Vehicular Cloud Data Collection for Intelligent Transportation Systems

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Abstract—**The Internet of Things (IoT) envisions to connect billions of sensors to the Internet, in order to provide new applications and services for smart cities. IoT will allow the evolution of the Internet of Vehicles (IoV) from existing Vehicular Ad hoc Networks (VANETs), in which the delivery of various services will be offered to drivers by integrating vehicles, sensors, and mobile devices into a global network. To serve VANET with computational resources, Vehicular Cloud Computing (VCC) is recently envisioned with the objective of providing traffic solutions to improve our daily driving. These solutions involve applications and services for the benefit of Intelligent Transportation Systems (ITS), which represent an important part of IoV. Data collection is an important aspect in ITS, which can effectively serve online travel systems with the aid of Vehicular Cloud (VC). In this paper, we involve the new paradigm of VCC to propose a data collection model for the benefit of ITS. We show via simulation results that the participation of low percentage of vehicles in a dynamic VC is sufficient to provide meaningful data collection.**

Keywords- Intelligent Transportation Systems (ITS); Internet of Vehicles (IoV); Vehicular Ad hoc Networks (VANETs); Vehicular Cloud (VC).

I. Introduction

The term ''Internet-of-Things'' (IoT) is used to refer to the global network interconnecting smart objects, along with the set of supporting technologies [1] [2]. IoT is anticipated to offer new applications and services for smart cities in several domains, by interconnecting billions of sensors to the Internet [3]. IoT will allow the evolution of the Internet of Vehicles (IoV) from existing Vehicular Ad hoc Networks (VANETs) [4]. IoV features gathering, sharing, processing, computing, and secure release of information to enable the next generation of Intelligent Transportation Systems (ITS). These systems will offer the delivery of new applications and services to drivers by integrating vehicles, sensors, and mobile devices into the global network [5].

Vehicular Cloud Computing (VCC) [6] is a new paradigm which takes advantage of cloud computing to serve VANETs with several computational services, in order to improve our daily driving by minimizing accidents, travel time and traffic congestion. Ultimately, the goal of VCC is to provide on demand solutions for unpredictable traffic events, where applications can adapt according to the dynamic environmental changes with the aid of a Vehicular Cloud (VC) [7].

What distinguishes vehicles from standard nodes in a conventional cloud is autonomy [8] and mobility [9]. Despite the fact that broadband communications and wireless technologies can provide Internet connectivity to the public on the road through roadside access points (APs), the high mobility feature that characterizes vehicular environments limits the amount of data that a passing vehicle can download from an AP, where peer-to-peer connection can be an alternative approach [9].

Congestion detection and avoidance applications can support drivers with efficient route planning based on the road condition. A centralized ITS will be slow to report eventual traffic problems and usually does not provide a mitigation solution. Alternatively, a VC can offer the most appropriate and effective applications that meet the requirements of ITS, by enabling vehicles to share their traffic experiences on demand. This way, vehicles can detect traffic congestion and accurately assess the traffic flow condition in city environments [9].

Data collection is an important aspect in ITS, which can effectively serve online travel systems with the aid of a VC. In this work, we involve the new paradigm of VCC to propose a pull-based data collection model for the benefit of ITS. Moreover, we show via simulation results that the participation of low percentage of vehicles in a dynamic VC is sufficient to provide representative and meaningful data collection for ITS. Furthermore, we highlight existing challenges to be addressed by IoV data collection models and services.

The remainder of this paper is organized as follows: in Section II, we provide a background on the topic and we review related work. In Section III, we describe our proposed model with design considerations highlighted, and we specify a service scenario based on the proposed model. In Section IV, we discuss issues and challenges to be addressed by data collection models and services. In Section V, we provide concluding remarks and suggestions for future work.

II. Background and Related Work

Despite the fact that VANETs represent a significant component of Intelligent Transportation System (ITS); they are unable to allow a global network view for individual vehicles. Therefore, they can provide short term applications but cannot offer services for large-scale networks [10]. In [11], ITS networking requirements are reviewed. IoT will allow the evolution of the IoV from existing VANETs and other vehicular networks, in order to enable the delivery of various services to drivers, by integrating vehicles, sensors, and mobile devices into a global network.

Existing IoV research focuses on proposing models and frameworks for various applications and services. Generalized IoT models cannot be directly applied for vehicular networks, due to the specific properties that characterize these environments. For example, the sensing as service model proposed in [12] can be applied in several IoT scenarios, due to the generalization provided by four conceptual layers. However, such models should be altered to adapt vehicular environments that are characterized by the high mobility of nodes and constrained by the road network. In [10], the authors propose an abstract network model especially for IoV, which integrates four basic components: humans, vehicles, things, and environment. The proposed model provides an abstract vision by focusing only on relations among the defined network components. More infrastructural and architectural specifications are required to propose a model that is convenient with an application scenario or a set of services with a common goal.

Vehicular Cloud Computing [6] can provide a self-organized model of vehicular environments, by effectively forming a cloud within which services are produced, maintained, and consumed. Vehicles on the road with a permanent Internet access and on-board computational and sensing capabilities are ideal candidates for nodes in a cloud [9]. The cloud is constructed by using the collection of vehicles' computing resources, in order to extend the capability of interactions among vehicles [13]. A primary goal of Vehicular Cloud (VC) is to provide on-demand solutions to events that cannot be handled by centralized approaches or proactive applications [9]. In [14], the authors provide the taxonomy of future VCs, and propose the potential framework architecture for different cloud scenarios in vehicular environments.

Vehicular Cloud has different but complementary functionalities in comparison with the Internet Cloud. Vehicular Clouds offload the Internet Clouds from tasks that the latter cannot perform efficiently [6]. It is costly and time consuming to rely on the global Internet Cloud for uploading and searching detailed traffic information such as traffic congestion status. Instead, timely traffic information can be created, maintained and propagated within the VC. This way, locally relevant content are stored on the moving vehicles instead of being uploaded to the Internet Cloud. Some of the benefits of using VCs instead of the Internet Cloud are: reduced communication delay, reduced spectrum costs, and expanded range of traffic applications [6].

Possible applications and implementation scenarios for VCC are recently proposed. In [15], the authors proposed to use parked vehicles to establish a vehicular cloud for the purpose of data storage and network connectivity provision between moving vehicles and the vehicle storing the requested data. A virtual coordinate based routing solution is proposed to provide distributed services and integrated greedy routing. The presented simulation results indicate the feasibility of the approach, which is able to cope with the dynamics of vehicles parking and leaving.

III. The Proposed Model

VANET applications [16] research basically concentrates on providing short-term services such as safety messaging. Long-term applications within VANET are still challenging since VANET networking does not efficiently support their evolving demands [13]. On the other hand, VCC can provide on demand proactive solutions for unpredictable traffic events that allow applications to adapt according to the dynamic environmental changes. In our proposed model, we rely on the IoV paradigm along with Vehicular Cloud for data collection in vehicular environments. In this section, we first provide a detailed description of our model. We then specify design considerations for architecture, infrastructure and applications. Finally, we describe congestion detection as a service scenario that can apply our data collection model.

A. Model Description

Our main objective is to provide better connectivity and therefore better services for driver convenience. We follow the pull-based model in which an interested vehicle can send a query on demand to a faraway location within the city, and receive a reply through IoV within reasonable delay. Vehicles participating in IoV will cooperate in providing a meaningful response by sensing and processing data with the aid of vehicular cloud. The proposed model is illustrated in Figure 1. Our model borrows the functions of SaaS and IaaS from mobile cloud computing [17]:

- Software as a service (SaaS): At SaaS level, real-time traffic information could be shared with the subscribed users. Travel convenience services and P2P applications are suitable to be used as SaaS [14].
- At IaaS level, the potential services provided by VCs is Network as a Service (NaaS) where a vehicular node moving on the road might be used as a Wi-Fi access point gateway to the Internet.

Our model is appropriate with data collection applications for ITS with delay tolerance. Specifically, these applications focus primarily on providing route guidance and navigation alternatives based on the timely information about road conditions, travel situations and traffic congestion points.

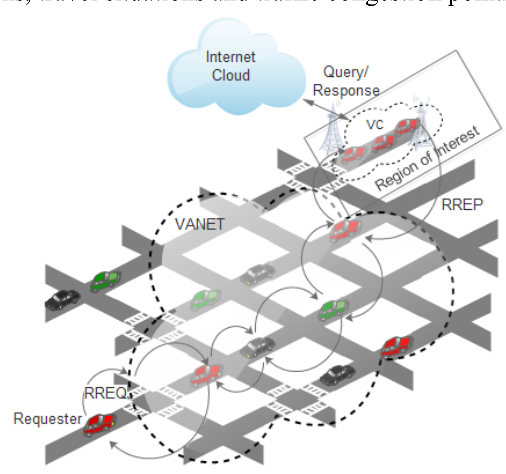


Figure 1. The Proposed Model

In the following, we describe each phase of our proposed model for data collection, until a reply is received by the requesting vehicle. These phases are summarized in Figure 2.

1) Phase I: Request Message Data Delivery

An interesting vehicle states its preferences for a data collection service in advance, such that it can request for traffic information on demand. A vehicle seeking traffic information determines its desired destination and creates a route request (RREQ) message. Desired destination can be referred to as the *Region of Interest (ROI)*, which can be expanded to a detailed road map, or limited to a single road segment.

The requesting vehicle broadcasts the created RREQ to its one-hop neighbors. RREQ is then routed to vehicles at the desired destination in order to obtain services using minimal infrastructure. The benefit of exploiting the advantages of vehicular cloud computing in routing is that the network can be divided into clusters for an improved efficiency [18]. If no infrastructure exists, the request will be routed via the ad hoc network by utilizing VANET routing protocols. These protocols usually aim to overcome the challenge of high mobility of vehicles that causes highly dynamic topology and frequent disconnections, by following directed broadcasting paradigm or geographic routing [19].

2) Phase II: Cloud Computing

When the RREQ is received by vehicles at the desired ROI, vehicles subscribed to the same service will cooperate in providing an answer to the requesting vehicle by announcing the required sensor data to the network. Sensor data may include environment condition data and/or internally sensed vehicular data such as speed, distance, acceleration or fuel consumption. We refer to receiving vehicles at the destination road which are subscribed to the requested service as *cooperating vehicles* (CVs).

CVs at the destination road try to form a dynamic vehicular cloud to publish their sensor data. Every vehicle in the set of CVs competes to be elected as a broker. Similar to other types of Wireless Sensor Networks (WSNs), a single node is elected to play the role of a broker, which is responsible for collecting data and communicating with the infrastructure. A nearby Roadside Unit (RSU) manages the process of broker election based on the connectivity criteria [20]. Once elected, the broker will try to form a vehicular cloud, and the rest of CVs will cooperate in the dynamic cloud formation process. Once the broker announces the VC formation, the VC accumulates computing resources to serve the request. Cloud resources consist of data sensors, storage and computing resources of CVs, which are shared among the vehicles to create a common virtual platform [13].

The broker requests the other CVs to send the required sensor data. Received data are collected via the vehicular cloud, stored in a hash table, and then sent by the broker to a server in the Internet cloud if further processing is required. In the case of simple request, VC resources may be sufficient to provide a response. In complex cases where the VC computing resources are unable to serve the request, the broker communicates with the Internet cloud in order to allocate the required computing resources. Whenever an internet access is required, vehicles with no networking services can borrow these services from vehicles with an internet access, which can be provided through mobile phones or fixed access points [18].

3) Phase III:Reply Message Data Delivery

In the case of complex requests that are sent to the Internet cloud, a response is sent from the allocated server in the Internet cloud to the VC broker. This response contains the requested information extracted from processing sensed data, such as route planning alternatives or navigation recommendation to avoid congestion points. On the other hand, simple requests that are fully processed by the dynamic VC usually contain simple data to denote traffic conditions or travel situations. Once the response is ready, a route reply message (RREP) is created by the broker and then routed to the requesting vehicle, either via another VC or through VANET.

B. Design Considerations

In this section, we specify design considerations for data collection in ITS from three different perspectives: architecture, infrastructure and applications.

1) Architecture

Our model uses the architecture shown in Figure 3, which is a modified version of the VCC architecture described in [7]. Three basic layers are defined: The in-vehicle layer, the communication, and the cloud. For the in-vehicle layer, we assume that each vehicle is equipped with an On-Board Unit (OBU), which has a broadband wireless communication for transferring data through 3 G or 4 G cellular communication devices, Wi-Fi, WiMAX, and Wireless Access in Vehicular Environment (WAVE) [21].

For the second layer, Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) are the two communication patterns considered by our model. V2V communication is utilized for data dissemination and ad hoc routing. On the other hand, V2I communication is responsible for exchanging the operational data among vehicles, infrastructures and the cloud over wireless networks and/or the Internet.

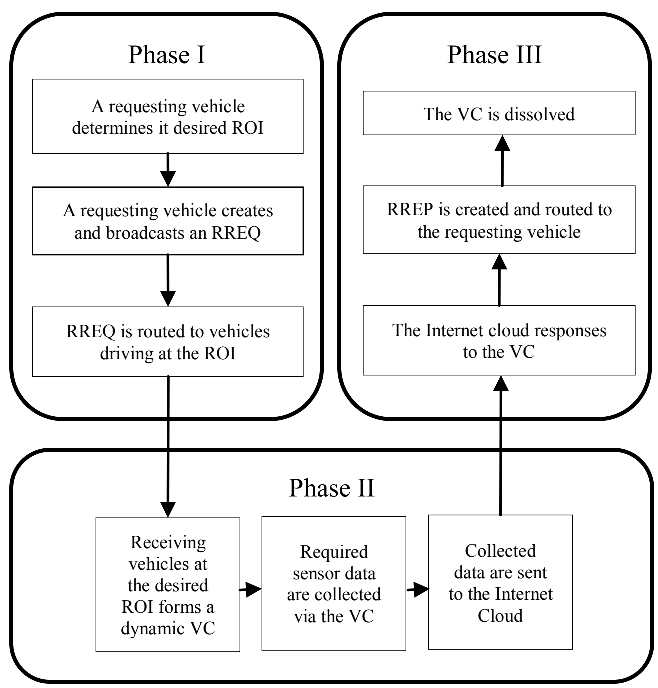


Figure 2. Model Phases

The cloud layer is the third layer consisting of three sub-layers: cloud infrastructure, cloud services and applications. The cloud infrastructure layer is responsible for two basic tasks: cloud storage and computation. The data that is collected via the in-vehicle layer will be stored according to the type of application. The cloud services sub-layer considers two basic services (SaaS and IaaS) for our pull-based data collection model. In the third sub-layer, real-time applications and services are considered. These applications are accessible remotely by drivers [7].

2) Infrastructure

For a data collection request, we consider the dynamic VCC formation [7], where a broker elected among the vehicles will try to form a vehicular cloud. The broker obtains an authorization from the authority to form a VC. One of the participating vehicles will secure authorization and succeed, while the rest will help to form the VC. The broker announces the VC formation and the VC accumulates computing resources to serve the request. The VC dissolves after implementing proposals.

3) Applications

Essentially, our service aims to serve data collection applications, such as traffic condition reporting, congestion detection and navigation recommendation. These applications usually follow the pull-based data model, where a requester sends a query to a target destination, and receives a reply within a reasonable delay. In conventional VANET applications, the request is sent and received through the ad hoc network. On the other hand, several benefits can be offered with the aid of the VC and the Internet Cloud.

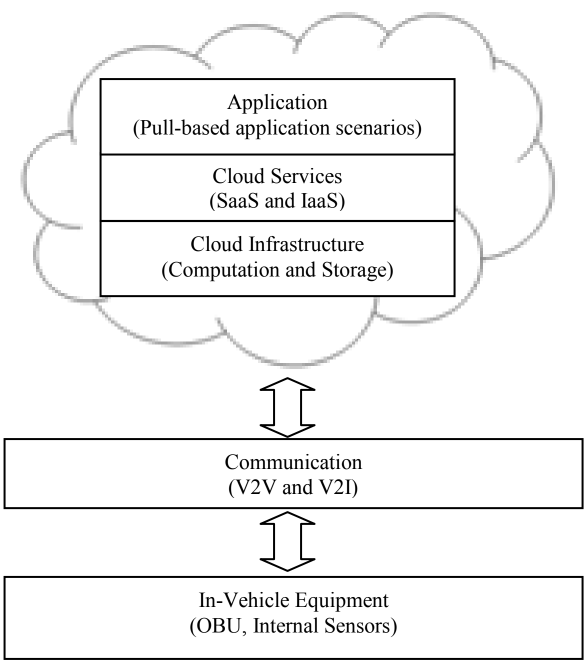


Figure 3. Model Architecture

C. Service Scenario

Our proposed model is appropriate for ITS applications in which data is collected upon request. Congestion detection is a representative scenario where vehicles share their sensor data with the aid of a dynamic vehicular cloud, in order to report traffic condition. Speed data is sufficient to denote traffic conditions in many situations. When the cloud is dynamically formatted, data can be collected and then sent to the Internet cloud for further processing, in order to support the requesting vehicle with route planning alternatives based on the driver's convenience.

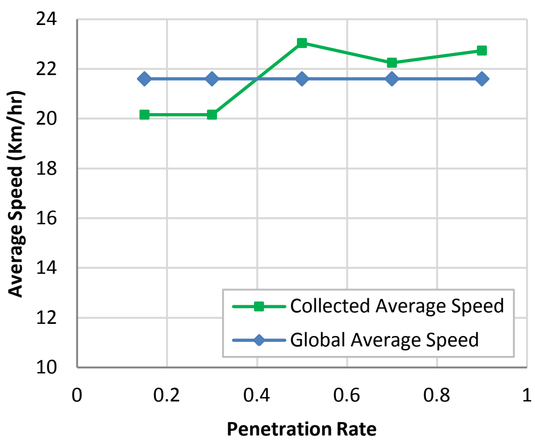
Only a percentage of travelling vehicles will be equipped with the required OBUs and subscribed to the service of interest. This percentage can be referred to as *penetration rate*, which is a significant factor that would affect the accuracy of collected data, especially at the early implementations of different types of VCs. To study this effect, we simulated medium and then high traffic demand on a multi-lane road using five different rates of penetration. We assumed that a requesting vehicle is interested in a data collection service for detecting traffic status on the modeled road, by expecting the average speed as experienced by vehicles travelling on that road. For every simulation, the average value of collected data is compared to the global average value (which can be achieved when 100% of the vehicles are participating in data collection).

The proposed scenario is implemented using Omnet++ [22] simulation environment. Traffic flow is generated using SUMO [23], and VANET is modeled using Veins [24] framework. We developed our own preliminary implementation of vehicular cloud. Simulation parameters are summarized in Table I. As the table shows, the physical and the MAC layer (which are implemented on the OBUs of participating vehicles) follow the IEEE 802.11p standard that extends the original IEEE 802.11to provide wireless access in vehicular environments [21]. For the physical layer, the frequency band is set to 5.9 GHz, and the bandwidth is 10 MHz. Transmission range is approximately 360 meter. For the MAC layer, bit rate is set to 6 Mbps and data frequency is 5 Hz. On the modeled road, traffic is simulated along 5 Km length with a maximum speed of 80 Km/hr. During 15 minutes of simulation time, high traffic demand is represented by generating vehicles on the road with an average density of 70 Vehicle/Km, while medium traffic demand is represented by the density of 50 Vehicle/Km.

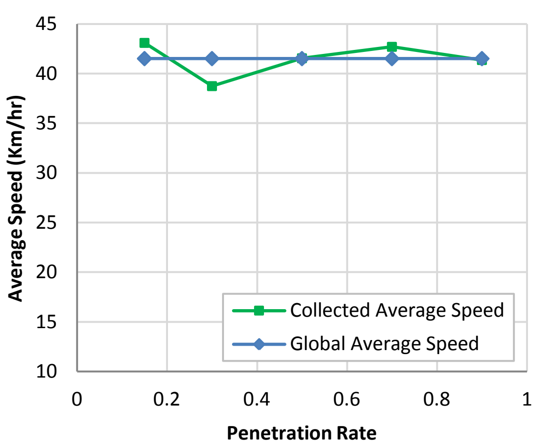
TABLE I. SIMULATION SETTINGS

Physical Layer	Frequency Band	5.9 GHz
	Bandwidth	10 MHz
	Transmission Range (R)	~ 360 m
Mac Layer	MAC Bit Rate	6 Mbps
	Mac Delay (τ)	20 ms
	Data Frequency	5 Hz
Scenario	Max. speed	80 Km/Hr
	Road Length	5 Km
	Number of Requests	1
	Simulation time	900 s
	Density	{50, 70} Vehicle/Km
	Penetration Rate	{0.15, 0.3, 0.5, 0.7, 0.9}

Simulation results are shown in Figure 4. In Figure 4(A), we show the simulation results under high traffic demand. As the Figure shows, the average value of speed data collected in the VC is closed to the actual average speed value, even under low penetration rates. This can be explained by the fact that vehicles travelling in the same road usually experience the same traffic condition, when neglecting other factors that may occasionally create little variations among participating vehicles. In Figure 4(B), we show the results under medium traffic demand. Similar to high traffic demand results, it can be clearly indicated that the collected average speed under medium traffic is closed to the global average under all rates of penetration. Despite that the best result is shown when 90% of the vehicles participate in data collection; we can conclude that vehicular cloud-based approaches can effectively support intelligent transportation systems with real-time data, even with low percentage of participating vehicles.



(A) High Traffic Demand (Density = 70 Vehicle/Km)



(B) Medium Traffic Demand (Density = 50 Vehicle/Km)

Figure 4. The effect of Penetration Rate on data dollection

IV. Issues and Challenges

In this section, we highlight the major issues and challenges in collecting data with the aid of VC. We mainly focus on the issues correlated with ITS applications such as traffic management, congestion detection and navigation systems. These issues include penetration rate, trust management, the interoperability of different clouds, and security.

A. Penetration Rate

Penetration rate in our proposed VC data collection can be defined as the percentage of vehicles equipped with the required OBUs and subscribed to the requested service. Due to the high expected impact of penetration rate in vehicular environments (especially at early implementation phases), we provide an evaluation of different penetration rates in a data collection scenario within a vehicular cloud. We show via simulation results that equipping 15% of the travelling vehicles can be effective in real-time data collection scenarios for the benefit of ITS.

B. Trust Management

In ITS applications, the VC sometimes requires to have local authority for taking actions or making decisions instead of a central authority [7]. Such local authority can be achieved through trust management system via cooperation between the cloud formation and the central authority, in order to automate the verification of actions.

C. The Interoperability of Different Clouds

Different types of clouds are anticipated to emerge in the near future. These clouds may interact with each other and connect on demand to the Internet cloud in real time scenarios. Therefore, issues related to communication, reliability, synchronization and efficiency are required to be addressed for the benefit of the interoperability of different clouds [7].

D. Security

VC suffers from the same security challenges of Cloud Computing, as anticipated in [25]. Since most of vehicular systems rely on location information, it is essential to ensure the secure location and localization. Moreover, the high mobility of vehicles requires verifying the authentication of users and the integrity of messages. For the stored data, it is required to provide secure data access to protect sensitive data against unauthorized access. Data isolation mechanisms can ensure the security of data stored in the cloud.

V. Conclusion

In this paper, we involve VCC to propose a model for data collection in ITS. Our model provides several benefits to drivers seeking traffic information for convenience purposes, by providing pull-based services on demand. In addition to design considerations, we describe a data collection service scenario that can involve our proposed model with low penetration rate. We also highlight the major issues and challenges correlated with data collection in VCs. In our future work, we are interested in designing efficient communication and data collection algorithm, with the consideration of data access issues in vehicular environments.

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