Wireless Sensor Networks; Cloud Computing; Mobile Computing;

1 Introduction

Vehicular Cloud Computing (VCC) can be seen as a combination of two paradigms i.e., one from the Vehicular Network point of view and another from Cloud Computing point of view. The Vehicular Ad hoc Network (VANET) primarily adapts from Mobile Ad hoc Networks (MANETs) where communication among the nodes is of prior importance and is generally single hop or multi hop based. In context of VCC this can be termed as Vehicular Cloud Communication. This component is aimed to assist and improve the intelligent transport systems. The Cloud Computing perspective of the VCC
model adapts from Mobile Cloud Computing where the primary concern is to access the all business services provided by remote Infrastructural-Cloud in a way similar access to the telecommunication and other data based services. This can be termed as Vehicular Cloud Computing.

A hybrid of the above models can be a cloud computing model that oscillates between being a pure Vehicular Cloud or semi-Vehicular Cloud which can executes jobs in a similar fashion to a conventional cloud providing “as a service” models. This is not possible in case of mobile devices like smart-phones or other sensing devices that have battery life and limited communication range. This works contribution is significantly different from Whaiduzzaman et al. in [15] due to the fact that through this survey we identify Vehicular Cloud Computing as an essential stepping stone towards visualizing the Internet of Vehicles (IoV) eco-system to integrate Mobile Adhoc Networks, Wireless Sensor Networks, Mobile Computing and Cloud Computing. Furthermore we envision Vehicular Cloud Computing as a supplement to Conventional Cloud Computing. Finally the VCC model also resembles the Wireless Sensor Networks due to a plethora of sensors on-board of the vehicular nodes.

Figure 1. Technologies contributing towards Internet of Vehicles

2 The relation between Vehicular Cloud Computing and Internet of Vehicles
The concept of Internet of Vehicles is an integral part of Internet of Things. Cloud Computing is seen as to fuel the infrastructure that runs the Internet of Things [1]. The evolution to internet of Things will never see the day unless a collective effort by forums across the globe let be political, industrial or academic which otherwise at least will result into a non-standardized, inefficient system. The Global vision of a Green World can come true if the components in the Internet of Things are glued seamlessly with consideration to the Global attributes of a healthy environment.

The Vehicular Cloud Computing model is proposed to enable the interaction of vehicular nodes with the environment i.e. roads, residential buildings, market places etc., through a collection of sensors that can gather useful information which can be utilized to build an efficient part of the eco-system that constitutes the Internet of Things i.e. The internet of Vehicles. The sort of information gathering will not be possible through other means which are both uneconomical and impractical. This natural extension of the vehicular networks to use the Cloud based service offerings can help in exhaustive information gathering, analytics and computations to evaluate the socio-environmental effects of the Internet of Things.

Vehicular Cloud Computing should not be seen just to complement and improve the Intelligent Transport Systems (ITS) but its far reach to cater across various walks of life makes it a potential candidate for modeling the tomorrow’s cyber-physical system i.e. The Internet of Things. In literature primarily Vehicular Cloud Computing has always been implied for enhancing road safety, driving assistance and infotainment services. But apart from these Authors have indicated its value in carrying out tasks to improve social security, energy efficiency and other areas. We present a chronological survey of the efforts towards building a platform for the future IoV eco-system. This work presents the survey of issues and challenges in Vehicular Cloud Computing with a perspective of Internet of Vehicles to explore its impact on eco-system of the Internet of Things.

Figure 2. Applications and Service domains where Vehicular Cloud Computing contributes towards Internet of Vehicles

3 The emergence of Vehicular Cloud Computing
The modern day vehicular networks need to evolve into tomorrow’s internet of vehicles through a substantial transformation in three different directions namely Client-Connection-Cloud [3]. The client
component represents the resources inside a vehicle that can locally store, compute and disseminate useful information to the surroundings. The Connection models the Communication technologies to be used as a medium for information interchange primarily between the Clients. The Cloud system provides the infrastructure needed for performing the heavy duty operations that cannot be fulfilled by the constrained resources available inside the vehicle. It also connects the Vehicular eco-system to the components of the Internet of things paradigm. The concept of Vehicular Cloud Computing borrows its architecture from Mobile Cloud Computing [4].

![Architecture of Vehicular Cloud Computing based on Mobile Cloud Computing, adapted from [14]](image)

### 3.1 A Comparison of Cloud Computing, Mobile Cloud Computing and Vehicular Cloud Computing

<table>
<thead>
<tr>
<th>Feature</th>
<th>Cloud Computing</th>
<th>Mobile Cloud Computing</th>
<th>Vehicular Cloud Computing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supports Mobile Resources</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Battery Constrained</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Locality of Processing of computationally intensive tasks</td>
<td>Local and Remote both</td>
<td>Remote</td>
<td>Local and Remote both are possible</td>
</tr>
<tr>
<td>Computational Power</td>
<td>Highest</td>
<td>Low</td>
<td>Medium sized</td>
</tr>
<tr>
<td>Network Architecture</td>
<td>Client-Server based</td>
<td>Client-Server based</td>
<td>Peer to Peer as well as Client- Server based</td>
</tr>
</tbody>
</table>
4 Modeling Vehicular Cloud Computing

4.1 The need for a Vehicular Global ID

[3] Proposed the idea of a vehicular global ID (GID) which helps to integrate the on-board sensors and the Controller-area network (CAN). It functionally provides Ubiquitous and converged communication, online vehicle IDs and Intelligent perception. Though the applications of using GID are far beyond thought the absence of global standards across the Vehicular industry is a real barrier. The other issues referred by the author include need for converged V2V and V2I communication technologies, Open CAN bus architecture, precise vehicle position measurements, need for IoV standards and modeling of IoV operations. IOV is envisioned as one of the first practical large-scale cloud IoT applications [3]. The potential of on-board units to be self sufficient devices for communication was of little consideration initially. The author highlighted the benefits of using a Cloud enabled VANETs (CeV) model and an architecture was proposed for the same. It does not highlight the other variations such as Vehicular Cloud or VANET enabled Cloud (VeC).

4.2 The Autonomous Vehicular Clouds

[5] Proposed the autonomous vehicular clouds as “a group of largely autonomous vehicles whose corporate computing, sensing, communication and physical resources can be coordinated and dynamically allocated to authorized users”. These autonomous vehicular clouds are seen to serve users with resources like storage carried by the Vehicular nodes through integration with the remote infrastructure based service offerings paradigm, the cloud computing. The author exemplifies the applications of autonomous vehicular clouds in Traffic management, assessment management and other fields. The proposed work foresees vehicular resources as to a supplement to conventional Cloud based offerings.

4.3 A True Vehicular Cloud

Authors in [6] classified mobile clouds as either be Mobile Vehicular cloud, mobile personal clouds and mission oriented mobile clouds. The research challenges pointed for mobile clouds include Privacy and security protection, Sensor filtering and aggregation and Content-based, secure networking. The Mobeyes system [16] an Internet connected mobile vehicle cloud to provide safety monitoring related services using vehicles fitted with cameras was selected to present a proof of concept for vehicular cloud computing. The information carried by the nodes of this system can be traced using protocols designed specifically for vehicular network. Using the example of the traffic management assistance through vehicular clouds the author reveals how timely updated information can be exchanged between Mobile Vehicular Cloud and a central navigation center over internet.

4.4 A Comparison of models for Vehicular Cloud Computing

The important differences between the VCC proposals of Olariu et al. and Gerla et al. is that the former foresees the under-utilized resources in the Vehicular Network to supplement the conventional Cloud based offerings while the latter envisions the Vehicular Nodes to form a self sufficient
Intelligent Vehicular Grid. Also Olariu et al. maintains the use of vehicle to infrastructure communication as a prominent feature for VANET enabled Cloud whereas Gerla et al. identified inter-vehicular communications to be upmost importance.

<table>
<thead>
<tr>
<th>Feature</th>
<th>VANET enabled Cloud</th>
<th>Vehicular Cloud</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed by</td>
<td>Olariu et al.</td>
<td>Gerla et al.</td>
</tr>
<tr>
<td>Idea</td>
<td>Conventional Clouds using In-Vehicular resources</td>
<td>Intelligent Cloud using In-Vehicular resources</td>
</tr>
<tr>
<td>Prominent Communication technology</td>
<td>Vehicle to Infrastructure</td>
<td>Vehicle to Vehicle</td>
</tr>
<tr>
<td>Layer of Cloud Computing supplemented</td>
<td>Infrastructure and Data Center Layer</td>
<td>Service, Infrastructure and Data Center Layer.</td>
</tr>
</tbody>
</table>

Table 2. Comparing VANET enabled Clouds and Cloud enabled VANETs

4.5 Cloud on the Run for Computing
[7] Proposed Ad hoc cloud network architecture and named it as “The Cloud on the run” to support traffic control structure through two models namely NaaS and SaaS based on ideas from [Stephen olariu]. The authors suggest Vehicular Clouds as better tools than inductive loop detectors used by the traffic department that are too costly for deployment. The issues highlighted are Security of the cloud networks, Mobility of the nodes, Signal Fading and Network Scalability.

4.6 Smart Transportation and IoT
The authors in [8] included smart transportation to be an important part of IoT and listed the important issues and challenges as privacy, participatory sensing, data analytics, GIS based visualization, Cloud computing architecture, Energy efficiency, security, protocols, and Quality of Service.

4.7 Internet of Freight Vehicles
In [8] the authors proposed an Internet of freight vehicles for the purpose of real-time communication and active safety monitoring. The system was interconnected to the back end monitoring center using GPRS technologies. It uses a 4 layer communication protocol stack. It provides various services by using the sensors installed on the vehicle and the mobile phone number being the identifier for the onboard sensor. This system can be classified as a Cloud enabled VANET using cellular communications.

4.8 The Vehicular Cloud for content sharing
The work in [5] addressed the content delivery and request forwarding issue in Vehicular networks assuming the clustered structure of the vehicle platoons as Vehicular Cloud which can share data when vehicle to Infrastructure communications is unavailable. Vehicular nodes are able to find...
distance to other nodes using the distance travelled field in the packets received. The findings of the study reveal that Content Centric Networking improves response time with slightly high traffic generation. The results are compared for raw flooding, Content Centric routing with Bloom filter routing. As known earlier bloom filtering performs better than raw flooding. But Content Centric routing generates more traffic.

4.9 The Vehicular Cloud networking model

[7] Puts forward the concept of vehicular cloud networking built on top of Vehicular cloud computing and information centric networking due to the specific sensing and sharing characteristics of VANETs. It identifies the properties specific to vehicular cloud computing like Application content, time-space validity, Content-centric distribution and Vehicle collaboration sharing sensory data from nearby vehicles. This new model can address the needs of Vehicular networks in a more efficient way compared to traditional IP based mechanism. It highlights the benefits of both VCC and ICN.

4.10 Internet of Electric Vehicles

[9] Proposed Internet of electric vehicles that aims to minimize the carbon reduction, foreign oil dependency and offers cost savings over traditional models but it requires a planned cooperation of consumers and the power grid. Low pricing during off-peak hours is seen as an opportunity. It also highlights the need for message exchange between electric vehicles and the charging equipment, between mobile electric vehicles and inter-control centre communication. It picks out the potential candidates for electric vehicular networking at home. It proposes the use of WRAN for Electric Vehicular networking in residential areas in white spaces. Finally for electric vehicle to control centre communication is to be supported by using 5G or wireless mesh networking.

4.11 The Intelligent Vehicular Cloud Grid

[10] Proposes intelligent vehicular grid that can shape the random behavior of the vehicular networks into an organized data intensive network with vehicular clouds. The challenges and issues for implementing these vehicular clouds with autonomous vehicles are related to the design of an NDN Network Layer, Beacons and Alarms dissemination techniques, Intelligent Transport assistance, Infrastructure Failure Recovery modeling, File and Media Downloading features, Cognitive Radios and Spectrum Data-base Crowd-sourcing, Virtualization and Security.

4.12 The Vehicular Cyber Physical System

[12] The authors propose a design for a vehicular cyber physical system to build smart roads. It contributes by evaluating for the delay modeling for event prediction and data delivery for mobile nodes and network packets. The network is modeled using routers, relays and roadside access point. The research issues identified are system level design of IoV, prompt selection of communication technologies and seamless handover between communication technologies, measurement of vehicular traffic statistics, predicting the motion of the elements of IoV, Autonomous dynamic system reconfiguration, self adaptive networking and connectivity mechanisms.
4.13 Vehicular Cloud based Mobile gateways

[13] Introduces the idea of using public buses as mobile gateways for Vehicular clouds for exchanging beacons and service requests and forwarding it to the internet cloud. The feasibility of such a scheme is examined using real-time picture of the network of public buses spread over an urban area.

4.14 The Future Challenges

[11] The APEC report submitted for information purpose on internet of vehicles highlights lack of coordination and communication, developing and enhancing middle-ware platforms and creating a trusted environment for the elements of IOV as the important challenges. It also suggests the promotion of deep integration of IoV and vehicles for the development of IoV.

5 Conclusions

5.1 Open research issues and challenges

Vehicular Cloud Computing is still more conceptual than practical at this point of time. The existing technology gap to realize Internet of Vehicles makes most of the applications visionary or at least inefficient in terms of seamless interaction among the cyber-physical elements. This survey was aimed to provide an in-depth understanding of the current state of art of Vehicular Cloud Computing which remains an active area of research for academicians and industry. The survey presented in previous sections is able to successfully identify the following open issues and challenges in Vehicular Cloud Computing.

- Vehicular mobility based Resources Discovery
- Vehicular mobility and Cloud session maintenance
- Reliability
- Scalability
- Availability
- Security and Privacy
- Computation Outsourcing framework

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Conflict of Interest

The authors declare no conflict of interest.

References and Notes


