Internet of Vehicles: Integrated Services over Vehicular Ad Hoc Networks

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Abstract. Internet of Things (IoT) and Vehicular Ad hoc NETwork (VANET) based clouds are two emerging technologies and offer myriad of new applications in many domains of smart cities including, but not limited to, smart infrastructure and intelligent transportation. Integration of these technologies will enrich the applications and services space that will eventually stimulate the proliferation of these technologies. Nonetheless, due to their different requirements, environments, and networking models, such integration will need definitions of new communication paradigms and frameworks. To fill the voids, in this paper, we propose an architectural framework to integrate vehicular clouds (VC) and IoT, referred to as IoT-VC, to realize new services and applications that include IoT management through vehicular clouds. We particularly focus on smart city applications controlled, managed, and operated through vehicular networks. This theoretical work provides initial insights into data management in such diverse paradigm with resource constrained environment. Furthermore, we also discuss research challenges in such integration that include data acquisition, data quality, security, privacy, coverage, and so forth. These challenges must be addressed for realization of IoT-VC paradigm.

Keywords: Vehicular clouds · Internet of Things · Future internet
Vehicular social networks

1 Introduction

The emerging phenomenon of Internet of Things (IoT) has caught eyes of academia, businesses, industries, and investors a like. The main idea behind the concept of IoT is to remove the distinction layers among different objects and enable them to communicate with each other and the Internet regardless of the underlying platform and/or hardware. Similarly, concept of a connected vehicle

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with access to Internet is replaced by a more intelligent car, equipped with a swarm of sensors, capable of communicating with other cars through vehicle-to-vehicle (V2V), vehicle-to-infrastructure (V2I), vehicle-to-cloud (V2C), and generally vehicle-to-X (V2X) communication. These communication paradigms are realized through vehicular ad hoc network (VANET) and a recent breed of VANET referred to as VANET-based clouds (VC) [1,2]. Although academia and industry has achieved remarkable research results in VANET; however, there are still challenges that need to be addressed before bringing this technology to the huge masses of vehicles. These challenges include, but not limited to, efficient resource utilization, big traffic data processing, mobility, connectivity, and so forth. For instance, normally the cars are parked in a parking lot for tens of hours which is equivalent to waste of computing, communication, and storage resources (should there be high-end vehicles). These resources could be used elsewhere and could earn revenue as well. Cloud computing is an ideal solution for such phenomena where either parked or mobile vehicles can rent out their resources, can use public cloud, and so forth. This new paradigm not only improves the resource utilization, but also enhances the applications and services sphere for intelligent transportation systems. To date, a number of services have been proposed that leverage vehicles as both services providers and consumers simultaneously, for instance data center at a parking lot [3,4], traffic information dissemination [5], vehicle witness as a service [6], visual traffic information dissemination [7], and public transport as gateways [8], to name a few.

There are range of applications and services offered by IoT, VANET, and VC that add values to our daily lives from comfort, ease of access, and safety perspective [1,9]. For instance IoT enables the realization of smart home, smart industry, and generally smartX [10], whereas VANET includes both safety and infotainment applications that enhance driving experience of the consumers. The full scale deployment of these two emerging technologies is still on its way; nevertheless, prototype implementations of both IoT and VANET have been tested by different service providers. Among other challenges, the impeded momentum in the deployment of VANET and IoT is, at least partially, caused by security and privacy issues [11–13].

VANET is based on dedicated short range communication (DSRC)[1] standard whereas IoT can opt from a bewildering choice of connectivity technologies that include well-known Zigbee, 3/4/5 G, Bluetooth, WiFi, RPL, MQTT, CoAP, Z-wave, 6LowPAN, NFC, Sigfox, Neul, and low power radio-based wide area network (LoRaWAN [14]). It is worth noting that LoRaWAN is used specifically for low power radio and long-range coverage. Therefore, LoRaWAN is ideal choice for applications that operate on long range.

There are unprecedented applications realized through IoT and the currently available management platform is android that uses Internet [9]. Since LoRaWAN operates on long range and does not need Internet connectivity, therefore in order to enhance the robustness, ease of access, safety, and personalization, it would be convenient to operate, configure, and manage the IoT services

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[1] http://www.etsi.org/technologies-clusters/technologies/intelligent-transport/dsrc.

in an ad hoc manner. To this end, vehicular networking and VC paradigms, because of their communication setup, are ideal to integrate with IoT paradigm for service exchange, service management, and functionality enhancement.

In this paper, we propose architectural framework and design of the IoT-VC integration and envision new exciting services and applications realized through IoT-VC. We focus on the abstract level integration of these two technologies and propose a blueprint framework that will enable IoT and VC to exchange data for applications and services in a cross-platform environment. Furthermore, we also outline the envisioned applications and the research challenges faced by such integration.

The rest of the paper is organized as follows: In Sect. 2 we outline the related work followed by our proposed framework in Sect. 3 and research challenges in Sect. 4. Section 5 concludes the paper.

2 Related Work

Vehicular networks and IoT have a rich literature that covers most of the implementation aspects, services, applications, security, privacy, and data exchange, to name a few [9]. Today major car manufacturers are equipping their high-end vehicles with smart applications that are used for smart parking, cooperative cruise control, emergency warning, infotainment, partial autonomy, and so forth. The real deployment of VANET is still awaited; however, remarkable research results have already been achieved in the field of VANET. A new breed of VANET-based clouds has also been proposed to enhance the application space of pure vehicular networks [2,5]. VANET-based clouds enhance the application space of the traditional VANET and leverage the rich resources of the cloud computing for intelligent transportation and resource management in general. With VANET-based clouds more applications and services like cooperation-as-a-Service, vehicle witness as a service [6], traffic violation monitoring through VANET-clouds [15], traffic information dissemination [5], Intelligent parking system through IoT [16], and Smart Traffic Light System (STLS) [17] to name a few. Furthermore the challenges faced by this breed of VANET has been outlined in detail by Yan et al. [18].

Recently, efforts have been made to look into the possibility of using IoT services in vehicular networks. Alam et al. proposed Social Internet of Vehicles which is the extension of social IoT for vehicular networks. However, their framework does not take into account the integration of IoT and VANET for data exchange, applications and extended services [19]. It is also worth noting that IoT is no longer used only for data exchange but also the ‘things’ act as nodes that interact socially. Ortiz et al. discussed the clustered structure for social IoT in detail and also outlined the future research challenges [20].

Moreover, several emerging networking paradigms have been discussed in literature such as Software Defined Networks [21] in order to provide flexibility, location awareness for the cloud, scalability in order to meet the needs of the future Vehicular Cloud based services and programmability in order to manage

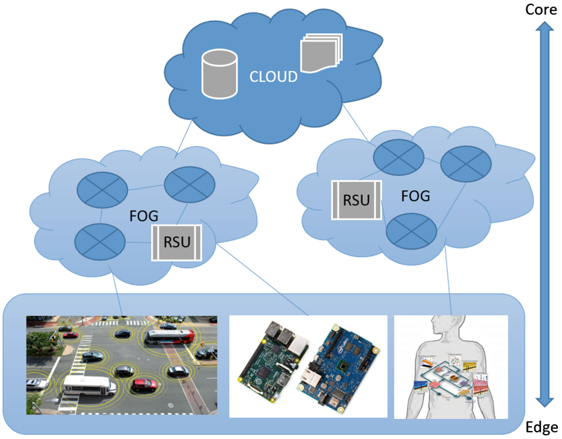

Fig. 1. Vehicular Fog: Internet of Things meet Vehicular Cloud

the network in an agile fashion. Internet in general and Cloud specifically is prone to latency, the data generated by vehicular networks is sent to the cloud for analysis, further decisive actions from cloud may get delayed which can be a problem in certain time critical scenarios. Several IoT-VC applications require cloud to respond in a timely manner in order to better cater the scenarios such as real-time traffic diversion in case of emergency situations. Fog Computing proposes that data generated by IoT be processed as near to the edge nodes as possible in order to achieve better through put of the overall system, thus overcoming the inherent latency of cloud computing and laying off the burden on core network as shown in Fig. 1. In case of Vehicles, Roadside Units (RSUs) can be leveraged to gather the data generated by Vehicular Clouds and process it locally and the analyzed data may be disseminated in a more robust manner.

Today's high-end vehicles are hosts to myriad of sensors and actuators that produce huge amount of data. Furthermore, these data are used for variety of purposes and applications. In its essence, vehicular networks and VANET-based clouds are ideal to integrate with IoT in order to get full potential of the sensory data from these technologies, and use IoT-generated data in VANET-based clouds. Nonetheless, this integration will need crafting of new middle-ware frameworks, protocol (re)design, writing new drivers that are able to talk to different technologies, and so forth. To fill the voids, we propose architectural level framework to integrate IoT with VC for huge amount of data acquisition, service and applications enhancement. Furthermore, we also outline the research challenges associated with the integration.

3 Integrated Services over IoT-VC

3.1 Baseline, LoRa, and DSRC

Vehicular clouds and networks consist of vehicular nodes (more precisely on-board units - OBUs), roadside units (RSUs), registration and management authorities and operates on DSRC/IEEE 802.11p standard. Vehicles communicate with each other, and with external entities through infrastructure. On the other hand, IoT has been realized through many technologies such as Zigbee, Bluetooth, WiFi, and so forth; however, due to the nature of our applications, we use LoRaWAN as an underlying technology for the realization of services and applications of IoT. There are twofold purposes of using LoRaWAN, it is long range and also energy-efficient. Furthermore, LoRaWAN infrastructure is relatively easy to deploy as compared to its other counterparts. Additionally, it meets the key requirements of IoT such as secure bi-directional communication, mobility and localization services and it provides seamless interoperability among smart things without complex installations. LoRaWAN network architecture usually follows star-of-stars topology where LoRaWAN gateway serves as bridge between end-things (LoRa Arduino, sensors) and a back-end network server. The Things Network has already taken initiative to deploy IoT through LoRaWAN [14]. The general baseline layered architecture of IoT is given in Fig. 2. There are two kinds of gateways in this IoT setup. 'Things' connect to the LoRaWAN gateways whereas these gateways connect to the central network routers. The routers are connected to both internet and the backend servers for data acquisition, service delivery and a number of other components. In order

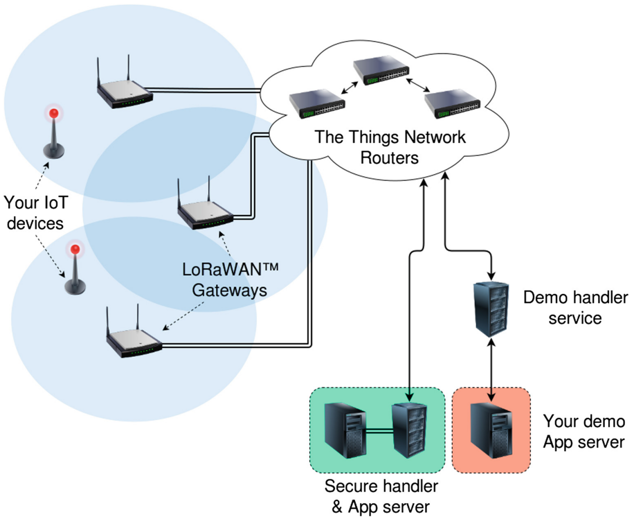

Fig. 2. The Things Network Reference architecture with LoRa (https://www.thethingsnetwork.org/)

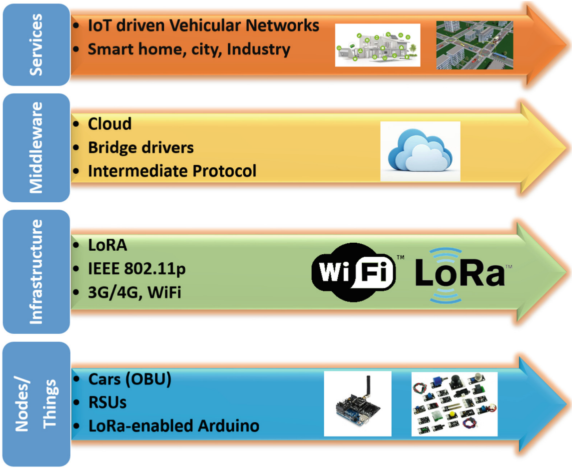

Fig. 3. Vertical IoTVC service architecture

to lay ground for our framework, the vertical service architecture for integration is shown in Fig. 3. It can be observed from the figure that in order to realize the IoT-VC applications and services, sensors and other nodes have to use both VANET infrastructure and the LoRa-based infrastructure to offload data to the cloud and receive information back from the cloud. This setup serves several-fold purposes such as increase in connectivity, multiple channels for data sharing, quality of service, and priority based communication, to name a few.

3.2 Architectural Framework

We propose a generalized infrastructural framework for IoTVC. The goal of the integration is to make sure that nodes from both IoT and vehicular networks/VC interact and share data in a seamless manner for service exchange. From bird's view, there are 3 main components of such integration, VC paradigm, IoT paradigm, and Middle-ware components. The role of the first two components is clear; however, the major component is middle-ware that is realized through the bridges, gateways, and drivers. General layout of the IoTVC design is given in Fig. 4, where IoT-generated data is stored in cloud and shared with vehicular network as well. In order to use IoT application and services in VANET through OBUs and RSUs, inter-protocol conversion and definitions are needed. It is worth noting that, as shown in Fig. 4, IoT services can be managed either directly from VANET or through clouds depending on the nature of applications. For instance a direct control of a home appliance would not need communication with cloud whereas querying the energy usage statistics at home would need a communication channel to the cloud in order to download the required statistics. In our scenario, we use Vehicles using Clouds (VuC) framework from Vehicular clouds [2].

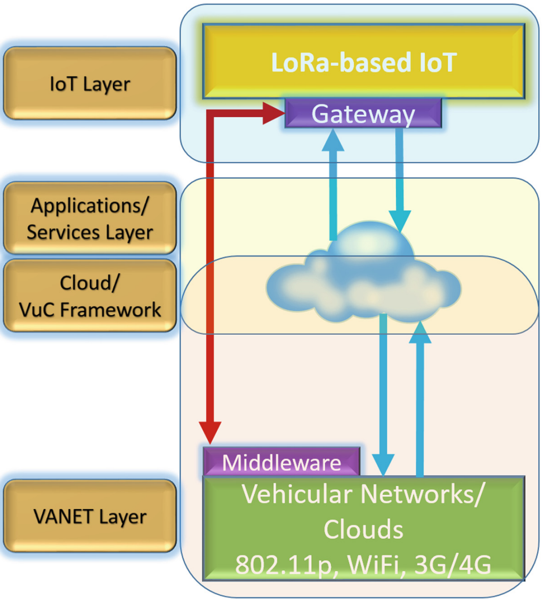

Fig. 4. Generic functional level design of IoTVC

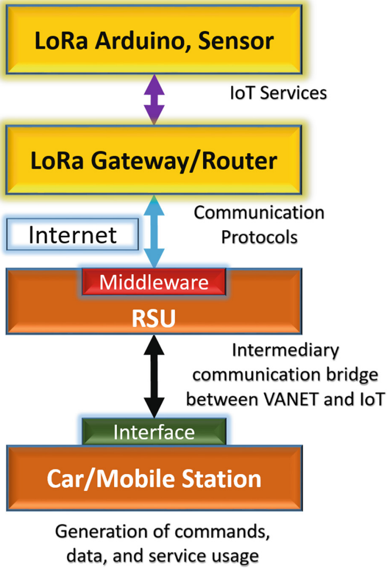

Fig. 5. Communication mechanism of IoTVC

The detailed communication mechanism for integrated IoT-VC is given in Fig. 5. We regard the RSUs as interfaces and bridges for LoRa gateways. In other words, the communication from VC paradigm will be encapsulated, tunneled, and/or converted to the LoRa communication format. With 3G capability, the bridging component in RSU can directly communicate with LoRa gateway and then route message to the intended node. Furthermore, in our extended work, we intend to formalize the security mechanism for this process as well. The upper half of the Fig. 5 is IoT world which is driven by the LoRa technology. Another important role of the bridging mechanism is to tune the communication from VC towards LoRa gateways and end-nodes. LoRa supports data rate ranging from 0.3 kbps to 50 kbps depending upon the transmission range and LoRa frequency channels. The transmission range is inversely proportional to the data rate offered by LoRa technology. Therefore, it gives more opportunity to application developers to tweak the RoRa modules in accordance with the application requirements. Furthermore, this variation in both transmission range and data rate gives more flexibility to host a diverse range of different applications. However, the adaptive data rate (ADR) of IoT end devices make the design of the middle-ware more challenging. There are basically 3 classes of end-devices in LoRaWAN (class A, class B, and class C) targeting different application requirements. These classes exhibit different characteristics on MAC layer. Communication mode, power usage, latency, and uplink/downlink capacity differentiate these classes. Class A end devices are the most energy-efficient devices at the expense of reduced data rate, class B devices are slightly moderate whereas class C devices consume more energy as compared to class A and B. However, class C has the lowest latency among all 3 classes. Therefore, LoRa can host a wide range of applications with different sets of requirements.

3.3 Application Scenarios

With the integrated IoT-VC, we target personalized IoT and envision applications that cover smart home management, smart office, smart industry, and intelligent transportation system (ITS). We particularly aim at controlling home appliances (operated based on LoRa IoT) through vehicular clouds. It is worth noting that our framework is generic; however, in our implementation phase, we target only personalized IoT. The integrated IoT-VC has applications in ITS, e-health care, smart grid, navigation, weather forecast, diagnostics, and office domains. In the smart home environment, a mobile application can be used to manage the home IoT network. For instance, controlling the temperature at home, operating washing machine, checking on refrigerator, and opening the door of garage. There are other such operations that can be performed through the integrated IoT-VC. On the other hand, through IoT network at home, one can know the current traffic situation and efficiently calculate route based on the current traffic conditions. Such information will not only save the time of commute, but also save fuel and thus-forth providing economical advantages. Furthermore, information about different sales in the market, favorite restaurants, location-based services, shopping centers, parking lots, and so forth can also be realized through IoT network. To this end, a rich spectrum of applications can be realized through such integration.

Another interesting application use case is intelligent traffic lights (ITL) which along with Vehicular Cloud and IoT leverages software defined network (SDN). In ITL, various kind of sensors are installed with Road Side Units (RSU) that continuously monitor the presence of vehicles and pedestrians, and based on the measurements, collected and/or aggregated data is sent to the gateway nodes where it is used to coordinate with the neighboring signals to maintain a constant and efficient traffic flow. Moreover, these RSUs are also capable of generating appropriate notifications in case of any incident which might be helpful for other vehicles, and if needed this analytics can be used to modify the traffic flow as well. While this information is useful locally, it can also be propagated to the cloud for long term storage and analysis in order to provide better insights on transportation needs of a smart city. Besides, intelligent parking lot management can also be realized through the collected data from different vehicles parked or mobile on the road.

4 Research Challenges

The integration of VANET-based clouds and IoT, despite of exciting applications and services, has to address key challenges that may keep the investors and key stakeholder at bay from deploying the integrated technology. Some of the research challenges are outline below:

4.1 Functional Challenges

One of the main challenges of integration is the difference in standard specifications. We have assumed LoRaWAN for IoT, and VANET follows WAVE/DSRC standard. The handshake negotiation, protocol selection, data rate, and other such factors will determine the performance of the underlying application. However, the diverse nature of both technologies advocate for in-depth analysis of the trade off among the aforementioned factors. To this end, different applications will exhibit different behavior and thus-forth require different set of parameters. The adaptation to such dynamic behavior will be a challenge for service providers and have to be dealt with in a reliable way, keeping in mind the consumer satisfaction. There exist different mechanisms that cope with the resource utilization and diversity in IoT environment [22]; however, the heterogeneity exhibited by the integrated IoT-VC calls for more insight obtain a trade-off solutions that are acceptable to both consumers and service providers.

4.2 Data Acquisition

Both VANET-based clouds and IoT generate different kind of data with relatively different goals, and with different speed and volume. Therefore, data acquisition across the different platforms will need smart pre-processing of the data locally. It is worth noting that in VANET-based clouds, there are different kind of data generated at different levels, such as in-car sensors generate data that could be useful for both owner of the car and the neighboring vehicles and auto-manufacturer for diagnostics. On the other hand, data generated by vehicles and shared with neighbors can be humongous and can be rendered as big traffic data (BTD). To be more precise, depending on the traffic regime (dense, moderate, and sparse), the data generated by each car and shared with different single-hop and multi-hop neighbors (such as beacon messages in the order of milliseconds [23]) could be so huge for the processing power of the individual vehicle. Therefore crowd-sourcing and/or offloading the data processing to the cloud could be a viable solution. Sharing VANET-generated data (which is fast and huge in volume) may have to be compressed before sharing in the IoT environment. Furthermore, the data may also need some refinement and aggregation because of the resource constraints in IoT. Similarly, using IoT data in VANET (inside car, to be more precise) must be well-presented and application specific. In our use-case environment, i.e. smart home IoT management through VANET, will require application level data sharing with in-car network and commands directed from in-car network to the IoT network at home.

4.3 Security and Privacy

Security and privacy are of prime importance in the realization of the integrated IoT-VC. It is to be noted that in personal IoT networks, the data generated can be highly privacy-sensitive and thus-forth requires privacy enhancing mechanisms for both data at rest and on the wire. Without effective measures for privacy preservation, the data shared from home IoT environment may easily cause user privacy abuse. Nonetheless, this requirement is conflicting with performance of the application. Usually privacy-preserving data sharing schemes affect the granularity of data and therefore decrease the performance. To this end, data sharing among IoT and VANET should not only be secure, but also privacy-aware, and trade off between granularity of data and performance of the application has to be made. Moreover, context aware privacy preservation techniques need to be employed in order to enable the vehicular clouds to adapt to the changing environment. Fog Computing can play an important role in preserving privacy because by design the data generated by the edge nodes is processed as near to edge nodes as possible. In case of Vehicular Clouds, Roadside Units (RSUs) can be leveraged to analyze the data locally and thus insuring that the data is not being propagated in the whole network. These roadside units may be enabled in such a way that they employ industry standard privacy preserving techniques.

4.4 Data Quality

Recent industrial advancements have enabled us to leverage the potential of millions of low cost, easily available sensors which are mostly left unattended in order to monitor certain parameters in a given environment for long periods of time. This puts question on the quality of data that these sensors are transmitting. While realizing an IoT-VC, this problem becomes more important as the mobile nature of Vehicular Clouds makes it difficult to keep check on provenance. In order to avoid such problems, it will be required to have checks in place for consistency and calibration of not only vehicular sensors but also the overall middle-ware. Moreover, different applications require different level of granularity from the same raw data. Therefore, context is an important parameter to measure while providing data to the applications. Security, integrity, and availability of data should be based on the underlying applications rather than the state of the network.

4.5 Coverage

Both IoT and VANET and its breeds are in their infancy, and a number of service providers are testing their waters for these technologies. The proliferation of these technologies is an incremental process and it will require time before we can bring these to the masses. Coverage and user satisfaction are other fronts that have to be addressed. Currently ‘The Things Network’ has been deployed in a number of European cities and provide partial coverage. It is also worth noting that other vendors are also competing for IoT deployment and the key market players are many. Therefore, since our envisioned framework targets only LoRaWAN, its coverage will be an important parameter in successful realization of this integration. On the other hand, VANET and its different breeds are going through legislation process in both US and Europe, therefore it is safe to assume that in a couple of years connected vehicles will pervade our highways.

5 Conclusion

In this paper, we proposed a generic abstract level framework for integrating IoT with vehicular clouds for service enhancement. Our proposed architectural framework will be a starting point towards realization of new and exciting applications in both IoT and VC domains. We particularly focused on the protocol level and functional-level integration. We also outlined the research challenges faced by such integration. In the extended version, we will work on a complete framework covering all aspects of the integration with a proof-of-concept architecture including protocols for infrastructure, communication, security, privacy, and data protocols and functional aspects such as asset management.

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