Toward Integrating Vehicular Clouds with IoT for Smart City Services

Hasan Ali Khattak, Haleem Farman, Bilal Jan, and Ikram Ud Din

Abstract

Vehicular ad hoc networks, cloud computing, and the Internet of Things are among the emerging technology enablers offering a wide array of new application possibilities in smart urban spaces. These applications consist of smart building automation systems, healthcare monitoring systems, and intelligent and connected transportation, among others. The integration of IoT-based vehicular technologies will enrich services that are eventually going to ignite the proliferation of exciting and even more advanced technological marvels. However, depending on different requirements and design models for networking and architecture, such integration needs the development of newer communication architectures and frameworks. This work proposes a novel framework for architectural and communication design to effectively integrate vehicular networking clouds with IoT, referred to as VCoT, to materialize new applications that provision various IoT services through vehicular clouds. In this article, we particularly put emphasis on smart city applications deployed, operated, and controlled through LoRaWAN-based vehicular networks. LoraWAN, being a new technology, provides efficient and long-range communication possibilities. The article also discusses possible research issues in such an integration including data aggregation, security, privacy, data quality, and network coverage. These issues must be addressed in order to realize the VCoT paradigm deployment, and to provide insights for investors and key stakeholders in VCoT service provisioning. The article presents deep insights for different real-world application scenarios (i.e., smart homes, intelligent traffic light, and smart city) using VCoT for general control and automation along with their associated challenges. It also presents initial insights, through preliminary results, regarding data and resource management in IoT-based resource constrained environments through vehicular clouds.

Introduction

The Internet of Things (IoT), through its promising capabilities and pervasive nature, has captured the attention of not only a vast majority of stakeholders in academia and research but also businesses, investors, and industries. One of the significant goals behind this promising idea of leveraging IoT is to minimize ubiquitous distinctive layers between everyday objects and to empower these things so that they can communicate with not only each other but also with the Internet irrespective of the underlying hardware and/or software platforms. The simple concept of an Internet connected vehicle is enhanced with a more intelligent vehicle. These vehicles are being equipped with a flock of various sensor nodes and other devices enabling the vehicle to capture variables regarding itself and its surroundings. Thus, making the vehicle capable of transmitting to other vehicles using vehicle-to-infrastructure (V2I), vehicle-to-vehicle (V2V), vehicle-to-cloud (V2C), and, broadly speaking, vehicle-to-everything (V2X) communications.

V2X communication models are achieved through leveraging vehicular ad hoc networks (VANETs). Recently, VANET technologies have emerged as promising enablers connected to the cloud to effectively disseminate the aggregated knowledge, referred to as VANET clouds (VCs) [1]. Even though R&D in academic as well as industrial settings equally have achieved promising research breakthroughs in the domain of VANETs, issues still exist that ought to be addressed in order to bring VC-based technologies to the swarm of vehicles. Such issues include big (traffic) data management (aggregation, efficient resource utilization, communication, and analytical processing), supporting mobility, effective and ubiquitous connectivity, and so on.

As an example, these intelligent and equipped vehicles are normally parked in a parking lot for several hours that waste valuable computing, communication, and storage resources. These valuable resources can be put to use elsewhere or by other vehicles and infrastructures on demand, in turn enabling end users to generate revenue. Similarly, cloud computing is a perfect facilitator while considering the above mentioned scenario where mobile or stationary vehicles can lease out unused resource resources through a publicly or privately hosted cloud. These new application possibilities not only improve the overall resource management and utilization by providing idle resources as utility, but also enable research and development of newer applications, thus enhancing the overall services infrastructure for intelligent transportation systems (ITS) in smart cities. Various application and service provisioning frameworks have been suggested in the literature that utilize vehicles as both service consuming entities and service providers. The need for services such as data centers in parking lots, traffic information

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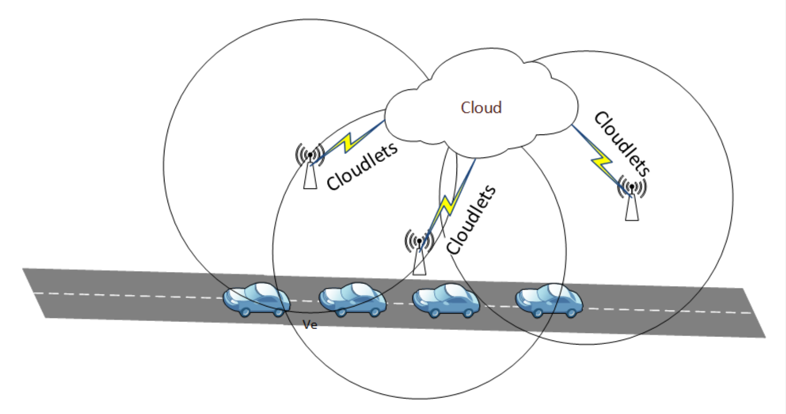

FIGURE 1. Vehicular clouds meet the Internet of Things, enabling smart cities to leverage vehicular fog computing.

communications, vehicle witnesses, effective visual traffic information communications, and public transportation as service gateway nodes [2, 3] are becoming a reality.

There are a wide variety of services as well as applications offered through VANETs, IoT, and VC that add value to daily lives by providing consolation, improved accessibility, and overall citizenship as well as asset security and safety [4]. For example, IoT facilitates the deployment of intelligent homes and buildings, intelligent industrial environments, and intelligent health, whereas a VANET includes various infotainment, facilitation, and safety applications for smart cities that improve the overall driving experience for citizens. A large-scale realization of such promising technologies is a feat that has yet to be achieved. Nonetheless, model realizations of IoT and VANETs have been published and deployed by various researchers and consequently different service providers. Among other challenges, security and privacy issues have been a challenging research issue to the overall progress in the full realization of VANET and IoT deployment [5–7].

VANETs utilize dedicated short-range communications (DSRC — http://etsi.org/technologies-clusters/technologies/intelligent-transport), while IoT leverages a huge variety of communication protocols such as fifth generation (5G), NFC, Bluetooth, WiFi, and protocols that include various well-known standards such as MQTT, RPL, Z-wave, CoAP, Zigbee, Neul, Sigfox, 6LowPAN, and the upcoming but promising low-power radio-based wide area networking (LoRaWAN). LoRaWAN has been an ideal candidate for developing applications as well as service infrastructures that operate over a long range, thus improving the efficiency through a low-power radio along with long-range coverage [8].

Various applications and service infrastructures have been realized through leveraging IoT. Android, as a significant device management platform, has been a pivotal force in realizing numerous applications for smart cities [4]. LoRaWAN works long-range and is not dependent on Internet connectivity, thus making it a favorable candidate for configuring, operating, and managing IoT-based services in an ad hoc fashion for enhancing robustness, providing ease of access, safety, and personalization. Vehicular networks as well as VC paradigms, due to their easier transmission setups, are good candidates for integrating with the IoT paradigms for services exchange, management, and overall functionality enhancements.

While extending our work in [9], where we proposed a model integrated framework for the Vehicular Cloud of Things (VCoT), in this work we propose a novel VCoT-based service and application infrastructure. This article also focuses on a conceptual integration of these technology enablers in order to suggest a model framework to enable VC and IoT to interchange information for better application and service provisioning in a cross-platform scenario. Additionally, the article also outlines future possibilities for VCoT, and the research issues that need to be addressed before realizing IoT and the VCoT.

The remainder of the manuscript is structured as follows. The next section outlines the related work, which is followed by the proposed VCoT framework and some of the prominent research challenges. Finally, the manuscript concludes while elaborating the benefits of IoT integration with vehicular clouds.

Related Work

IoT and VANETs have a very rich and state-of-the-art literature that provides insights on most implementation and deployment aspects, service provisioning, and possible application integration, along with issues related to security, privacy, and data exchange [4]. Nowadays, most vehicles are stocked with various intelligent options and services that are used for cooperative cruise control, smart parking, emergency warnings, infotainment systems, and partial and in some cases full autonomy. A real and full-scale deployment of VANETs still needs to be done; however, significant results have been achieved in this domain [2], as shown in Fig. 1.

VANET-based cloud infrastructures elevate the application space of traditional VANETs while leveraging a larger resource pool of cloud computing paradigms for realizing intelligent transport systems and resource management applications in smart cities. Using VANET-based clouds, several services and applications such as vehicle cooperation for resource pooling, vehicles as witnesses, traffic violations monitoring using vehicular clouds [10], traffic information dissemination [2], efficient parking systems using IoT technologies [11], and smart traffic lights systems (STLS) can be realized.

Researchers have made tremendous efforts to leverage IoT-based applications of VANETs in a wide array of scenarios. Ayesha *et al.* have suggested SIoV, Social Internet of Vehicles, as an extension of the social IoT for VANETs. However, the proposed framework does not consider the integration of VANETs with IoT for transmission of data, promising applications, and extended smart city services [12]. Another aspect of this is that IoT is not used for transmission of data only. These Things in IoT are acting as nodes that interchange information among themselves to collaborate in order to achieve certain tasks.

Various emerging networking architectures have been described in the literature. Providing flexible network scaling and location awareness for the cloud infrastructure can be achieved through utilizing software defined networking

(SDN) [13]. Similarly, SDN also provides robust scalability for meeting the requirements of future vehicular cloud-based applications. The most promising feature of SDN is the programmable network controller, which enables management of the network in an agile fashion, especially when considering vehicular networks [14]. In vehicular networks, the aggregated vehicular data is transmitted to the cloud infrastructure for analysis. Similarly, the data stored on the cloud is used for making decisions upon which actions may be triggered. In such a case, any kind of delays from the cloud may cause catastrophic problems in various time-critical situations. The Internet architecture generally, and specifically cloud computing, is vulnerable to the issue of latency.

Various VCoT application scenarios need cloud-based infrastructures in order to promptly respond to better cater for events like a real-time traffic flow diversion mechanism in an emergency situation. Fog or edge computing enables the IoT generated data to be processed in the vicinity of fog nodes for achieving improved throughput of the full system. For vehicular networks, roadside units (RSUs) are ideal candidates to not only gather the generated vehicular data but also locally process it. Thus, this analyzed data is disseminated in a more robust way. This will enable us to overcome the inherent problem of latency in cloud computing thus reducing the overall burden on the network, as depicted in Fig. 1.

Integrated Services over VCoT

Standards and Protocols

The proposed vehicular cloud architecture consists of different types of entities such as vehicles equipped with onboard units (OBUs), infrastructural components such as RSUs, and management authorities responsible for registration, monitoring, and control of vehicles connected to the cloud. All these entities operate on IEEE 802.11p or DSRC standards. These vehicles connect with one another and with other external entities through the underlying vehicular network infrastructure. Also, several IoT applications have been developed using technology enablers, such as LoraWAN, Zigbee, WiFi, and Bluetooth, which are extending the service space for enhancing citizens' lives as a whole. However, the specific nature of smart city use case applications, LoRaWAN, has been shown to perform well as an emerging and promising technology for the effective deployment of smart city services.

There are manifold purposes of LoRaWAN, for instance, energy efficiency coupled with long-range transmissions. The LoRaWAN based infrastructure provides easier setup compared to its counterparts such as SigFox, RPMA, Symphony Link, and Weightless. Moreover, it fulfills the key requirements of the smart city applications for IoT such as security, mobility, localization services, and bidirectional communications. To further extend, it also provides unified and seamless interoperability with the rest of IoT-enabled smart things without going through complex installation setups. The LoRaWAN-enabled architecture typically follows the star-of-stars topology in which LoRa-based gateways serve as bridge nodes for enabling communications among the LoRaWAN-based Arduino sensor nodes and the back-end cloud server.

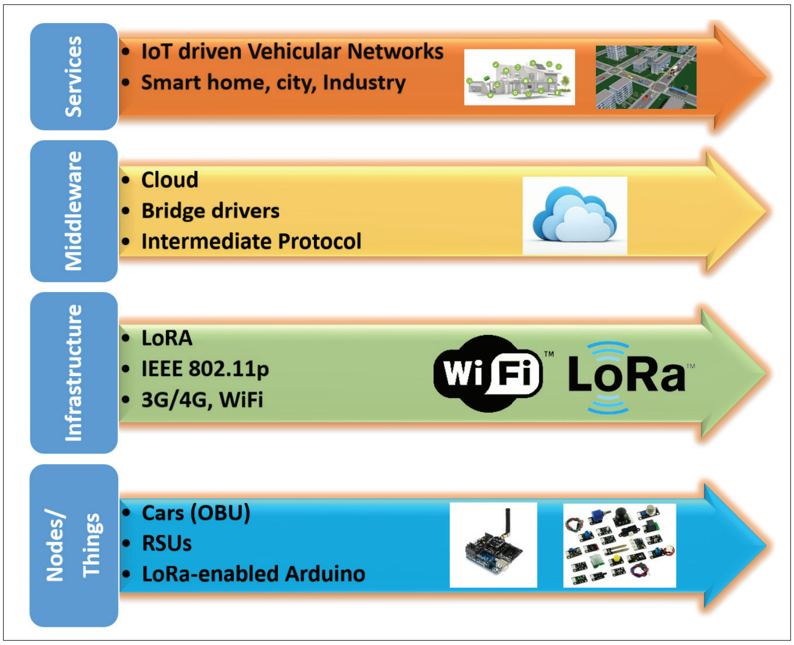

FIGURE 2. Vertical VCoT service architecture and its enabling technologies.

The things network (https://www.thethingsnetwork.org) is among the pioneers in deploying IoT based infrastructures utilizing LoRa based technologies [8]. There are two types of gateway nodes in their setup. Things in the things network are connected to LoRaWAN gateway nodes whereas these gateways are further connected to the core network routers connected directly with the cloud servers. These routers are connected to the Internet as well as the back-end servers for service delivery, data acquisition and several other components such as load balancing, authentication, and authorization systems.

In order to lay the groundwork for the proposed system, a vertical architecture for service provisioning through VCoT integration is presented in Fig. 2. In the proposed VCoT-based applications and services provisioning system, embedded sensors in OBUs and the rest of the nodes utilize the VANET-based infrastructure along with the LoRaWAN-based IoT infrastructure through RSUs to not only offload information to the cloud but also retrieve data back from it. This setup serves manifold purposes such as lower latency, enhanced connectivity, quality of service, data transmission through multiple channels, and a priority-based communication mechanism, among others.

Architectural Framework

The goal of integration through our proposed generalized infrastructural framework for VCoT is to ensure that the nodes from vehicular networks enabled with VC and IoT qualified smart city applications share data and interact in a very seamless way for service data exchange and enhanced user experience. There are three main parts of such integration: IoT infrastructure, middleware components, and the vehicular cloud paradigm. The roles of the first and last are quite straightforward and have been discussed in the literature in detail. However, the most important component is the proposed middleware, which is realized through

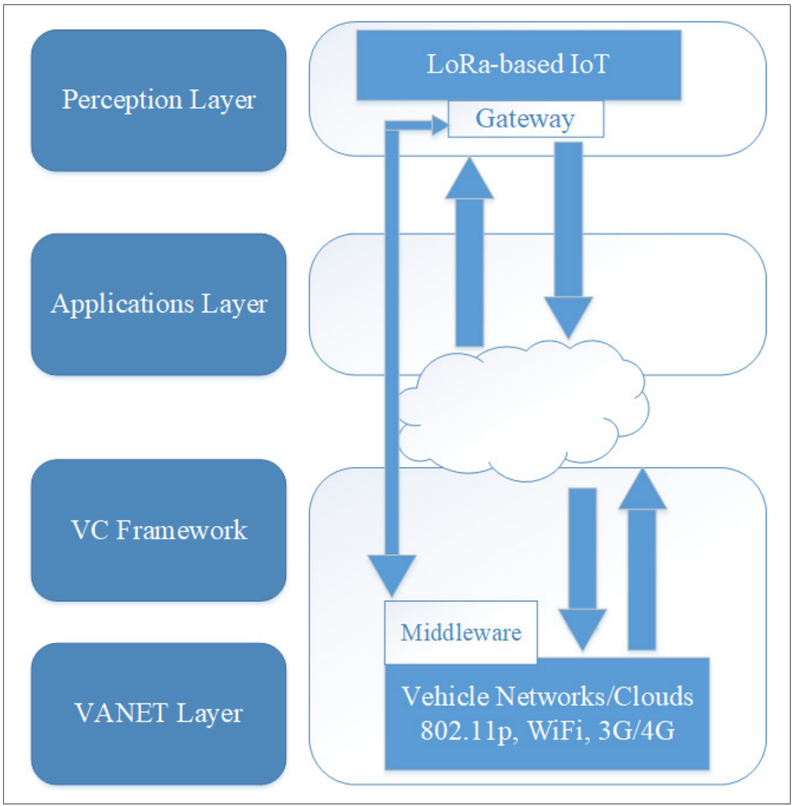

FIGURE 3. Layered design for VCoT connecting IoT with VANET for service enhancements.

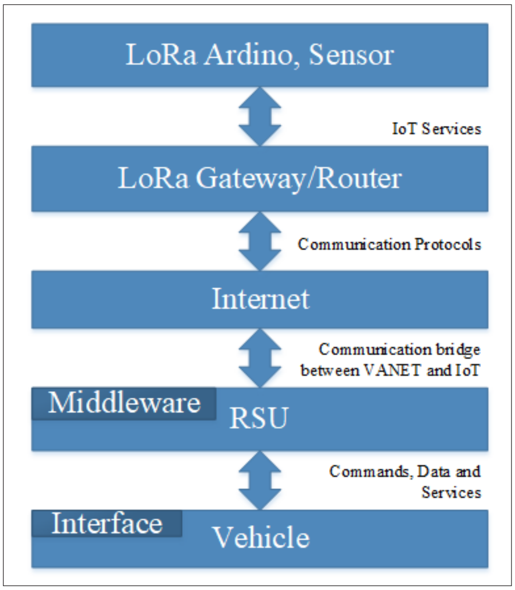

FIGURE 4. A communication mechanism of IoTVC.

several devices such as bridges, gateways, nodes, and other enabling technologies.

The generic design of our proposed VCoT is given in Fig. 3, where the IoT information is pushed to the cloud infrastructure and then shared with the vehicular network. For leveraging IoT-based applications and their respective services in VANETs using RSUs and OBUs, inter-protocol conversions are required. It should be kept in mind that IoT services are managed directly from VANETs or through cloud computing infrastructure depending on the very nature of the applications, as shown in Fig. 3. For example, monitoring and directly controlling an appliance connected to a home automation system would not require any communications with the cloud infrastructure, whereas querying the energy utilization at a smart home would require a communication medium by the cloud for downloading the requested information.

A detailed communication mechanism of the proposed VCoT infrastructure is shown in Fig. 4. We have considered RSUs acting as interfaces for LoRaWAN nodes as well as LoRaWAN gateways. These communications from the VCoT paradigm are converted to LoRa-compatible communication format and are encapsulated. With 5G capabilities present in OBUs in most modern vehicles, the bridging components in these RSUs can then communicate directly with the LoRaWAN gateway, which routes these messages to intended nodes. The top part of Fig. 4 is from the IoT paradigm, which is driven by the LoRaWAN technology. Another significant objective for adopting this bridging mechanism is finetuning the communications from the vehicular cloud toward LoRa-enabled edge nodes acting as gateways, and then IoT sensors and actuators.

The transmission range in LoRa is inversely proportional to the LoRaWAN data rate. The LoRa protocol supports a data-rate between 0.3 and 50 kb/s, which depends on its frequency channel and transmission range. Thus, it provides more opportunity for service providers and application developers to tweak the LoRaWAN protocol on their nodes in accordance with their specific application needs. This variation in both data rates and transmission ranges gives flexibility for providing wide-range application scenarios catering for different situations. Nonetheless, using IoT adaptive data rates (ADRs) for end devices makes the middleware design process rather challenging.

Application Scenarios

We have targeted a personalized IoT through the integrated VCoT paradigm and envisioned several applications that cover smart healthcare management, intelligent building automation, efficient industrial automation, and intelligent transportation systems. Our particular aim is controlling LoRaWAN-enabled IoT-based home automation services through VCoT. It's important to mention that the proposed architecture is quite generic; however, during the implementation stage, only customized IoT applications were targeted.

VCoT has several applications such as e-health monitoring and diagnosis, smart grid and energy management, navigation and transportation, weather monitoring and forecasting, diagnostics, and building automation domains. In the building automation use case, a mobile application or service can manage the heating, ventilation, and air conditioning (HVAC) system through an IoT network via a vehicular cloud infrastructure.

There are other such use cases that can be achieved through the proposed VCoT, for example, in order to monitor and control climate at a smart home operating appliances such as a washing machine and a coffee maker, checking on the refrigerator and edibles inside, and opening the garage door upon a vehicle's arrival. Consequently, the current traffic situation is used to efficiently calculate routes from the application data from other vehicles [12]. This information saves precious commute time while providing fuel efficiency. Additionally, several other applications including notifications about different sales and discounts in nearby markets, preferred restaurant recommendations, available parking spaces, and other location-based information (e.g., weather and news) can also be realized using the VCoT paradigm.

Another use case is the intelligent traffic lights (ITL) system, where various kinds of sensors are installed and connected to RSUs that are continuously monitoring the presence of pedestrians and vehicles. Based on recorded observations, the aggregated information is transmitted to LoRaWAN gateway nodes. This information is then coordinated with all connected traffic signals for maintaining efficient as well as consistent traffic flow.

Besides monitoring, these RSUs are also able to generate emergency notifications, which can be useful for other nearby vehicles and services. The analytic data is also useful to modify the normal traffic flow to suit the needs of certain scenarios such as public events. While this overall information is useful in the local context, it is also transmitted to the cloud infrastructure for long-term storage followed by analyses for providing insights and forecasting regarding the smart city transportation requirements. Other use cases (e.g., efficient parking lot) can also be realized by applying data analytic activities on the collected information from different vehicles running on roads or parked.

Experiment and Results

A proof of concept has been developed using Java SE and Android, where an emergency response vehicle is able to send information to the cloud. The IoT-based solution installed on the emergency response vehicle or ambulance is able to detect the current location, patient's vital signs, and criticality level. The vehicular cloud system uses this data to suggest the nearest hospital where the hospital management system — an important application for smart cities — is able to pre-book this patient and inform the concerned department of the recommended tests or immediate treatment path. In order to assess the whole system, we have established some parameters that act as a benchmark to help the overall system performance, as shown in Table 1.

LoraWAN-Enabled Emergency Response Vehicle

We assume each client as an ambulance. Multiple clients have been created for this setup using the following parameters: ambulance ID, emergency type, criticality level, and location. Every node sends a request to the healthcare system cloud through LoRa-enabled RSUs. The results show that ambulances sendg frequent requests to the cloud with information about them such as ambulance ID, emergency type, current location, and critical level, as shown in Fig. 5.

Vehicular-Cloud-Based Decision Support System

The decision support systems based on the cloud infrastructures can leverage the information received through the LoRa-enabled RSUs. These RSUs not only forward the information from sensors onboard ambulances but also from sensors attached to the patient that can help in better diagnosis. On the server end, the Haversine formula is used to find the distance between ambulances and the nearest hospitals. Upon selecting the hospital, the system sends requests to relevant departments to book for that specific patient beforehand. Similarly, the real-time data for this patient is continuously communicated to the designated healthcare professional, as shown in Fig. 5.

No.	Events	Description	Status
1	Server active	VCoT ready to listen vehicle requests	OK
2	Get requests	VCoT receiving requests from vehicles	OK
3	Get suitable hospital	VCoT selecting hospital for incident type	OK
4	Get nearest hospital	VCoT finding closest hospital using location	OK
5	Client getting response	VCoT sent response to vehicle	OK

TABLE 1. Parameters and capabilities in a smart city emergency management system.

We tested our results by creating a simulation environment using SUMO (open source vehicular network simulation framework; http://veins.car2x.org) for traffic generation and an Android Auto (Android-based telematics system for automobiles; https://developer.android.com/training/auto/) client for interacting with the smart city cloud server to depict emergency response systems in smart cities. Different scenarios have been generated artificially to observe the response of the system in various settings such as peak request and normal request queues. Table 1 presents the test results and shows the behavior of IoT integration with vehicular networks. It is concluded that the system can find the nearest and best suited hospital for the ambulance. Similarly, the server generates a request for the chosen hospital with all information for initiated and outpatient handling scenarios.

Issues and Challenges

The VANET-based IoT and clouds infrastructure integration, despite its exciting services and applications, needs to address several issues that keep key stakeholders and investors from deploying fully integrated technologies. Some major research challenges are discussed in the following subsections:

Functional Challenges

Among major issues, the most significant is the integration of IoT and VANET as both of them have several differences in their respective specification standards. LoRaWAN is an ideal candidate for deploying IoT, while VANETs follow DSRC or WAVE-based standards. The protocol selection, handshake negotiations, data rates, and similar factors decide the overall performance for dependent applications. However, the diversified nature of these two technologies suggests the trade-offs and their respective in-depth analysis.

Until now, various applications exhibit different behaviors under various circumstances and hence demand diverse sets of variables. Thus, adaptation of dynamic vehicular behaviors is also a challenging task for service providers and needs

```
Sending request to Main Server
Message sent to server:[Amb005, Emergency, 450, 560, Severe]
Response from server: Nearby Hospital [Go to the nearest hospital]
The distance between hospital and ambulance is : 5559.746332227935

****************************************

Sending request to Main Server
Message sent to server:[Amb005, Cardio, 350, 250, Low]
Response from server: Nearby Hospital [Hosp004, Cardio, 500, 250]
The distance between hospital and ambulance is : 16679.238996683813

****************************************

Sending request to Main Server
Message sent to server:[Amb004, Burn, 400, 250, Severe]
Response from server: Nearby Hospital [Hosp002, Burn, 500, 250]
The distance between hospital and ambulance is : 11119.492664455873

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(a)

```
Waiting for client request
The distance between two lat and longitude is: 5559.746332227934
Message Received: [Amb005, Emergency, 450, 560, Severe]

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Waiting for client request
The distance between two lat and longitude is: 7570.201271718275
Found [Hosp004, Cardio, 500, 250]
Message Received: [Amb005, Cardio, 350, 250, Low]

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Waiting for client request
The distance between two lat and longitude is: 4200.837677628848
Found [Hosp002, Burn, 500, 250]
Message Received: [Amb004, Burn, 400, 250, Severe]

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(b)

FIGURE 5. Simulation of IoT-enabled clients sending data to vehicular cloud through RSUs: a) IoT-enabled ambulance acting as client; b) cloud-based server for handling requests.

be handled in a very reliable way. However, we have to consider the satisfaction of customers. In addition, there are various mechanisms that deal with resource utilization efficiently while dealing with the diversity in IoT-based environments [15]. Therefore, the overall heterogeneity shown by the integrating VCoT infrastructure requires more insight to obtain a trade-off solution that is acceptable for service providers as well as consumers.

Data Acquisition

Both IoT and VANET-based clouds tend to generate diversified data with relatively different objectives and varying frequencies in speed as well as volume. Hence, the data acquisition across different platforms needs smarter pre-processing of the data locally. It is also significant to mention that in the VANET-based cloud, at various layers there are diverse types of data conceived. One such example is in-car sensors, which generate data that is significant for both the car owner, close to vehicles, and auto manufacturers for diagnostic purposes. On the other hand, data generated by vehicles and shared with neighbors can be huge and rendered as big traffic data (BTD).

Depending on the traffic pattern (sparse, moderate, or dense), each vehicle's generated data is shared with neighbors in either a single-hop or multi-hop way through beacon messages on the order of milliseconds, requiring larger processing power for vehicular nodes. Therefore, an effective solution is to offload data processing tasks to the cloud's resources. Prior to this offloading, this data (in high frequency and large volumes) has to be pre-processed, cleaned, and compressed before sharing with any IoT environment. Likewise, IoT data in VANETs, which is used by vehicular applications, should be sophisticated and very application-specific.

Data Quality

Contemporary advancements in industrial IoT have empowered researchers in utilizing the potential billions of low-cost and readily available wireless sensor nodes. These nodes are often left unattended to continuously monitor a certain set of parameters in a given environment for longer periods of time. This unattended nature gives rise to questions regarding the quality of data that these sensors have gathered and transmitted. In order to make decisions based on the VCoT data more reliable, data quality becomes significantly important as the mobile nature of vehicular clouds makes it hard to provide provenance. To avoid such issues, checks should be in place for uniformity and continuous calibration of not only vehicular sensors but also the overall middleware architecture. Furthermore, diverse application sets require different levels of data granularity, thus making context a significant parameter to consider.

Coverage

IoT and VANETs along with various other applications are in their early stages. A huge number of service providers have deployed and tested their proposed frameworks for these technology enablers. The expansion of these technology enablers has been a progressive process, thus requiring some time prior to bringing full benefits to the public. Service coverage and user satisfaction are other requirements that need to be fulfilled. For the moment, infrastructures based on the Things network have been adopted in a number of scenarios that provide partial coverage. It is also worth mentioning that other manufacturers are competing as well in order to deploy to fill the market gap. Therefore, since our proposed framework leverages LoRa-based technologies, network coverage will be among the significant parameters for successful realization of this VCoT. On the contrary, VANET and its various applications are going through standardization all over the world; hence, it is safe to state that in coming times connected vehicles will be roaming across smart cities.

Security and Privacy

Privacy as well as security are considered of utmost significance while realizing VCoT integration. It is worth mentioning that data generated by IoT infrastructures is privacy-sensitive in nature, thus requiring privacy preserving mechanisms for both data on the wire as well as at rest. Without such effective privacy preserving measures, IoT information shared easily causes end-user privacy abuse. Nevertheless, privacy requirements such as granularity conflicts with application performance.

Information sharing between VANETs and IoT must be secure as well as private. Similarly, trade-offs between the data granularity and application performance should be considered as well. Besides, context-aware privacy preserving techniques need to be adopted for enabling vehicular clouds to provide for the change. The fog computing paradigm plays an important role in preserving privacy, as by design the information is processed in the vicinity of edge nodes. In the case of VCoT, RSUs that are equipped with industry standard privacy preservation mechanisms, are optimal candidates to examine the data locally and hence ensure that the data is not forwarded to the core network.

Conclusion

The integration of IoT with VANETs is a promising domain where we can leverage vehicular clouds for disseminating information from the vehicular domain to the IoT domain. In this article, we have proposed and evaluated an abstract-level generic framework, integrated with VCoT, for overall service enhancements in smart cities. The proposed architectural framework is a stepping stone toward the deployment of novel and exciting applications as well as services in IoT and vehicular clouds. We specifically focus on the integration at the protocol and functional level.

One of the main contributions of this work is extending the network capability enhancement via LoRaWAN through which we are able to not only increase the coverage but also improve the energy consumption of corresponding IoT applications. We also outline the research issues faced while leveraging such an integration, which serves as a way for researchers to explore the VCoT domain further. In the future, we intend to extend the current work to provide a fully integrated framework that covers most aspects using an architectural proof of concept, including standards and protocols for the infrastructure, communications, privacy and security provision, and various data protocols along with functional features, for example, assets and resource management.

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Biographies

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